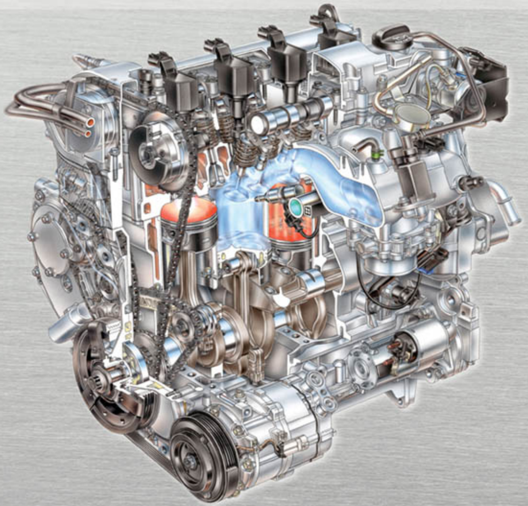
AUTOMOTIVE ENGINES

Diagnosis, Repair and Rebuilding

6th Edition



TIM GILLES

AUTOMOTIVE ENGINES

DIAGNOSIS, REPAIR AND REBUILDING

6TH EDITION

TIM GILLES
Santa Barbara City College
Santa Barbara, CA

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Dedication

The completion of this book was made possible with the help of a great many individuals. *Automotive Engines* is dedicated to them and especially to my parents, for the inspiration, and to my wife, Joy, and children, Jody and Terri, without whose help the book would not have been completed. Special appreciation is due to my wife, Joy, who has managed the organization of the art package, spending countless after-work and weekend hours developing and organizing all the spreadsheets, captions, photos, and sketches, making certain they are in their correct locations—a substantial task.

This book is also dedicated to four important mentors: Lloyd Corliss, my first automotive teacher, who shared his love of engines and whose integrity and example inspired me to become an automotive teacher; Roger Aylesworth, who became a big brother to me while I worked in his automotive business and who shared, by example, his attitude that, with knowledge, a good mechanic can fix just about anything; and Bob Barkhouse, another big brother and good friend. Bob is a retired automotive teacher and the author of a very fine best-selling textbook on the upper end of engines. His example is one of generosity. He has been a big help and an inspiration to me and countless other teachers. My good friend and mentor, Joe Schuit, has been helping the engine-rebuilding students at Santa Barbara City College in my engine rebuilding classes since shortly after he retired from his automotive machine shop business. Joe is an inventor with a gifted mind for automotive engines and an enthusiasm that is contagious. A day never goes by without Joe sharing something new and valuable from his vast library of knowledge and experience.

"In memory of our friend, Jimmy Stephens (1964-2009),

Delmar Cengage Learning Marketing Manager."

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Preface

ABOUT THIS BOOK

It is often said that engines never change. Although large changes are not the norm, the internal combustion (IC) engine is constantly evolving. When the first edition of this text was written in 1980, futurists were questioning whether the four stroke cycle engine would still be around in 20 years. The long history of this well-proven engine has shown continuous small refinements, and it is still the engine that powers most of today's vehicles. Compared with the engines that powered the muscle cars of 1980, today's engines are more refined, lighter, and offer improved performance and durability.

Automotive Engines, Sixth Edition provides the reader with the comprehensive knowledge needed to repair and rebuild these automotive engines. The most complete book of its kind, it takes a generic, rather than product-specific, approach. The text provides all of the need-to-know information in an easy-to-understand format. Much effort has gone into organizing this book to make it easily readable, like a story. To facilitate learning, all items related to a given topic are included within a single chapter. Appropriate for entry-level as well as more experienced technicians and machinists, this text also provides opportunities for the reader to develop critical diagnostic and problem-solving skills.

Organization of This Edition

This text is divided into four sections and is designed so that the student can begin working in the shop right away. Section 1 covers engine construction, disassembly, inspection, and parts ordering. Diagnosis techniques, both before and after disassembly, are covered in detail. Also included are repair procedures that can be performed while the engine is still in the vehicle. Tools and equipment procedures, as well as safety issues, are covered throughout. Section 2 deals with the breathing system. This includes the valvetrain and manifolds. Cylinder head repair, as well as camshafts and turbochargers, are also discussed in this section. Section 3 discusses the cylinder block assembly with a focus on lower-end repair procedures. The lubrication and cooling systems are also covered. Section 4 deals with final reassembly and starting the engine. Gaskets and miscellaneous repair procedures are covered in this section as well.

New to This Edition

This sixth edition of *Automotive Engines* has been updated and refined to reflect changes in the marketplace. The text has an updated two-color design with many new and updated photos and sketches. An emphasis on photos and art anticipates the needs of those with different learning styles and encourages student interest in reading the related text. Many previously grouped photos from earlier editions have been separated so individual captions are displayed directly beneath, making it easier for students to survey each chapter by looking at the photos and captions before reading the text.

The design and engineering of the internal combustion engine is continuing to evolve, with high-performance sport compact cars becoming a larger share of the engine repair and enhancement market. Vehicle restoration also accounts for a substantial part of the industry. In response to reviewer comments, these and other areas have been addressed in this revision of the text.

Some of the new changes are listed next:

- New or updated case histories highlight real-world situations, providing more critical thinking practices.
- An updated and expanded high-performance chapter, including more detailed information on engine breathing, including intake and exhaust manifolds, flow benches, turbocharging, supercharging, advance materials, and high-performance camshaft information.
- Updates to the engine diagnosis chapter present the material the way it is presented in class. Students need to learn to diagnose an engine during disassembly so they can assess its suitability for repair prior to spending a lot of money and wasting a lot of time. Analyzing unusual wear or part failure will also help them correct problems so they do not recur.
- New up-to-date information on cooling and lubrication systems has been added to this edition of the text. Engines last far longer than they did 25 years ago, so maintenance has become more important to vehicle owners. Cooling system failures that result in serious engine damage have become more common.
- New *Vintage Engines* additions help put newer technologies in historical perspective by offering interesting facts about older technologies while separating them from the core text.

Use of the Text

A goal of *Automotive Engines* is to fill the needs of many, merging commonplace and vintage content with the latest high-tech information. Some schools have smaller engine course offerings, whereas others have large programs with classes of long enough duration to complete the entire text. Some instructors will choose to assign certain chapters, leaving others for an introductory course. Others will use some chapters in a prerequisite introductory engines course, saving others for an advanced engine-rebuilding course. For instance, Chapter 9 covers all of the camshaft-related items that would be needed for an entry-level automotive apprentice, whereas the new Chapter 17, Engine Power and Performance, consists of more advanced technical material for aspiring engine machinists and high-performance specialists.

There are many new and updated photos of engine disassembly and reassembly on newer vehicles. The camshaft chapter emphasizes timing belt service, including cam lobe position identification, so you can be sure you are doing the right thing. This is something all good technicians should know, but many do not.

This book is used in schools that teach NATEF A-1 (Engine Repair). Coverage emphasizes procedures that would be performed in a typical automotive facility that does engine repairs. The book is also used in schools that teach in-depth engine machining processes. One of my challenges as an author is to present machining tips in a way that will benefit all students who study the book. Instructions on the use of a particular machine are avoided because they are available in the manual that comes with the machine.

The primary aim of the text is to provide a student with adequate preparation for entry-level employment with emphasis on the ASE A1 and M1 engine assembly specialist areas. The text also provides a foundation for the M2 and M3 areas, especially in regard to ASE test preparation.

To the Student

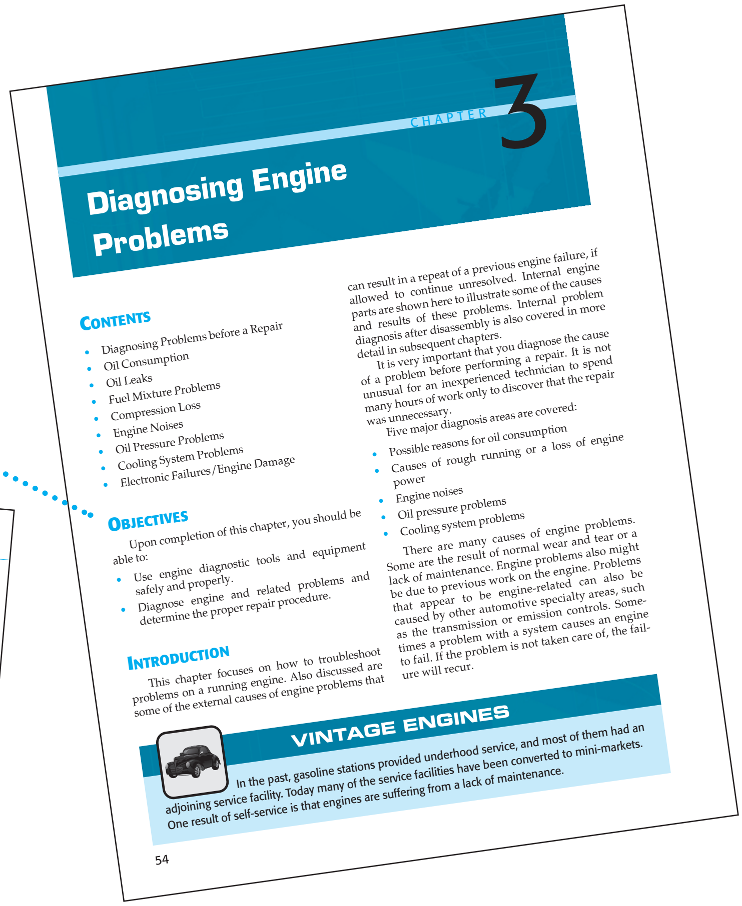
Restoration and improvement is a very popular automotive technology area and you should be prepared to capitalize on that interest. Most cities and towns have residents who can afford to spend money on their cars and pickups. You will need a good understanding of performance and vintage material to be successful in this field. Additionally, you need a good grounding in the broad area covering four stroke cycle engine basics if you are to be successful as an engine diagnostician. During engine diagnosis and disassembly, the text gives an emphasis to analyzing worn and damaged parts. The aim is to improve your diagnostic ability and develop a method of approaching things in an inquisitive manner. Get into the habit of asking yourself, “What caused this to happen?” You will want to take measures so it does not happen again. This can be applied to more advanced topics as you further your automotive studies.

Features of the Text

Learning the theory, diagnosis, and repair procedures for today's complex engines can be challenging. To guide readers through this material, a series of features are included that will ease the teaching and learning processes.

Objectives

Each chapter begins with a list of objectives. The objectives state the expected outcome that will result from completing a thorough study of the contents of the chapter.


CHAPTER 3

Diagnosing Engine Problems

CONTENTS

OBJECTIVES

Upon completion of this chapter, you should be able to:

- Use engine diagnostic tools and equipment safely and properly.
- Diagnose engine and related problems and determine the proper repair procedure.

INTRODUCTION

This chapter focuses on how to troubleshoot problems on a running engine. Also discussed are some of the external causes of engine problems that can result in a repeat of a previous engine failure, if allowed to continue unresolved. Internal engine parts are shown here to illustrate some of the causes and results of these problems. Internal problem diagnosis after disassembly is also covered in more detail in subsequent chapters.

It is very important that you diagnose the cause of a problem before performing a repair. It is not unusual for an inexperienced technician to spend many hours of work only to discover that the repair was unnecessary.

Five major diagnosis areas are covered:

- Possible reasons for oil consumption
- Causes of rough running or a loss of engine power
- Engine noises
- Oil pressure problems
- Cooling system problems

There are many causes of engine problems. Some are the result of normal wear and tear or a lack of maintenance. Engine problems also might be due to previous work on the engine. Problems that appear to be engine-related can also be caused by other automotive specialty areas, such as the transmission or emission controls. Sometimes a problem with a system causes an engine to fail. If the problem is not taken care of, the failure will recur.

VINTAGE ENGINES

In the past, gasoline stations provided underhood service, and most of them had an adjoining service facility. Today many of the service facilities have been converted to mini-markets. One result of self-service is that engines are suffering from a lack of maintenance.

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Before sophisticated computer-controlled spark timing, a common cause of detonation was over-advanced ignition timing.

Older engines required more spark advance to complete combustion by the targeted point of 11–14° after TDC. On modern engines, to help speed up normal combustion and prevent detonation, the spark plug location is often centrally located, or there are multiple spark plugs. This is more efficient mechanically because firing the spark closer to TDC means that the piston is not working against compression for as long a time. One of the advantages of a four-valve pent-roof combustion chamber is its faster burn time.

Sometimes the pistons and cylinder head absorb the sound of engine knock, making it inaudible. This condition is called cold knock or inaudible ping. Other times the rattling that results from detonation can be very loud. The noise is caused by vibration of the combustion chamber walls.

When the air-fuel mixture detonates, the explosion is instantaneous and the loss of power can result in serious engine damage, including broken pistons, piston rings, and head gasket failure.

(a)

(b)

FIGURE 3.52 Damage due to (a) preignition and (b) detonation.

SHOP TIPS

- Spark plugs are a window to combustion chamber action. **Figure 3.52** shows spark plug conditions that resulted during preignition and detonation.
- Dynamometers (see Chapter 10) are used to test engines under load. Experienced dyno operators know that the temperature of exhaust gas in a detonating engine will drop.

Fuel Octane, Spark Advance, and Detonation

Octane rating is a measurement of a fuel's ability to resist explosion under pressure. Design engineers test an engine on a dynamometer, using fuels of different octanes. Different spark advances are tested at various speeds and loads to determine the engine's highest torque output. Ignition timing is best when it is advanced to the furthest point without causing detonation. Modern computer-controlled engines use a detonation sensor (**Figure 3.53**), sometimes called a knock sensor. When it senses the vibration caused by detonation, the computer retards the ignition timing until the spark knock goes away. The computer continually relearns the best timing for the fuel by advancing the timing until detonation occurs and then retarding the spark slightly until detonation stops. All modern automotive engines have this capability. Manufacturers recommend fuel of a particular octane rating for each of their vehicles. When fuel of a lower octane rating is used, the timing will be adjusted to a lower amount of advance. The price is a slight penalty in fuel economy and performance.

Shop Tips

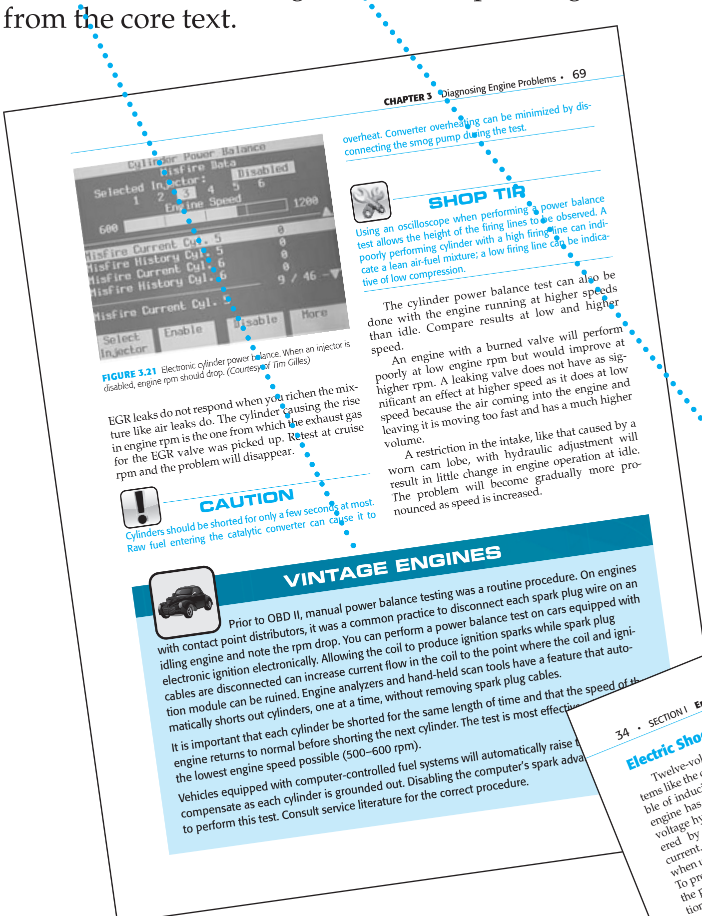
Found throughout the chapters, these tips cover things commonly performed by experienced technicians.

Safety Notes and Cautions

Safety is a major concern in any automotive shop, so safety notes and cautions are listed throughout to focus the reader's attention on important safety information.

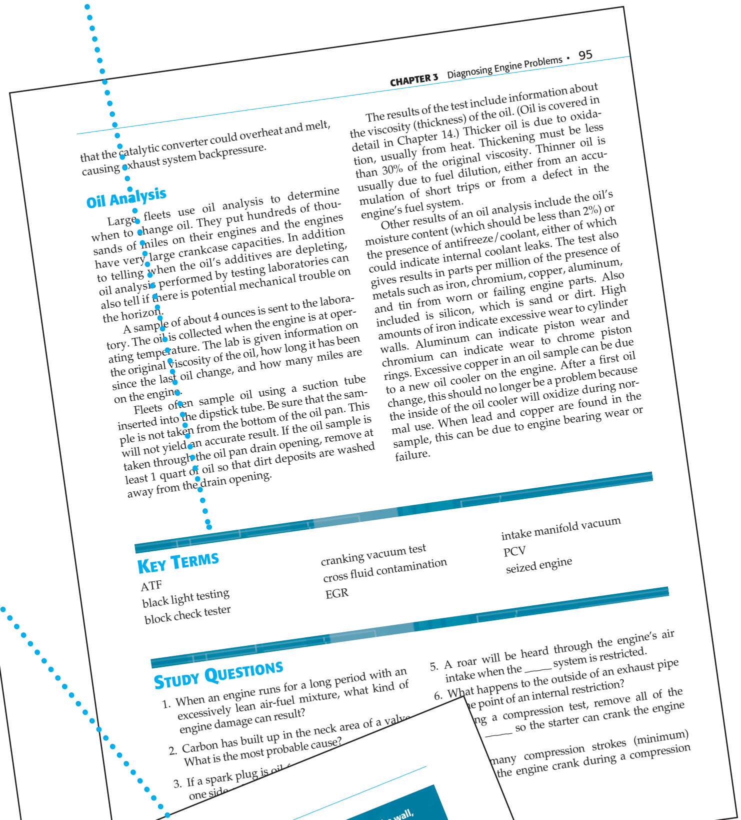
Vintage Engines

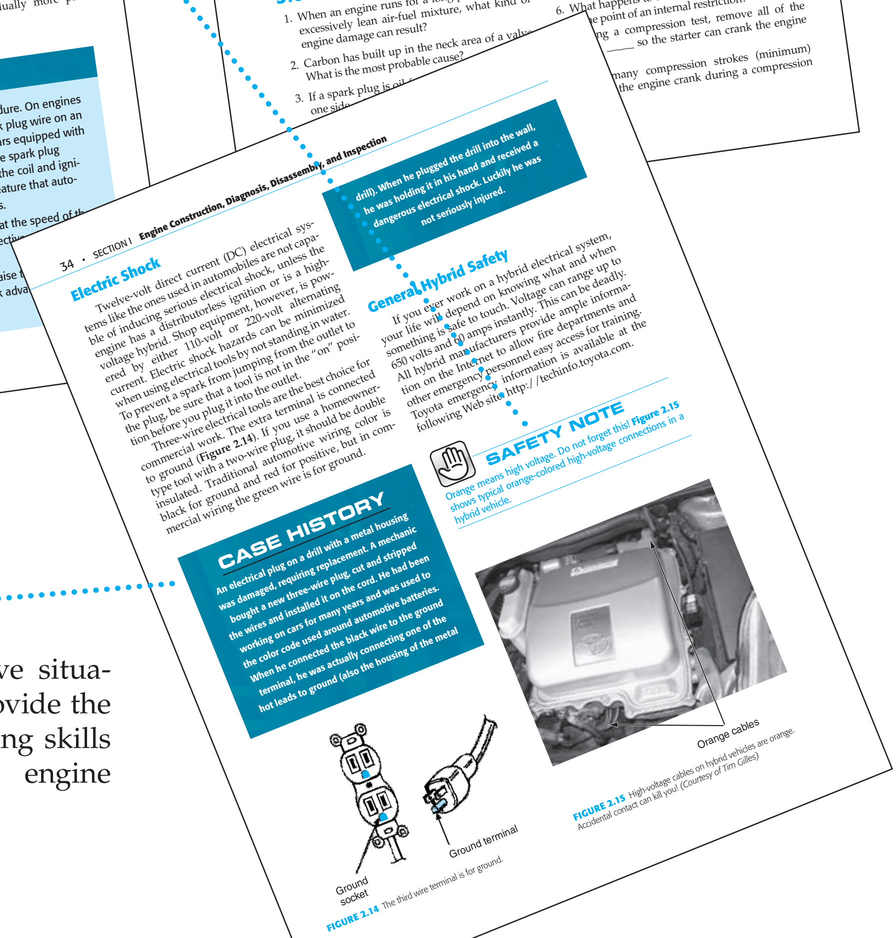
These text boxes place newer technologies in historical perspective by offering interesting facts about older technologies while separating them from the core text.



Key Terms

Each chapter ends with a list of the terms that were introduced in the chapter. These terms are highlighted in the text upon first use.





Case Histories

These true stories describe automotive situations encountered by the author. They provide the reader with insight into the critical thinking skills necessary to diagnose automotive engine problems.

Notes

Throughout the text, notes are included to call attention to need-to-know information.

ASE-Style Review Questions

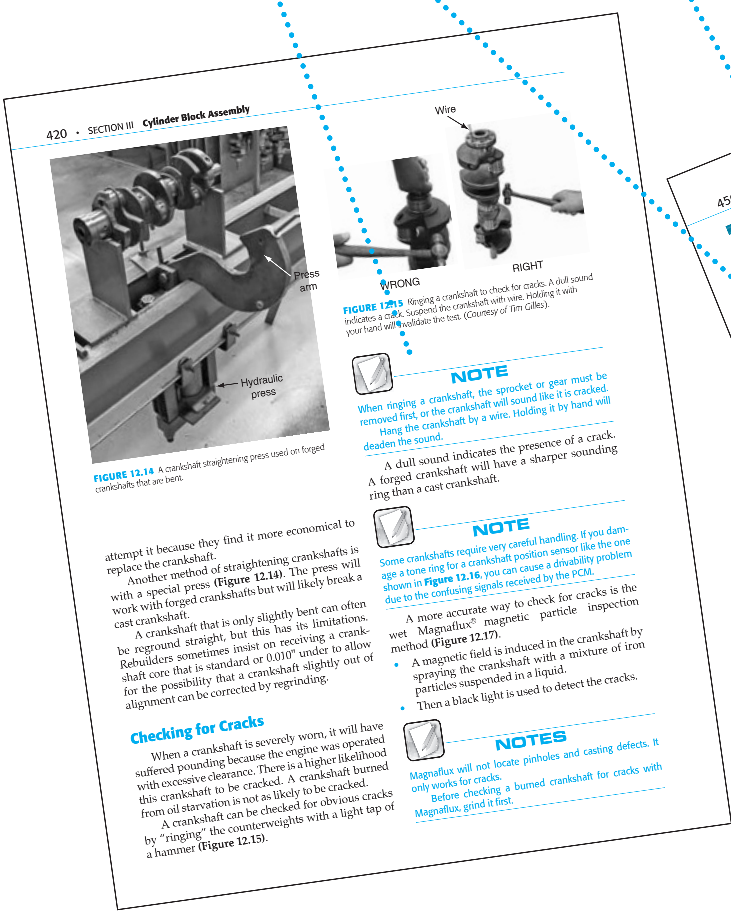
Each appropriate chapter concludes with ten ASE-style review questions to help the reader prepare for the ASE Certification Exam.

Study Questions

At the end of each chapter, there are 15 study questions of varying types. The questions provide an opportunity for reinforcement and review of key concepts presented in the chapter.

Instructor Resources

An *Instructor Resources* CD is available to instructors and includes the following components: an electronic Instructor's Guide with answers to all end-of-chapter questions, Word files of all end-of-chapter questions, a computerized test bank in ExamView with hundreds of questions for quizzes or exams, chapter presentations in PowerPoint for each chapter of the text, a searchable Image Library with hundreds of illustrations to support in-class presentations, a NATEF correlation grid connecting the chapter content with the most current A1 task list, and electronic job sheets to guide students through common engine diagnosis and repair procedures.



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Press arm

Hydraulic press

FIGURE 12.14 A crankshaft straightening press used on forged crankshafts that are bent.

Wire

WRONG

RIGHT

FIGURE 12.15 Ringing a crankshaft to check for cracks. A dull sound indicates a crack. Suspend the crankshaft with wire. Holding it with your hand will invalidate the test. (Courtesy of Tim Gilles).

attempt it because they find it more economical to replace the crankshaft.

Another method of straightening crankshafts is with a special press (Figure 12.14). The press will work with forged crankshafts but will likely break a cast crankshaft.

A crankshaft that is only slightly bent can often be reground straight, but this has its limitations. Rebuilders sometimes insist on receiving a crankshaft core that is standard or 0.010" under to allow for the possibility that a crankshaft slightly out of alignment can be corrected by regrinding.

Checking for Cracks

When a crankshaft is severely worn, it will have suffered pounding because the engine was operated with excessive clearance. There is a higher likelihood this crankshaft to be cracked. A crankshaft burned from oil starvation is not as likely to be cracked.

A crankshaft can be checked for obvious cracks by "ringing" the counterweights with a light tap of a hammer (Figure 12.15).

NOTE

When ringing a crankshaft, the sprocket or gear must be removed first, or the crankshaft will sound like it is cracked. Hang the crankshaft by a wire. Holding it by hand will deaden the sound.

A dull sound indicates the presence of a crack. A forged crankshaft will have a sharper sounding ring than a cast crankshaft.

NOTE

Some crankshafts require very careful handling. If you damage a tone ring for a crankshaft position sensor like the one shown in Figure 12.16, you can cause a drivability problem due to the confusing signals received by the PCM.

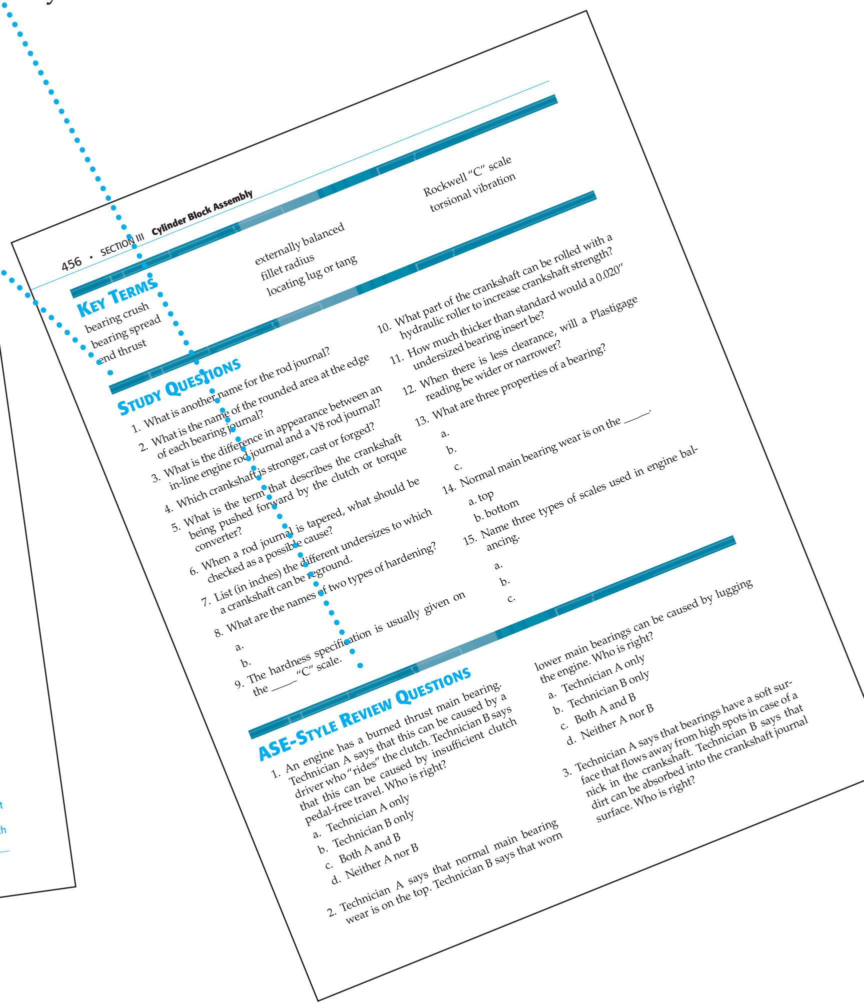
A more accurate way to check for cracks is the wet Magnaflux® magnetic particle inspection method (Figure 12.17).

- A magnetic field is induced in the crankshaft by spraying the crankshaft with a mixture of iron particles suspended in a liquid.
- Then a black light is used to detect the cracks.

NOTES

Magnaflux will not locate pinholes and casting defects. It only works for cracks.

Before checking a burned crankshaft for cracks with Magnaflux, grind it first.



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KEY TERMS

bearing crush
bearing spread
end thrust
externally balanced
fillet radius
locating lug or tang
Rockwell "C" scale
torsional vibration

STUDY QUESTIONS

1. What is another name for the rod journal?
2. What is the name of the rounded area at the edge of each bearing journal?
3. What is the difference in appearance between an in-line engine rod journal and a V8 rod journal?
4. Which crankshaft is stronger, cast or forged?
5. What is the term that describes the crankshaft being pushed forward by the clutch or torque converter?
6. When a rod journal is tapered, what should be checked as a possible cause?
7. List (in inches) the different undersizes to which a crankshaft can be reground.
8. What are the names of two types of hardening?
   a.
   b.
9. The hardness specification is usually given on the ____ "C" scale.
10. What part of the crankshaft can be rolled with a hydraulic roller to increase crankshaft strength?
11. How much thicker than standard would a 0.020" undersized bearing insert be?
12. When there is less clearance, will a Plastigage reading be wider or narrower?
13. What are three properties of a bearing?
    a.
    b.
    c.
14. Normal main bearing wear is on the ____.
    a. top
    b. bottom
15. Name three types of scales used in engine balancing.
    a.
    b.
    c.

ASE-STYLE REVIEW QUESTIONS

1. An engine has a burned thrust main bearing. Technician A says that this can be caused by a driver who "rides" the clutch. Technician B says that this can be caused by insufficient clutch pedal-free travel. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that normal main bearing wear is on the top. Technician B says that worn lower main bearings can be caused by lugging the engine. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that bearings have a soft surface that flows away from high spots in case of a nick in the crankshaft. Technician B says that dirt can be absorbed into the crankshaft journal surface. Who is right?

About the Author

Tim Gilles has authored and coauthored several textbooks. He has been an automotive teacher since 1973 and is currently a professor in the Automotive Technology Department at Santa Barbara City College. He has a Master of Arts degree in Occupational Education from Chicago State University and a Bachelor of Arts degree from Long Beach State University. He holds the industry certifications of ASE Master Engine Machinist and ASE Master Automotive Technician.

Tim has been active in professional associations for many years, serving as president and board member of the California Automotive Teachers (CAT) and as a board member and election committee chair of the North American Council of Automotive Teachers (NACAT). He is a frequent seminar presenter at association conferences. Tim has been a longtime member of the California Community College Chancellor's Trade and Industry Advisory Committee. He is active in industry associations, including AERA, ARC, and IATN and has served several terms as education representative on the board of the Santa Barbara Chapter of the Independent Automotive Professionals Association (IAPA).

ASE Certification Tests

The National Institute for Automotive Service Excellence (ASE) certifies automotive technicians in the eight specialty areas of automotive repair. Tests are given twice a year at locations throughout the country and on the Internet. To become certified in one of the specialty areas, you must correctly answer between 60% and 70% of the questions, depending on the difficulty of the particular test. To become a Master Auto Technician, you must pass all eight tests. To receive certification, you must also have at least 2 years of automotive work experience. School training can count as one of the years. If you do not have the work experience, you can still take the tests. ASE will provide you with the test results and will certify you as soon as your experience requirement is met.

ASE and AERA have developed an Engine Machinist test series. The three tests in the series are Cylinder Head Specialist, Cylinder Block Specialist, and Engine Assembly Specialist. Passing machinist tests in all three of the areas qualifies you as a Master Engine Machinist. Tests are administered as part of the regular ASE Technician test series.

Many employers ask for ASE certification when they advertise a job opening. ASE certification provides a technician or machinist with a means of showing a prospective employer that he or she has a validated training background. The practice tests at the end of the chapters in this text provide examples of the types of questions that will be found on the ASE A1 test on Engine Repair and ASE M1–3 tests on Engine Machining. Sample ASE Engine Machinist test questions and explanations are included at the back of the book.

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SECTION 1

Engine Construction, Diagnosis, Disassembly, and Inspection

Overview

Automotive Engines is a book about the diagnosis, repair, and rebuilding of engines in modern automobiles and light trucks. Section 1, comprising the first six chapters, introduces the reader to the internal combustion engine. Chapter 1 provides a brief overview of engine construction and operation. Safety and shop equipment are covered next in Chapter 2. Chapter 3 deals with engine problem diagnosis that can be performed before engine repair while the engine is still running. The chapter has been designed so that it can be used as a reference while studying the rest of the text. Problems are listed alphabetically throughout the index at the back of the book. Chapter 4 covers engine removal, disassembly, inspection, and diagnosis of internal engine parts wear. Also covered are in-chassis repairs—those that can be done on an engine without removing it from the vehicle. The final two chapters in this section deal with engine cleaning and measuring after disassembly.

CHAPTER 1

Engine Operation

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Explain the principles of internal combustion engine operation.
- Identify internal combustion engine parts by name.
- Explain various engine classifications and systems.

Introduction

Most of today's automobiles and light trucks are powered by a spark-ignited four stroke reciprocating engine. The first engine of this type was built in 1876 by Nicolaus Otto in Germany. Thus, it was named the Otto-cycle engine. Compared to previous internal combustion engine designs using the same amount of fuel, Otto's four stroke engine weighed less, ran much faster, and required less cylinder displacement to produce the same horsepower. A few years later, this engine design powered a motorcycle and then a horseless carriage. Other engine designs in limited use in modern autos include the rotary (Wankel), two stroke, and compression ignition (diesel) engines.

In a spark-ignited internal combustion engine, a precise mixture of air and fuel is compressed in a cylinder. The fuel must be of a type that vaporizes easily (such as gasoline, methanol, or ethanol) or a flammable gas (such as propane or natural gas). When the compressed air-fuel mixture is burned, it pushes a piston down in a cylinder. This action turns a crankshaft, which powers the car (**Figure 1.1**).

SIMPLE ENGINE

A simple reciprocating engine has a cylinder, a piston, a connecting rod, and a crankshaft. The

VINTAGE ENGINES

Although Nicolaus Otto has been credited with the invention of the four stroke internal combustion engine in 1876, the French inventor Alphonse Beau de Rochas developed the concept 14 years earlier in 1862. He applied for a patent but did not pay the required taxes so the French government did not validate his patent.

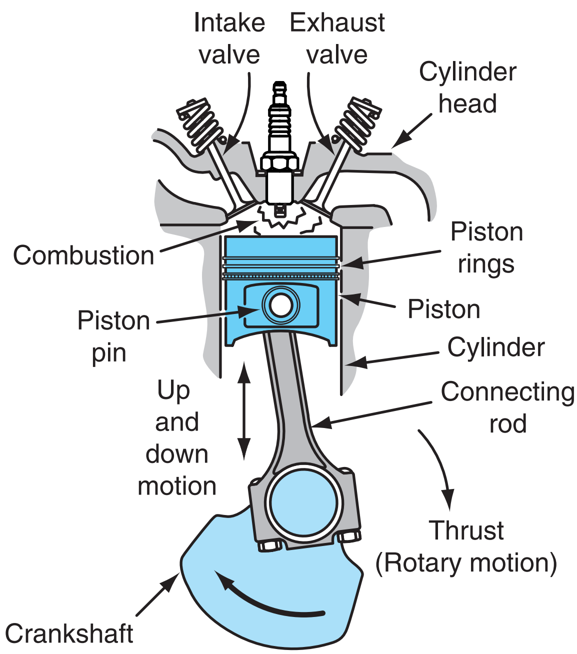


FIGURE 1.1 A piston forces a crankshaft to turn.

cylinder can be compared to a cannon and the round piston can be compared to a cannonball. The end of the cylinder is sealed with a cylinder head. The piston, which is sealed to the cylinder wall by piston rings, is connected to the crankshaft by a connecting rod and a piston pin (also called a wrist pin).

This arrangement allows the piston to return to the top of the cylinder, making continuous rotary motion of the crankshaft possible. Because of the powerful impulses on the piston as the fuel is burned in the cylinder, a heavy flywheel is bolted to the rear of the crankshaft (**Figure 1.2**). The weight of

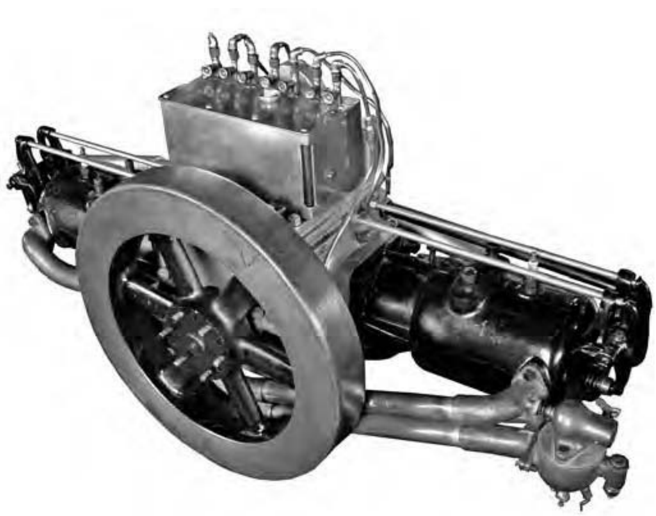


FIGURE 1.2 A flywheel is installed at the end of the crankshaft. This is a Buick opposed engine from the early 1900s. *(Courtesy of Tim Gilles)*

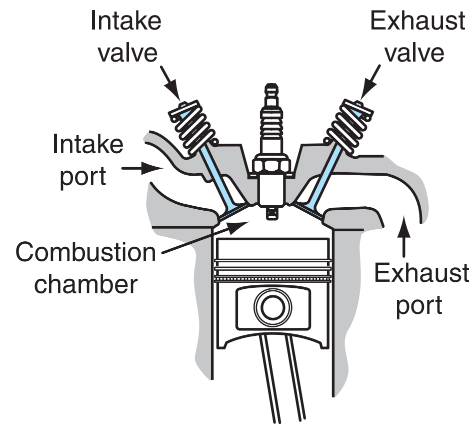


FIGURE 1.3 Valves seal off the valve ports.

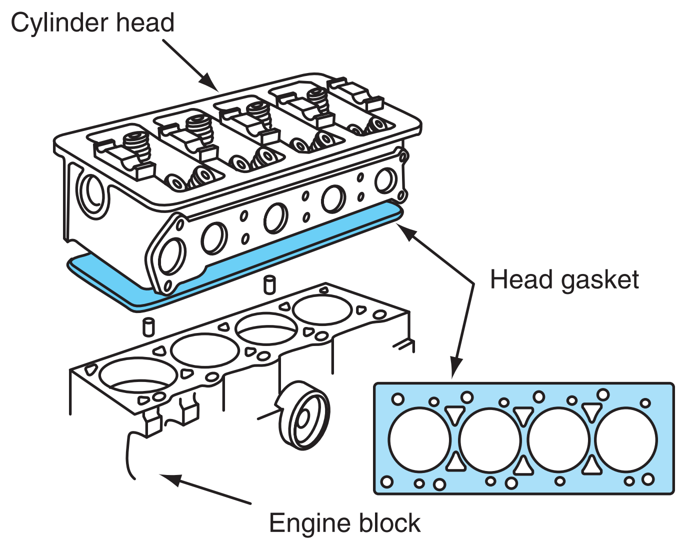


FIGURE 1.4 A head gasket seals the head to the block.

the flywheel blends the power impulses together into one continuous motion of the crankshaft.

The cylinder head has one combustion chamber for each cylinder (**Figure 1.3**). An intake valve port allows a mixture of air and fuel to flow into the cylinder, and an exhaust valve port allows the burned gases to flow out. Each port is sealed off by a poppet style valve. The head is sealed to the cylinder block with a head gasket (**Figure 1.4**). The opening of the valves is controlled by the camshaft (**Figure 1.5**).

FOUR STROKE ENGINE OPERATION

A stroke is the movement of the piston from **TDC** (top dead center) to **BDC** (bottom dead center), or from BDC to TDC. There are four strokes in

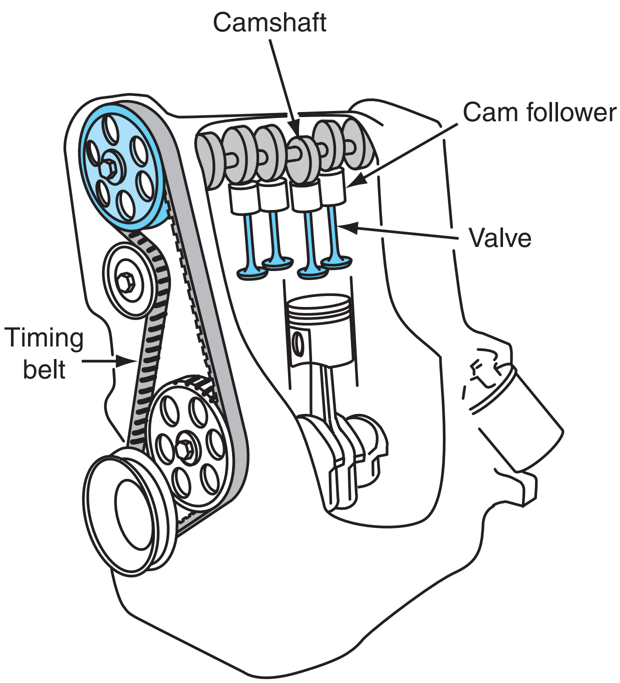


FIGURE 1.5 The opening of the valves is controlled by the camshaft.

one four stroke cycle of the engine. They are called the intake stroke, compression stroke, power stroke, and exhaust stroke.

- *Intake Stroke.* Gasoline will not burn unless it is mixed with the correct amount of air. It is very explosive when 1 part is mixed with about 15 parts of air. Shortly before the piston reaches TDC, the intake valve begins to open. As the crankshaft turns, it pulls the rod and piston down in the cylinder toward BDC (**Figure 1.6**). This action creates a low-pressure void that is filled by atmospheric air pressure and fuel through the open intake valve. About 10,000 gallons of air is drawn in for every 1 gallon of fuel supplied by the fuel system. The ideal mixture (called stoichiometric) for the combined purposes of engine performance, emission control, and fuel economy is about 14.7:1 (at sea level).

  Older vehicles had carburetors and newer vehicles manufactured since the mid-1980s have fuel injection systems with computer controls. The computer monitors the oxygen content in the vehicle's exhaust and then adjusts the fuel supply to provide the correct amount of fuel and air for each intake stroke.

  As the crankshaft continues to turn, the piston begins to move back up in the cylinder and the intake valve closes.
- *Compression Stroke.* The piston moves up in the cylinder, compressing the air-fuel mixture (**Figure 1.7**). If you light a puddle of gasoline on fire in open air it does not produce power. If it is confined in a cylinder, however, usable power can be produced. Compressing the mixture of air and fuel into a smaller area makes it easier to burn. The compression stroke begins at BDC after the intake stroke is completed. As the piston moves toward TDC, both of the valves are closed as the mixture is compressed to about ⅛ of the volume it occupied when the piston was at BDC. In this case, the **compression ratio** is said to be 8:1 (**Figure 1.8**). If the mixture is

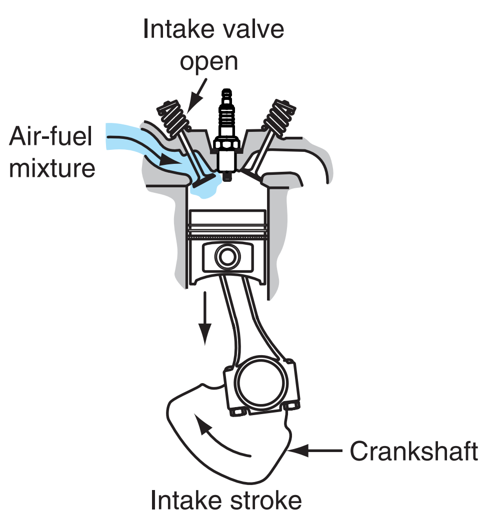


FIGURE 1.6 The air-fuel mixture is drawn into the cylinder.

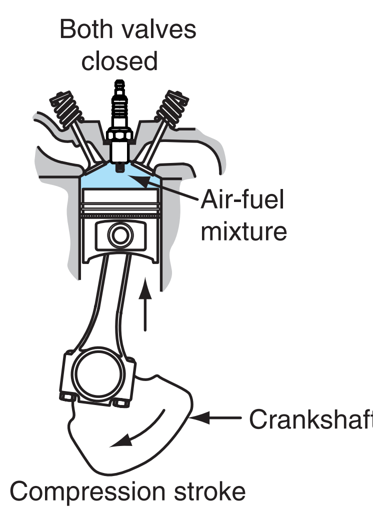


FIGURE 1.7 The air-fuel mixture is compressed.

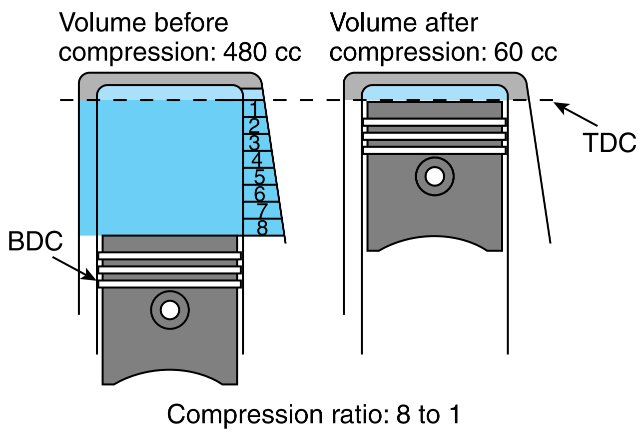


FIGURE 1.8 Compression ratio is a comparison of the volume of the air space above the piston at BDC and at TDC. In this example the compression ratio is 8:1.

compressed to 1⁄12 its original volume, the compression ratio is then 12:1.

- *Power Stroke.* As the piston approaches TDC on its compression stroke, the compressed air-fuel mixture becomes very explosive (**Figure 1.9**). When the ignition system generates a spark at the spark plug, the fuel ignites. The air-fuel mixture burns, but it must not explode. As the mixture burns it expands, forcing the piston to move down in the cylinder until it reaches BDC (**Figure 1.10**). The action of the piston turns the crankshaft to power the car. The power stroke is sometimes called the expansion stroke.

  Some leakage of gases past the rings occurs during the power stroke. This leakage, called **blowby**, causes pressure in the crankcase (**Figure 1.11**).
- *Exhaust Stroke.* As the piston nears BDC on the power stroke, the exhaust valve opens, allowing the spent gases to escape. Because the burning gases are still expanding, they are forced out through the open exhaust valve. As the crankshaft continues to turn past BDC, the piston moves up in the cylinder, helping to push the remaining exhaust gases out through the open exhaust valve (**Figure 1.12**). A few degrees after the piston passes TDC, the exhaust valve closes. The entire four stroke cycle repeats itself, starting again as the piston moves down on the intake stroke.

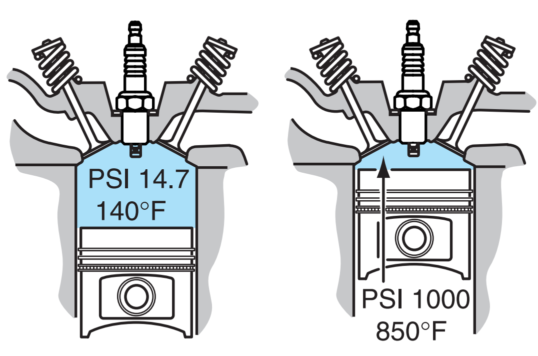


FIGURE 1.9 The air-fuel mixture heats up as it is compressed.

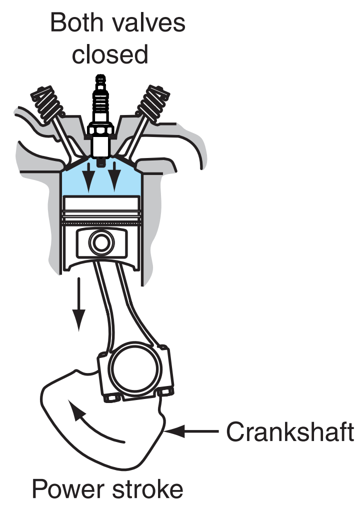


FIGURE 1.10 The air-fuel mixture ignites, pushing the piston down.

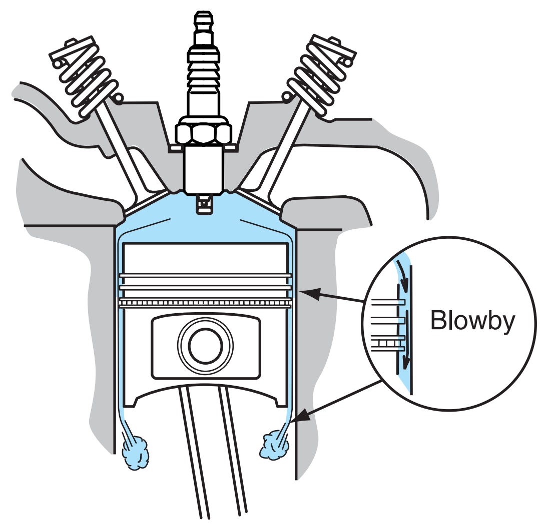


FIGURE 1.11 Leakage of gases past the ring is known as blowby.

The four stroke cycle is considerably more complicated than this simple explanation. When the engine is running, the timing of the opening and closing of the valves actually determines when each stroke effectively begins. Valve timing is discussed in much greater detail in Chapter 10.

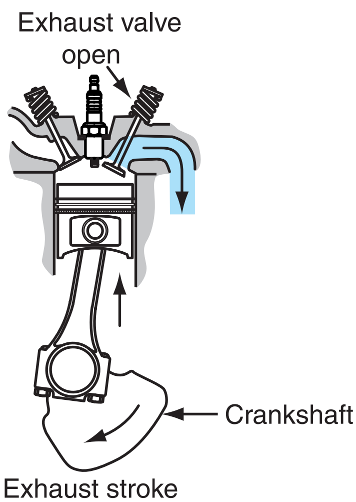


FIGURE 1.12 The exhaust valve opens and exhaust gases escape as the piston comes up.

CYLINDER ARRANGEMENT

Automobile and light truck engines have three, four, five, six, eight, or more cylinders. Cylinders are arranged in one of three ways: in-line, in a "V" arrangement, or opposed to each other (**Figure 1.13**).

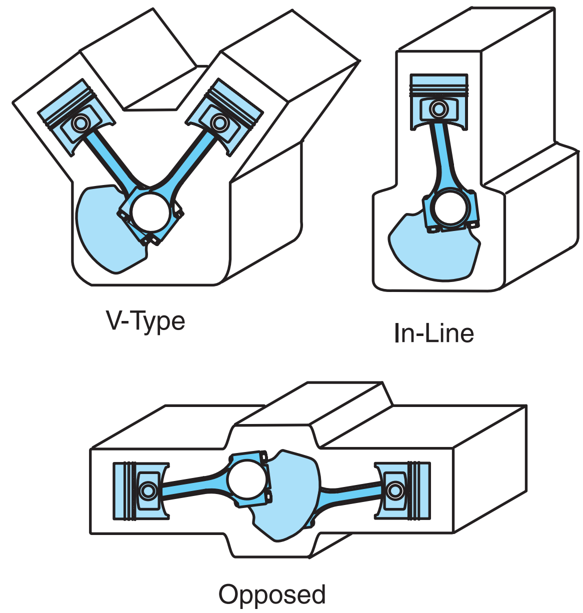


FIGURE 1.13 Cylinder arrangements.

VINTAGE ENGINES

In the first half of the 20th century, before the jet age, airplane engines had cylinders arranged in a radial arrangement (**Figure 1.14**).

The V arrangement is popular with designers when an engine has more than four cylinders because this design can be considerably shorter in length. A completely assembled V-type engine typically weighs less than an in-line engine with the same number of cylinders.

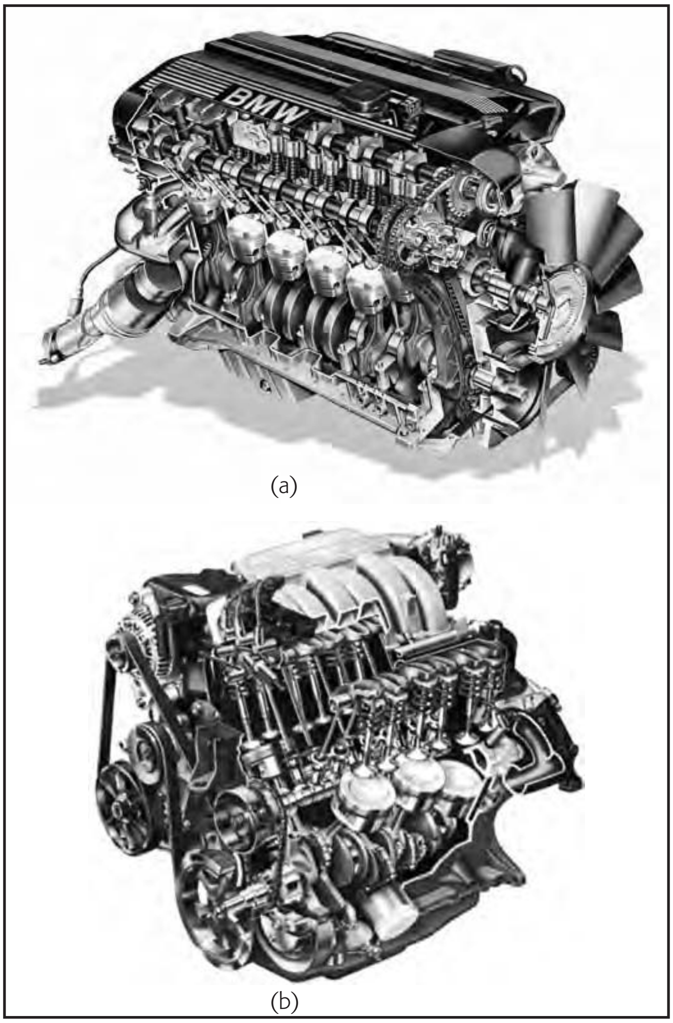
V-type engines have connecting rods from two cylinders on opposite sides of the engine that share one crankpin (see Chapter 11). This allows the engine block to have fewer supports for the crank-shaft main bearings. An in-line six cylinder engine might have seven main bearings; a V6 block is shorter and will typically have only four main bearings, whereas a V8 block will usually have five main bearings.

VINTAGE ENGINES

A V-type engine uses a carburetor more efficiently than an in-line engine. This is because the intake manifold runner lengths are more equal (see Chapter 10).

In-line six and V6 engines are shown in **Figure 1.15**.

FIGURE 1.14 A radial engine from a vintage airplane. *(Courtesy of Tim Gilles)*



(a)

(b)

FIGURE 1.15 (a) Section view of an in-line six cylinder engine. *(Courtesy of BMW of North America, LLC)* (b) Section view of a V6 engine. (© *DaimlerChrysler Corporation*)

VALVETRAIN

One complete four stroke cycle requires the crankshaft to rotate two times. Two 360° crankshaft revolutions means the crankshaft travels a total of 720° to complete one cycle. During these two revolutions, each cylinder's intake and exhaust valves open once. The valves are opened by the camshaft, commonly called the "cam," which is considered the "heart" of the engine. The cam has lobes that are off-center and push against the valvetrain parts, causing the valves to open at precise times (**Figure 1.16**).

The camshaft controls the rate at which the engine breathes. Its design can be for best operation at maximum power and high speed, or for fuel economy and best low-speed operation. A production engine is an engine produced at the factory. Production engines are a compromise between these two concerns, and this is the reason many late-model vehicles use variable valve timing. Chapter 10 deals with different "cam grinds" and variable valve timing in detail.

Camshafts can be located either in the block (see Figure 1.16a) or in an overhead cam cylinder head (see Figure 1.16b). One or more camshafts are driven via crankshaft rotation using one of several combinations, including gears or sprockets and chains or belts. The crank must turn twice for every one turn of the cam, so there are half as many teeth on the crank drive as there are on the cam drive (**Figure 1.17**).

CYLINDER BLOCK

The cylinder block is an intricate casting that includes oil galleries as well as jackets for coolant, which are commonly called *water jackets*. Cylinder blocks are made of cast iron or aluminum, cast into a sand mold called a core. Many engine blocks today are made of aluminum, cast around iron cylinder bore liners called sleeves (**Figure 1.18**). This allows for the weight savings provided by aluminum, coupled with the durability and trueness of cast iron in the cylinder bore area. Some aluminum blocks do not have iron sleeves because aluminum cylinder wall surfaces can be made very hard.

There are different casting processes for engine parts. In the *sand casting* process, the core is suspended in a container with a liner that will provide the shape for the outside surface of the engine block

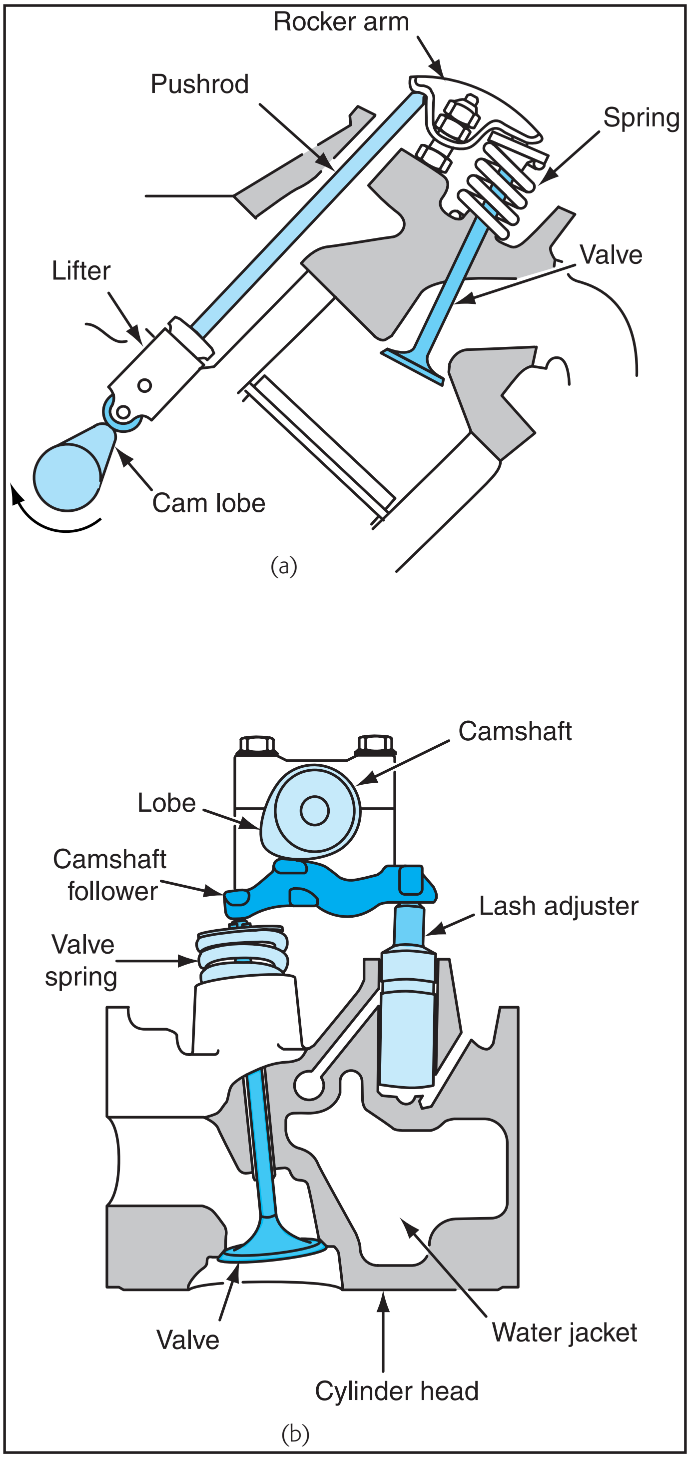


FIGURE 1.16 A cam lobe forces the valve open. (a) The cam-in-block design uses pushrods to open valves. (b) In the overhead cam design, the camshaft is located in the cylinder head. *(Courtesy of Tim Gilles)*

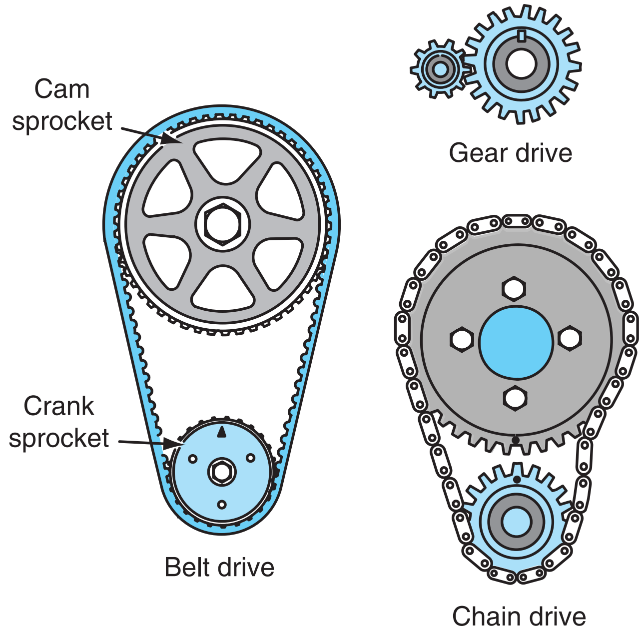


FIGURE 1.17 There are half as many teeth on the crank drive as there are on the cam drive.

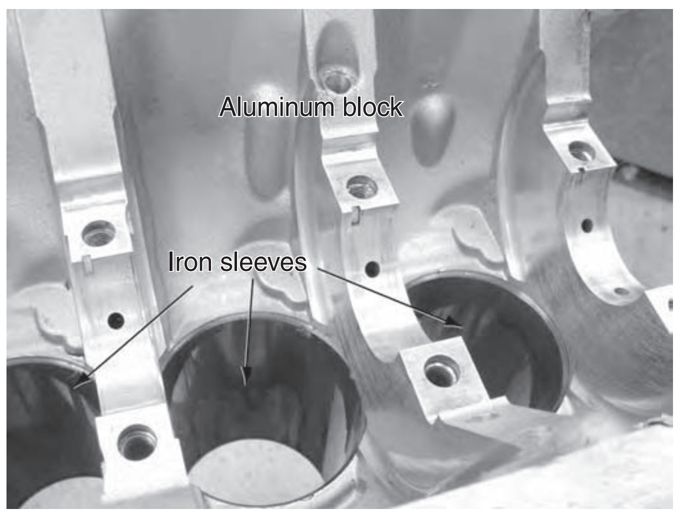


FIGURE 1.18 An aluminum block with cast iron sleeves. *(Courtesy of Tim Gilles)*

(**Figure 1.19**). The core is supported at several points around the outside of the core box, which leaves core holes in the finished block. The sand casting process uses binders to hold the grains of sand

FIGURE 1.19 Sand casting cores.

together. When molten iron or aluminum is poured into the core box, the heat of the casting process cooks the sand. When the casting cools, the sand breaks up. The casting is shaken out and any remaining sand is washed away through the core holes, leaving the finished casting.

In another casting process, *lost foam casting (LFC)*, foam is "lost" or burned up during the pour. General Motors first experimented with LFC in 1982 and since then has refined the process for use in casting blocks, heads, and crankshafts. Saturn used this process since its beginning in 1990. With conventional sand casting, oil galleries must be machined in the block casting. With LFC, the oil galleries and coolant passages can be cast into the part. Foam also provides a more accurate casting compared to sand casting. The completed casting is smoother in appearance and there are no parting lines. More intricate castings are possible because the pattern does not need to be removed as was the case with sand castings.

The LFC pattern is made of expendable polystyrene beads, otherwise known as Styrofoam. Patterns are made by injecting the beads into a die and then superheating them with steam to bond them together and form the finished mold. The foam pattern is coated with a refractory coating, which smoothes the surface of the pattern. Gates and risers are attached to the pattern to allow for the pouring and venting of the molten metal. Unlike the conventional sand casting process, which uses binders to hold the sand together, LFC uses dry, unbonded sand that is poured around and into the internal passages in the pattern. The sand is vibrated and compacted to thoroughly fill the voids around the pattern. During the pour, the molten metal replaces the pattern as it vaporizes. When the finished casting has cooled and become solid, the unbonded sand is dumped out. It can be reused, unlike conventional casting sand, which requires disposal.

The core holes are closed off with core plugs (**Figure 1.20**). Core plugs are usually made of steel or brass, although rubber and copper expandable plugs are available, too. Brass core plugs are superior because they do not rust. Brass plugs are not used in new cars because of their extra cost and because new engines are filled with coolant, which prevents rust. Core plugs are sometimes referred to as expansion plugs, welsh plugs, freeze plugs, or soft plugs.

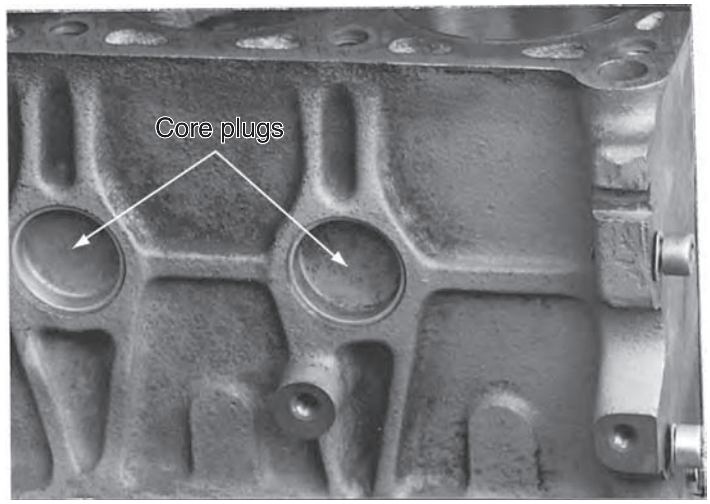


FIGURE 1.20 Core plugs. *(Courtesy of Tim Gilles)*

On V-type blocks, cylinders are cast in two rows called left and right banks.

NOTE

The location of the left and right banks is determined when viewing from the transmission end of the engine.

V8 blocks are cast with the cylinder banks separated by a 90° angle. V6 blocks have either 60° or 90° between banks. There are also unusual engine designs, such as Volkswagen's V6, which has 15° between banks.

There are *big block* and *small block* engine designs. Smaller, lighter blocks are more popular in passenger cars because of their fuel efficiency. Some intake manifolds cover the area between the heads known as the *valley* (**Figure 1.21**), whereas others use covers and a separate intake plenum.

A complete block assembly with the entire valvetrain (cylinder heads and related parts) included is called a *long block*.

Short Block and Long Block

The cylinder block assembly (without the heads installed) is called a *short block*. The short block includes the crankshaft, piston and rod assembly, and all bearings. On pushrod engines, the camshaft, timing sprockets, and timing chain are also part of the short block (**Figure 1.22**).

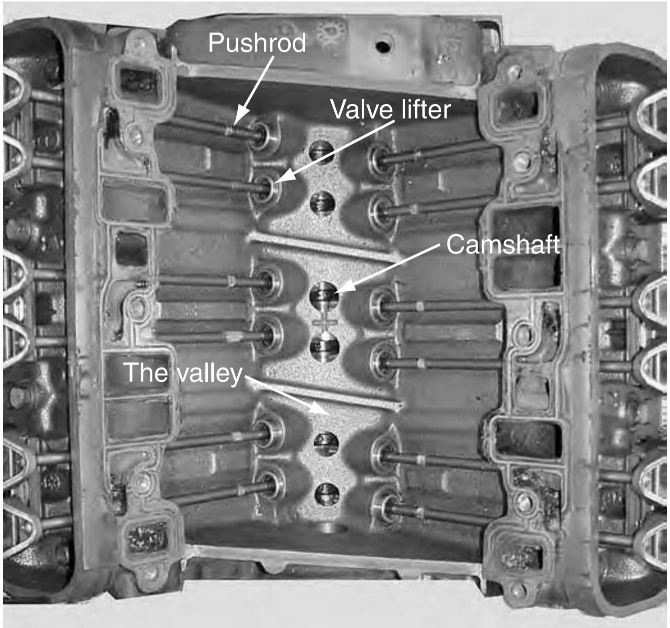


FIGURE 1.21 The area between the heads of a V-type engine is known as the valley. *(Courtesy of Tim Gilles)*

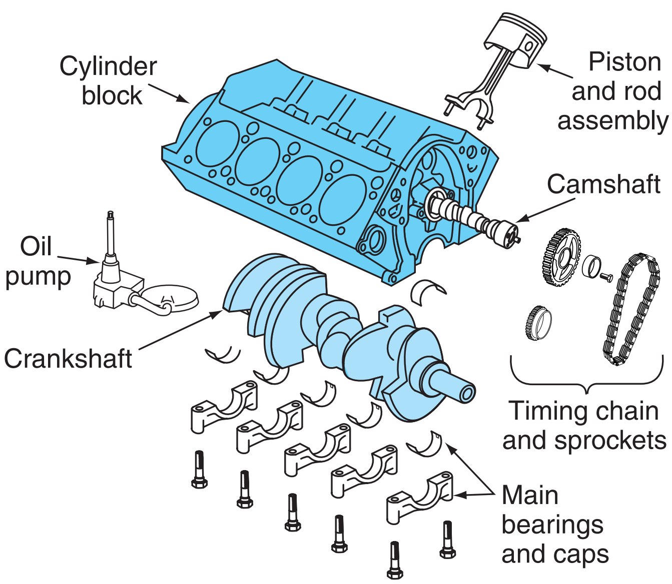


FIGURE 1.22 Exploded view of a short block for a cam-in-block engine.

The lower area of the cylinder block surrounded by the oil pan is called the *crankcase* because the crankshaft is located there. Main bearing bore holes are precisely align-bored in the lower end of the block to provide a mounting place for the main bearings and crankshaft. Main bearing caps are removable, but they must be replaced in exactly the same location. At the factory, the camshaft bore holes, cylinder bores, cylinder head mounting surface, all threaded holes, and all gasket surfaces are machined automatically and in perfect alignment to each other. During rebuilding, the technician or machinist's job is to maintain the original alignment.

The following lists typical components common to both short and long blocks:

- *Oil Pan.* The oil pan is a stamped sheet metal or cast aluminum part that encloses the crankcase (**Figure 1.23**). It provides a reservoir where the engine oil is cooled as air passes across its surface. Oil pans are sometimes damaged when driving or during engine removal and replacement. Sometimes a sheet metal oil pan can be bent enough so that the crankshaft comes in contact with it. After a rebuild, the resulting noise can cause a great deal of worry when the engine is first started.
- *Flywheel.* Mounted on the rear of the crankshaft is a flywheel or flexplate. The weight of the flywheel helps carry the crankshaft beyond BDC after the power stroke and smoothes out the power impulses of multiple cylinders. A flywheel is used with a standard transmission. It also provides a surface for the clutch to work upon. When the vehicle is equipped with an automatic transmission, a torque converter and flexplate are used (see Chapter 4). A ring gear on

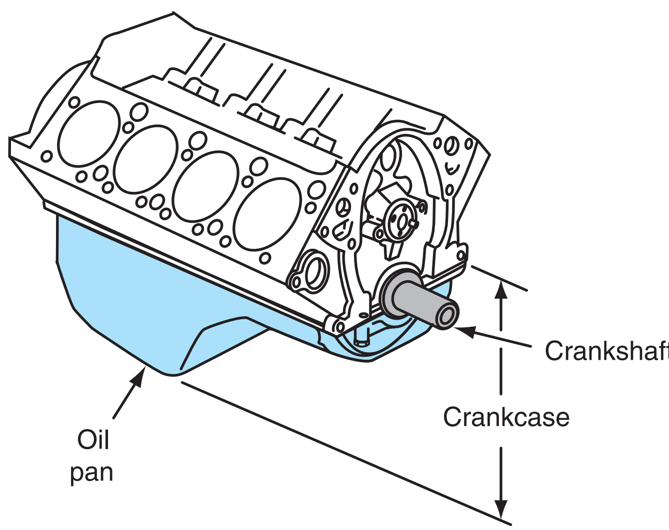


FIGURE 1.23 The oil pan encloses the crankcase.

the circumference of the flywheel or flexplate provides a gear drive for the starter motor. Ring gears on flywheels and flexplates are sometimes damaged by faulty starter motors. Replacement of a flywheel ring gear or a flexplate is a relatively easy job while the engine is out of the vehicle.

- *Vibration Damper.* The vibration damper, also called a *harmonic balancer*, is mounted on the front of the crankshaft on V-type and in-line six cylinder engines. The power impulses on the pistons cause the crankshaft to twist and untwist in much the same manner as a tuning fork vibrates. The damper dampens out these torsional vibrations, which could result in a broken crankshaft if allowed to continue. Most four cylinder engines do not require a damper and use only a pulley.
- *Crankshaft.* The crankshaft is made of either cast iron or forged steel. Its bearing surfaces for the main and rod bearings are called *journals*. The main bearing journals are those that run down the centerline of the crankshaft, in line between the front and rear journals. Oil galleries provide lubrication to the main bearing journals through oil holes in the main bearings. Holes are drilled in the crankshaft, from the main bearing journals to the connecting rod bearing journals, to provide the rod bearings with pressurized lubrication.

Rod journals, also called crankpins, are offset 90° on V8s, 180° on four cylinders, and 120° on six cylinders (**Figure 1.24**). Some V6s have offset crankpins (also see Chapter 11).

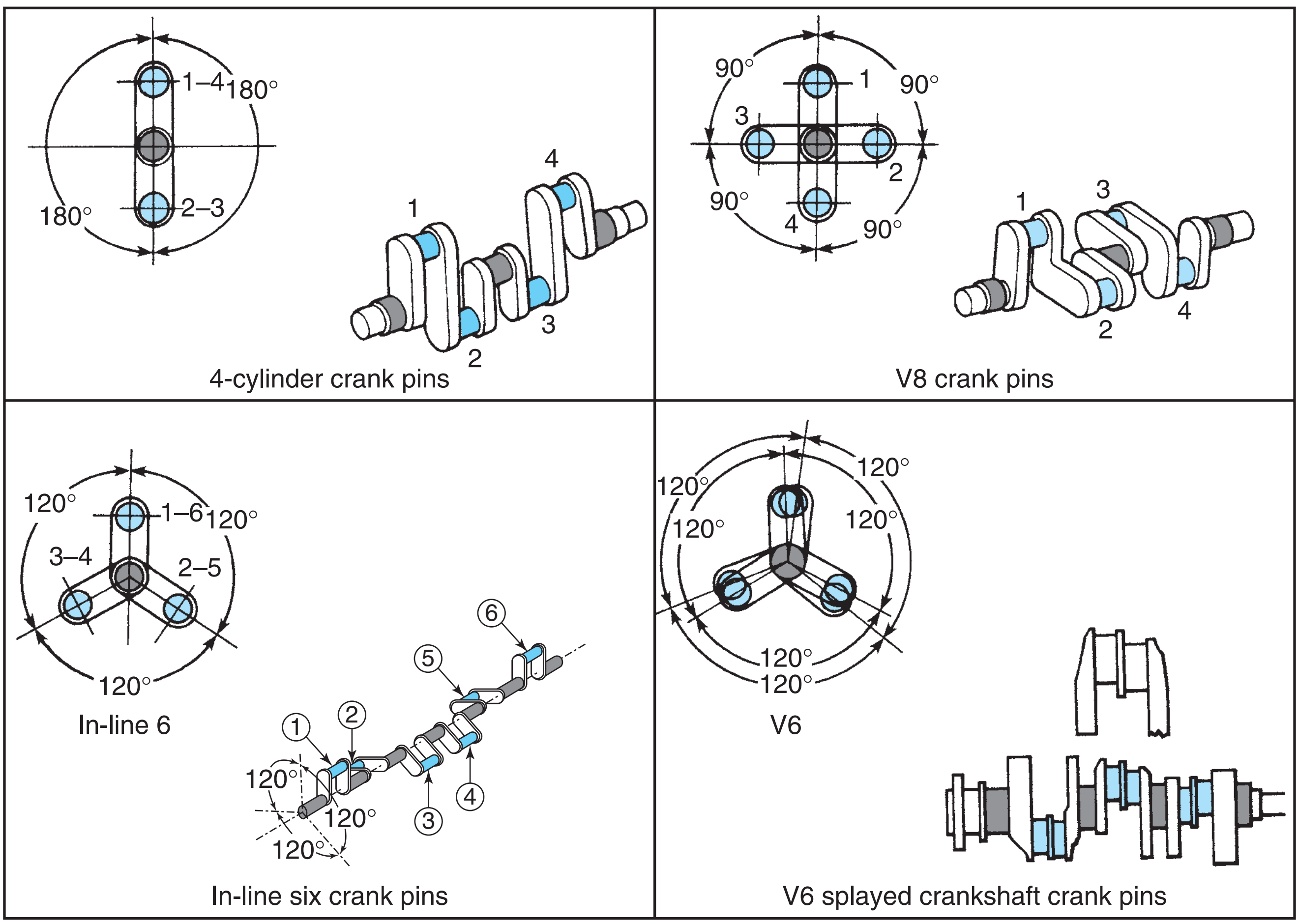


FIGURE 1.24 Crankshaft rod journals are offset 180° for four cylinders, 120° for six cylinders, and 90° for eight cylinders.

FRONT-WHEEL DRIVE

Front-wheel drive (FWD) vehicles often use a **transverse** (sideways) **engine** (**Figure 1.25**). The smaller four cylinder engines and the 60° V6 are suited for small car, FWD use, although there are some 90° V6 engines in FWD vehicles; larger engines tend to be used in rear-wheel drive (RWD) vehicles. Some manufacturers have used large engines in FWD cars. If FWD drive shafts are not of equal length, a car with substantial horsepower will experience torque steer. Torque steer is when the vehicle pulls to one side under heavy acceleration.

ENGINE CLASSIFICATIONS

Engines are classified according to their displacement and valve arrangement. **Displacement** refers to the volume that the piston displaces in the cylinder (**Figure 1.26**). The engine's total displacement is determined by multiplying:

$$\text{Bore}^2 \times \text{Stroke} \times 0.7854 \times \text{Number of Cylinders} = \text{Displacement}$$

The larger the displacement, the larger the engine. Engine size in North American vehicles used to be described in CID, or cubic inch diameter. In late-model vehicles, volume is described in liters or cubic centimeters. (Converting between metric system measurements and English system measurements is covered in Chapter 6.) Another means of determining displacement is to multiply the swept volume of the cylinder by the number of cylinders. Swept volume is determined by multiplying:

$$\frac{\text{Bore}}{2} \times \frac{\text{Bore}}{2} \times \text{Stroke} \times \pi\ (3.14) = \text{Swept Volume}$$

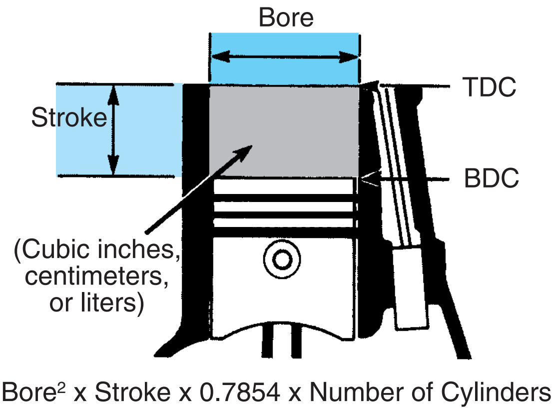


FIGURE 1.26 Displacement is a measurement of the cylinder's volume.

Valve Arrangement

Modern engines use an *overhead valve (OHV)* arrangement known as *I-head* or *valve-in-head* (**Figure 1.27**). This design has a more direct path of air-fuel flow than earlier engine designs. Fewer

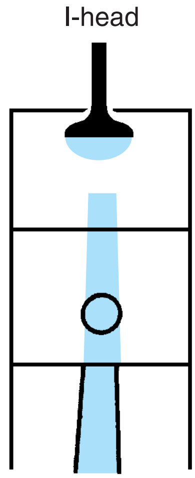


FIGURE 1.27 When the valves are in the cylinder head, the engine is known as an I-head engine.

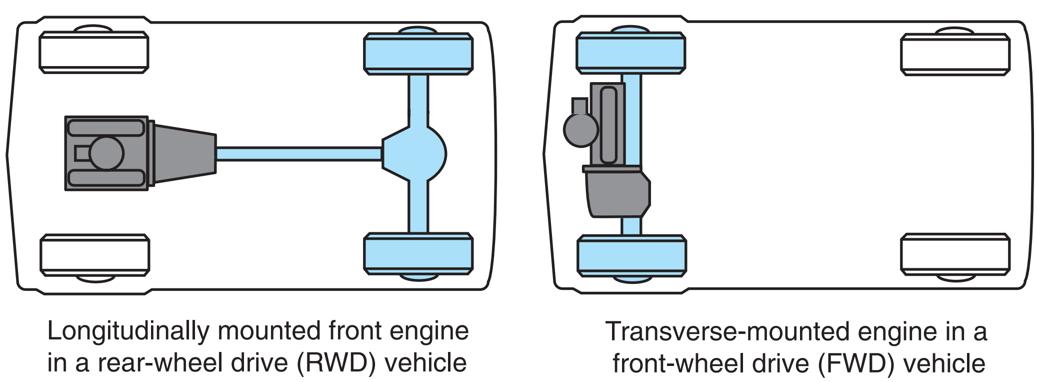


FIGURE 1.25 Rear-wheel drive (RWD) and front-wheel drive (FWD) engines.

exhaust emissions are produced because of the smaller amount of surface area in the combustion chamber. When cool engine surfaces are exposed to unburned fuel, a *skin effect* occurs and the unburned fuel ends up in the exhaust stream.

Increasing the valve opening, called *valve lift*, to a certain point is necessary to allow enough air-fuel mixture into the cylinder to develop maximum power. Increased valve lift is possible with the I-head engine design. This is because as the intake valve opens, the piston is moving down in the cylinder, providing clearance. When the exhaust valve is wide open, the piston is near the bottom of the cylinder, providing plenty of piston-to-valve clearance as well. If more air-fuel mixture is packed into the cylinder, more power will be developed. This is called volumetric efficiency, which is the reason that supercharging is so effective in producing extra power from relatively small engines. In supercharged engines, an air pump compresses more air-fuel mixture into the cylinder (see Chapter 10).

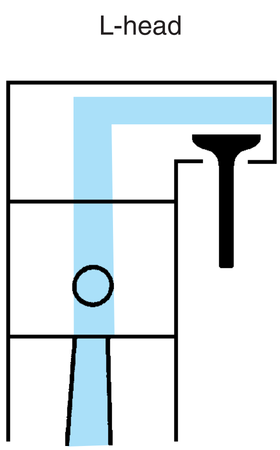


FIGURE 1.28 An L-head, or flathead, engine has the valves in the block.

VINTAGE ENGINES

Until the early 1950s many automobiles had L-head engines whose valve configuration resembles the letter L upside down (**Figure 1.28**). These engines, also called *flatheads* or *sidevalves,* are still used in lawnmowers, generators, and other industrial engines. L-head engines are less expensive to manufacture, but they produce more smog due to the high amount of surface area exposed to unburned fuel. Flatheads are also limited in their compression ratio and valve lift. Increased valve lift requires more clearance in the combustion chamber, which would lower compression.

The photo in **Figure 1.29** shows an L-head Studebaker engine with the cylinder head removed. Notice how the valves are located in the block. Flatheads were very popular with early hot rodders and racers (**Figure 1.30**). A popular hot-rodding trick was to remove the cylinder head (a relatively easy thing to do) and mill it to increase the compression ratio.

FIGURE 1.29 A flathead Studebaker block with the head removed. *(Courtesy of Tim Gilles)*

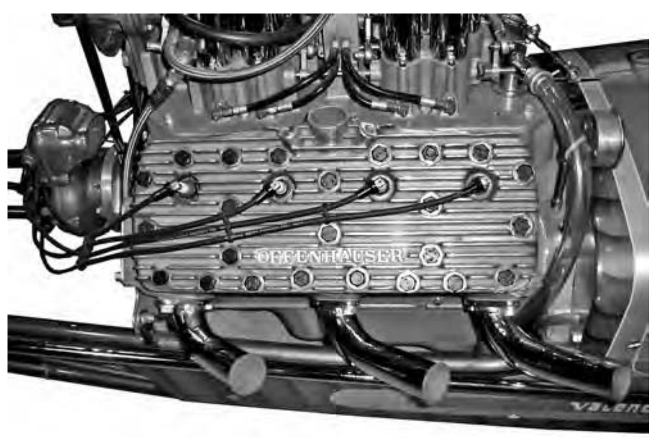


FIGURE 1.30 A flathead V8 engine from a vintage dragster. *(Courtesy of Tim Gilles)*

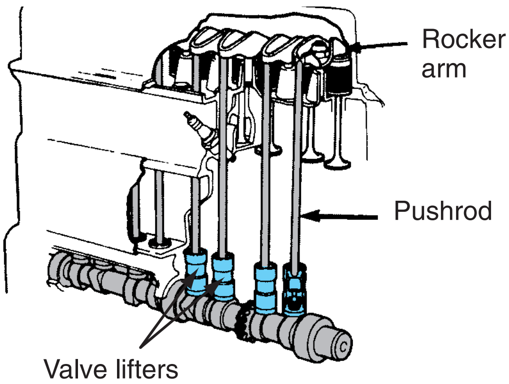


FIGURE 1.31 Some overhead valve (I-head) engines use pushrods to operate rocker arms.

Cam-in-Block or Overhead Cam

Some I-head engines have the camshaft located in the block. This engine design is called a *pushrod engine*, or *cam-in-block engine.* Cam lobes raise valve lifters that act on pushrods to operate rocker arms and open the valves (**Figure 1.31**). In late-model vehicles, pushrods are found most often on V-type engines.

A more popular type of valve operating arrangement for late-model engines is the *overhead cam* design, or OHC. This engine has the camshaft mounted on top of the cylinder head just above the valves (**Figure 1.32a**). It has the advantage of having fewer parts and less weight. *An engine running on the freeway at 3000 rpm has to open and close a valve 25 times per second,* so valvetrain weight is very important. It is even more important in high-speed engines.

Some OHC engines have a single cam (SOHC). Each cylinder is provided with two separate lobes to operate the intake and exhaust valves. High-performance OHC engines often have two cams per cylinder head. On this design, known as dual overhead cam (DOHC), one camshaft operates the intake valves and the other operates the exhaust valves (**Figure 1.32b**). DOHC engines have become more common in recent years as the base engine of many vehicle manufacturers.

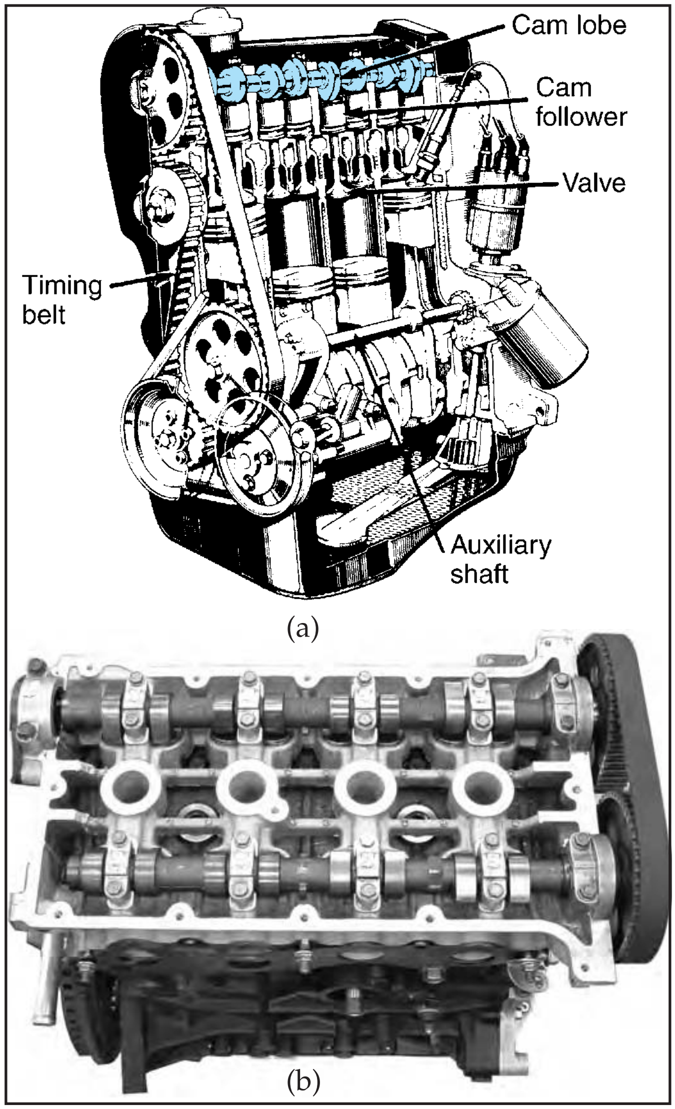


FIGURE 1.32 In-line four cylinder overhead cam engine. (a) An OHC engine with the cam positioned over the valve. *(© DaimlerChrysler Corporation)*. (b) A dual overhead cam (DOHC) engine. *(Courtesy of Tim Gilles)*

The OHC engine uses a long chain or belt from the crankshaft to the cylinder head to drive the cam(s) (**Figure 1.33**). When the ignition system uses a distributor, some OHC engines use an auxiliary shaft to drive it, whereas others have a crankshaft-driven distributor.

VINTAGE ENGINES

OHC was limited in the past to smaller, in-line engines, except for its use in luxury or racing automobiles. In recent years, belt-driven OHC engines have become commonplace.

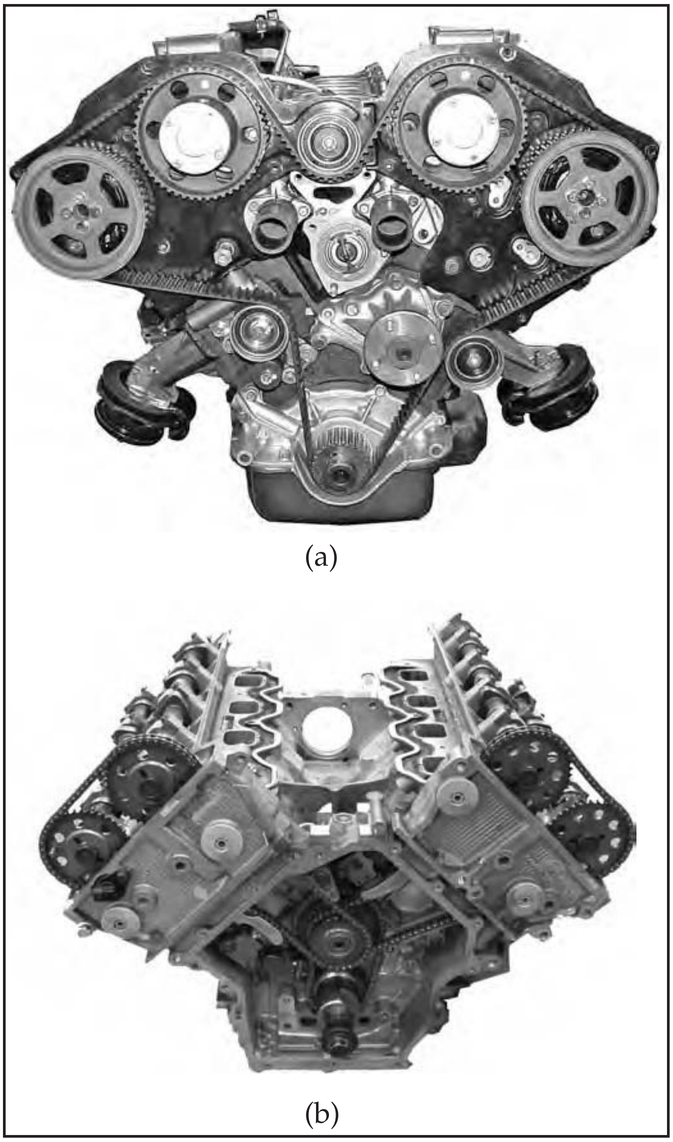


FIGURE 1.33 V-type overhead cam engines. (a) Belt-driven overhead cam V6. (b) Chain-driven overhead cam V8. *(Courtesy of Tim Gilles)*

COMBUSTION CHAMBER DESIGNS

The principal combustion chamber designs are the hemi, the wedge, and the pent-roof. There are also some combustion chamber designs with "D" or heart shapes. The wedge is the most common combustion chamber design with pushrod engines (**Figure 1.34**). It has a squish/quench area that causes movement (turbulence) of the air-fuel mixture and cooling of the gases to prevent abnormal combustion (see Chapter 3). This movement causes more complete burning at lower speeds with less chance of detonation.

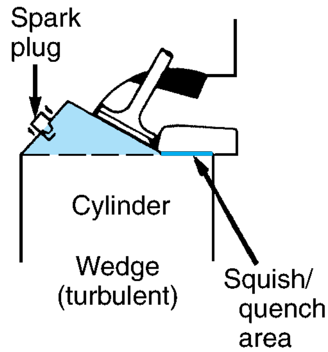


FIGURE 1.34 A wedge combustion chamber.

There are turbulent and nonturbulent combustion chambers. Turbulent combustion chambers, like the wedge, can cause air and fuel to separate from each other at high speeds. A nonturbulent combustion chamber, the hemispherical (hemi) design, is more efficient for high-speed use (**Figure 1.35** and **Figure 1.36**). Because the mixture is centered near

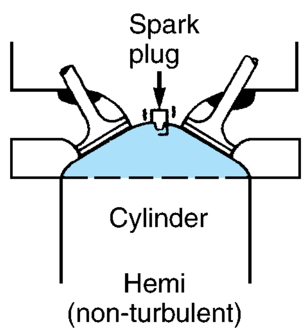


FIGURE 1.35 A hemispherical combustion chamber.

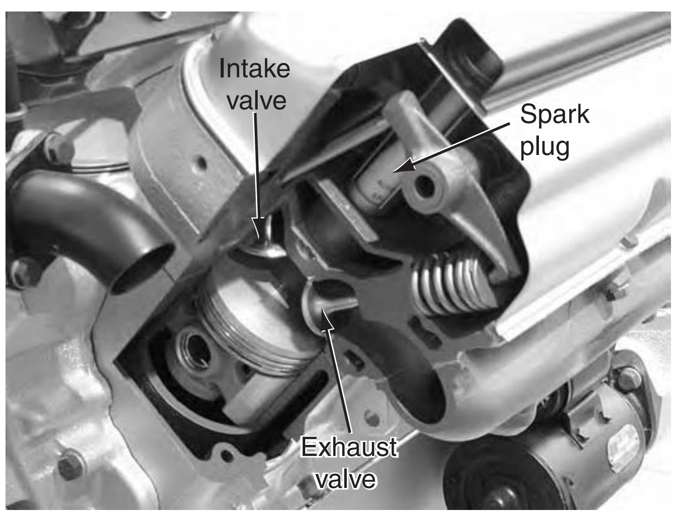


FIGURE 1.36 A cutaway of a Chrysler hemi head. The valves are on opposite sides with the spark plug in the center. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

The stratified charge design is the type pioneered by Honda (**Figure 1.37**). The name comes from the stratification, or layering, of different densities of air-fuel mixtures. Honda and Mitsubishi used a very small amount of rich mixture to ignite a very lean (normally unburnable) mixture in a small precombustion chamber. When it was ignited by the spark plug, the advancing flame front from this small, rich mixture ignited the leaner mixture in the main cylinder. This made it possible for the engine to run on an air-fuel mixture leaner than normal. Today's direct-injected engines (covered later in this chapter) use a stratified fuel charge.

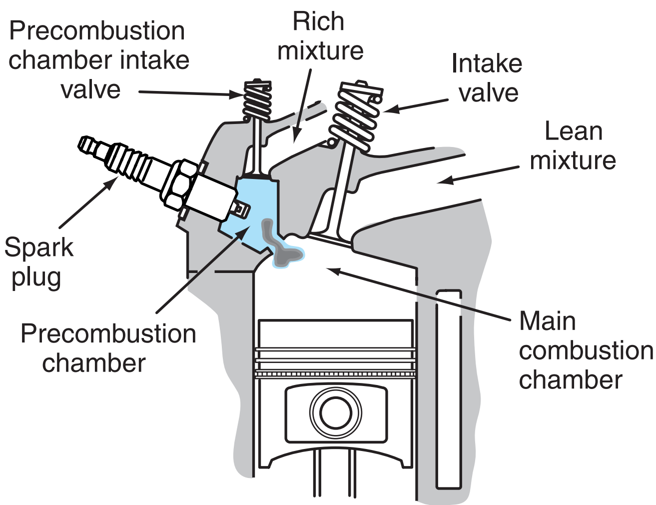


FIGURE 1.37 In this stratified charge head a small valve in the precombustion chamber provides the rich air-fuel mixture needed to ignite the lean mixture in the main combustion chamber.

the spark plug, the flame spreads evenly. A hemi chamber allows the use of bigger valves, too. Sometimes hemis have a tendency to "spark knock" on lower octane fuels (see Chapter 3).

Diesel engines have no chamber in the cylinder head itself; the combustion chamber side of the head is virtually flat. Turbulence and squish in the cylinder are controlled by the shape of the piston head.

A pent-roof combustion chamber is shaped like a "V." This design is popular for use with four valve-per-cylinder designs. The pent-roof and other newer designs are designed for more efficient combustion and better emission control. In a high swirl chamber, like in the wedge chamber, areas on the head surface are raised to cause a planned turbulence of the air-fuel mixture.

DIRECTION OF CRANKSHAFT ROTATION

The front of the engine is the side opposite the transmission. The front of most engines includes the camshaft drive, a timing cover or front cover, and the crankshaft vibration damper or pulley. Volkswagen has some engines that have the timing cover at the rear of the engine.

The Society of Automotive Engineers (SAE) standard for engine rotation says that automotive engines rotate counterclockwise when viewed from the flywheel end of the engine. This means that longitudinally mounted engines (called front to rear or north to south) turn clockwise when viewed from the front. Transverse mounted (sideways) engines also follow this standard, although a few engines (Honda, for instance) rotate in the opposite direction.

FIRING ORDER

To make a smooth-running engine, multiple-cylinder engines have their power strokes spaced at specified intervals. In a four cylinder engine, one cylinder starts a power stroke at every 180° of crank rotation (**Figure 1.38**). This interval between power strokes is known as the ignition interval.

Cylinders are fired in a sequential order known as the **firing order**. The firing order does not usually follow the order of cylinder numbering. **Figure 1.39** shows several ways of determining an engine's

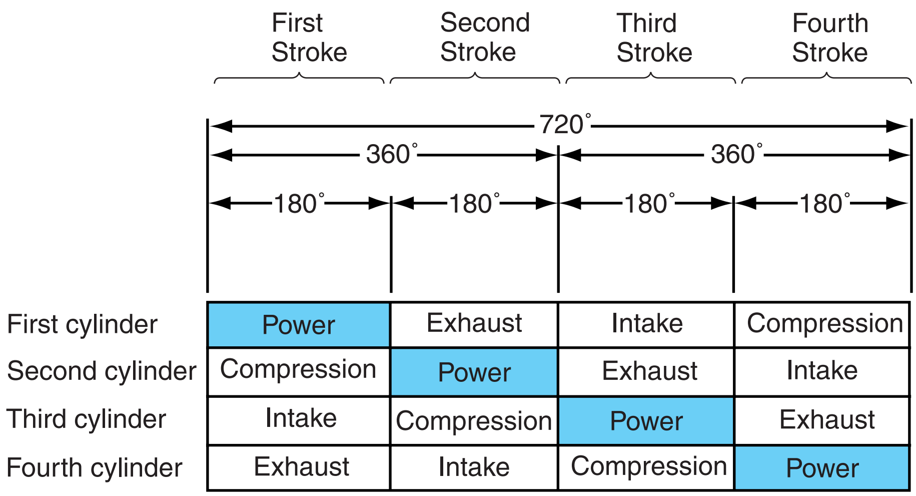


FIGURE 1.38 A four cylinder engine has one cylinder on a power stroke during every 180° of crankshaft rotation.

firing order. Sometimes the firing order is found cast into the surface of the intake manifold for easy reference.

SHOP TIP

Most V-type engines have one bank of cylinders positioned farther forward than the others. The cylinder closest to the front is usually the one denoted as number 1 (**Figure 1.40**).

Companion Cylinders

Engines with an even number of cylinders have pairs of cylinders called **companion cylinders**, or running mates. Pistons in companion cylinders go up and down in pairs. When one piston is starting its power stroke, its companion piston is at the start of its intake stroke. To find out which cylinders are companions, take the first half of the engine's firing order and place it above the second half. For a V8 with a 1 8 4 3 6 5 7 2 firing order, put numbers 1, 8, 4, and 3 above numbers 6, 5, 7, and 2. The resulting pairs are companions.

first revolution	1	8	4	3
	|	|	|	|
second revolution	6	5	7	2

Remember, during a complete four stroke cycle the crankshaft will revolve twice (720°). The first half of the firing order represents the first crankshaft revolution (360°) and the second half of the firing order represents the second revolution (360°).

In the preceding example, when cylinder number 7 is beginning its intake stroke, cylinder number 4 is beginning its power stroke. This is an eight cylinder engine so one power stroke occurs during every 90° of its 720° four stroke cycle.

$$\frac{720^\circ}{8(\text{cyl.})} = 90^\circ$$

It appears at first glance that a single cylinder engine would require the same airflow into its cylinder as a four cylinder engine with cylinders of the same displacement because the four stroke engine only uses the intake manifold during the intake stroke. In actual practice, however, the engine breathes air and fuel for a period longer than the intake stroke's 180° of crankshaft rotation (refer to the chart in Figure 1.38). The valve starts to open before TDC and closes after BDC when the crankshaft has traveled considerably into the compression stroke. The reason for this is to allow the cylinder to fill with as much air-fuel mixture as possible.

An in-line six cylinder engine has one power stroke every 120° of its 720° four stroke cycle.

$$\frac{720^\circ}{6(\text{cyl.})} = 90^\circ$$

If the engine were carbureted instead of fuel injected, a single carburetor on this engine would have

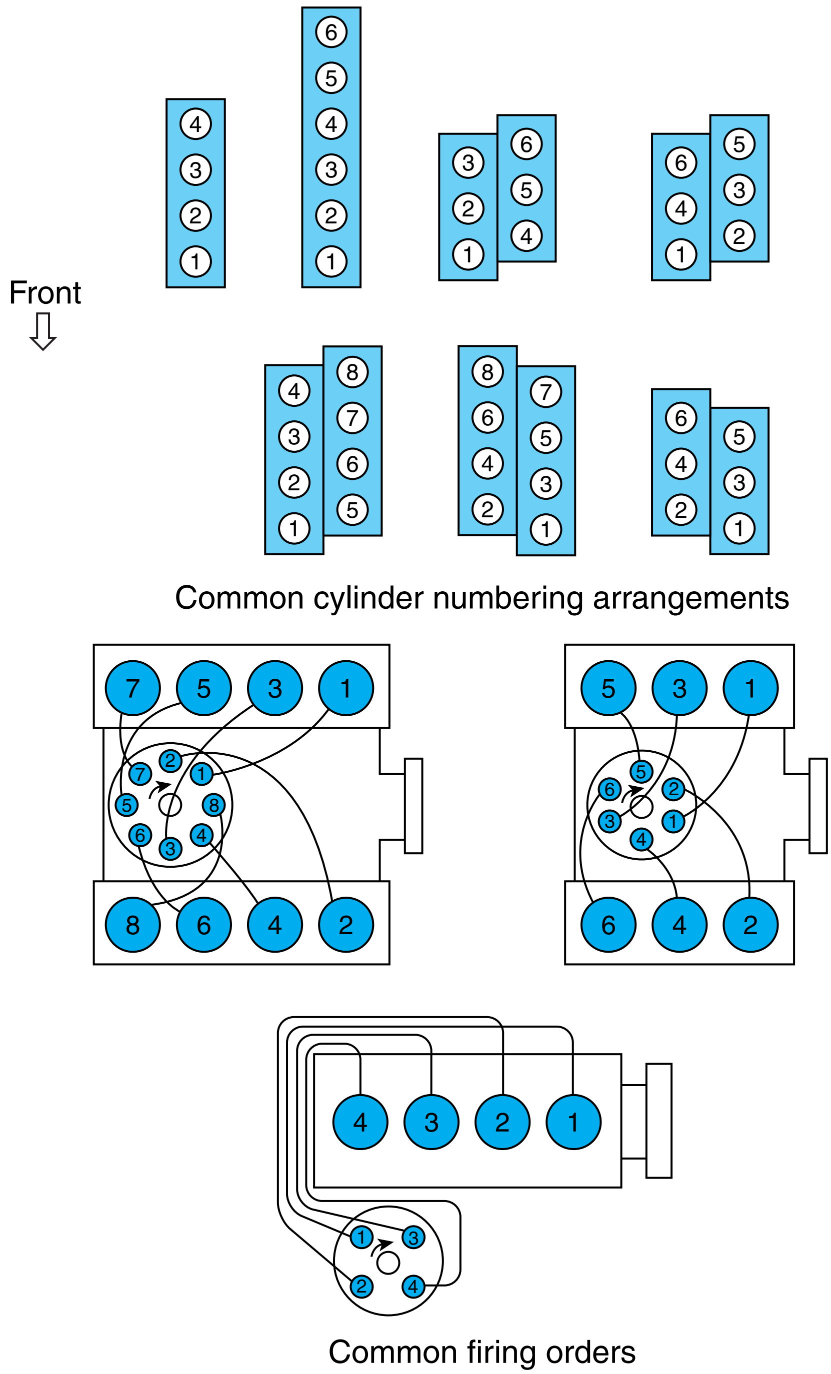


FIGURE 1.39 Several different cylinder numberings and firing orders.

to be larger so it could serve more than one cylinder at a time because of the overlapping intake strokes.

ENGINE COOLING

Power produced at the crankshaft is called gross horsepower. Accessories that rob power include the alternator (charging system), air conditioning, coolant pump, cooling fan, power steering pump, and smog pump. Combined, these absorb about 25% of the power available at the crankshaft. The power remaining to be used is called net horsepower. Power is also lost through friction in the driveline (transmission and differential) and due to wind resistance, increased vehicle weight, tires, and weather.

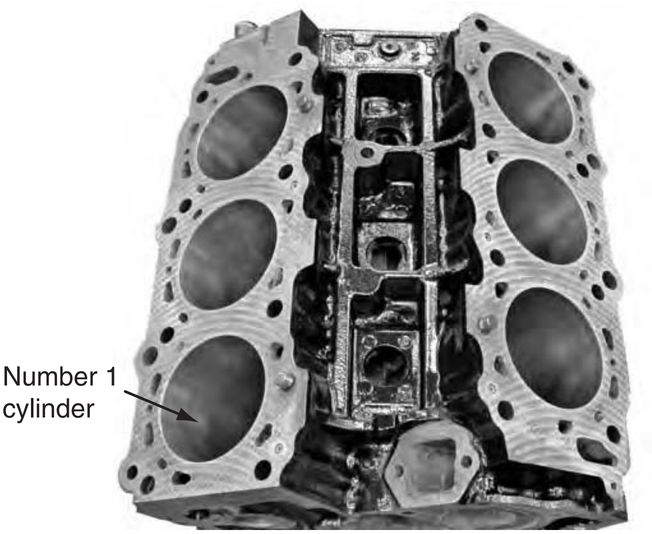


FIGURE 1.40 The number 1 cylinder is the closest to the front of the engine on almost all V-type engines. *(Courtesy of Tim Gilles)*

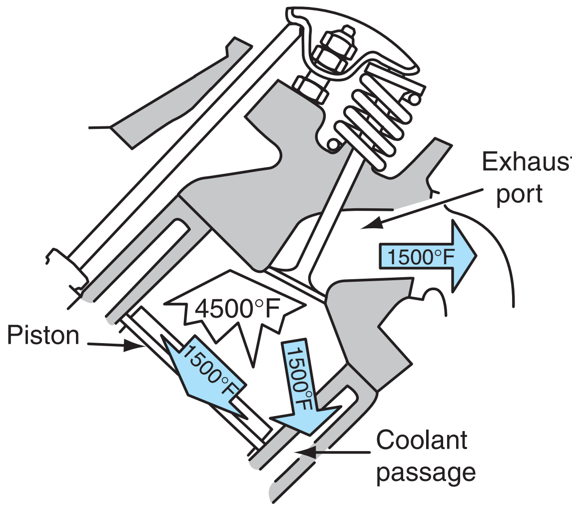


FIGURE 1.41 One-third of the heat energy produced is converted to work. The other two-thirds go to the cooling system, exhaust, and metal castings.

In a spark ignition engine, only about one-third of the energy of the burning fuel is converted to work at the crankshaft. The remainder is wasted as heat; half of it goes out the exhaust and the other half is carried off through the cooling system and by air contact with the metal castings (**Figure 1.41**).

Automotive engines use liquid cooling systems. Air cooled engines are found in lawnmowers, motorcycles, and some older automobiles.

Liquid cooled engines have water jackets to cool the areas around all cylinders and throughout the cylinder head, especially around the valve seats. Coolant is pumped throughout by a coolant pump,

VINTAGE ENGINES

On a few older engines, the number 1 cylinder was positioned behind the front cylinder in the opposite cylinder bank. These include Ford's Y-block engines from the mid-1950s to mid-1960s as well as Ford and Mercury L-head engines and some older Pontiacs.

VINTAGE ENGINES

The V-type engine uses a two-barrel intake manifold. On most V8s each barrel serves four cylinders. In theory, the V8 is actually two four cylinder engines operating together and a V6 is two three cylinder engines. An in-line engine with more than four cylinders would require fuel injection or multiple carburetors to distribute fuel more efficiently. Intake manifolds are covered in detail in Chapter 10.

VINTAGE ENGINES

Until emission requirements curtailed their use, air cooled automobile engines were produced in vehicles like Volkswagen, Porsche, and Corvair. Air cooled engines operate at higher temperatures than liquid cooled engines. Higher running temperatures result in increased NO_x (oxides of nitrogen) emissions (a major component in photochemical smog).

commonly called a water pump. A thermostat regulates the flow of coolant between the engine and radiator to maintain a specified temperature.

Freezing and boiling protection is provided by a mixture of water and coolant in a concentration of about 50% water and 50% coolant. One of coolant's important jobs is to inhibit rust and electrolysis, which cause corrosion. The **bimetal engine**, found in some of today's cars and trucks, combines iron cylinder blocks and aluminum cylinder heads. These two dissimilar metals promote electrolysis, or the creation of an electrical current. Electrolysis causes much faster deterioration of metals.

SPARK AND COMPRESSION IGNITION

Although this text does not deal specifically with diesel engines, most of the automobile engine information included here applies to light-duty diesel engines found in some passenger cars and light trucks. Diesel-cycle and Otto-cycle engines share the same basic principles of operation. The difference is in the way the fuels are introduced to the cylinder and ignited. The gasoline engine is called a spark ignition (SI) engine.

Diesel Engine

The diesel engine was invented by Rudolf Diesel in 1892 in Germany. Diesel engines, which can be either two stroke or four stroke cycle, are used extensively in heavy equipment and were not used in automobiles until the 1930s. In operation and appearance, the diesel engine is very similar to the gasoline engine.

A diesel is a compression ignition (CI) engine. It does not use a spark to ignite the fuel. Diesel engines use fuel injectors (**Figure 1.42**). When air is compressed in the cylinder and high-pressure fuel is injected into it, the fuel ignites. Whereas gasoline engine compression ratios most often range between 8:1 and 10:1, diesel compression ratios range from 15:1 to 22:1 (**Figure 1.43**). When air is compressed, it heats up. In a diesel engine the temperature of the compressed air can be approximately 1000°F. An air-fuel mixture will explode if it is compressed too much, so the diesel engine compresses only air. Diesel fuel does not burn at room temperature; its autoignition temperature is 410°F (210°C). However, when diesel fuel is injected into the cylinder at the exact moment when ignition is desired, it burns easily in the hot environment of the compressed air.

Diesels use different types of injections, all of which must have injector pressure that is very high so it can overcome the cylinder pressures reached during the compression stroke. Older diesel engines had mechanical injectors operated by a camshaft. Later engines used a precision fuel distributor and individual injectors. The most recent diesel engines use high-pressure, direct injection similar to gasoline direct injection described earlier.

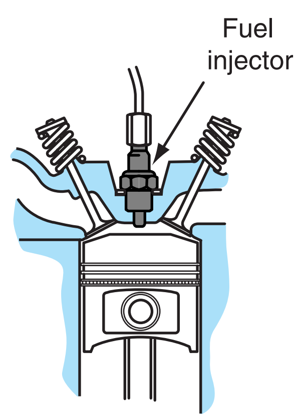


FIGURE 1.42 A diesel engine has a timed, high-pressure fuel injector to control the point of ignition.

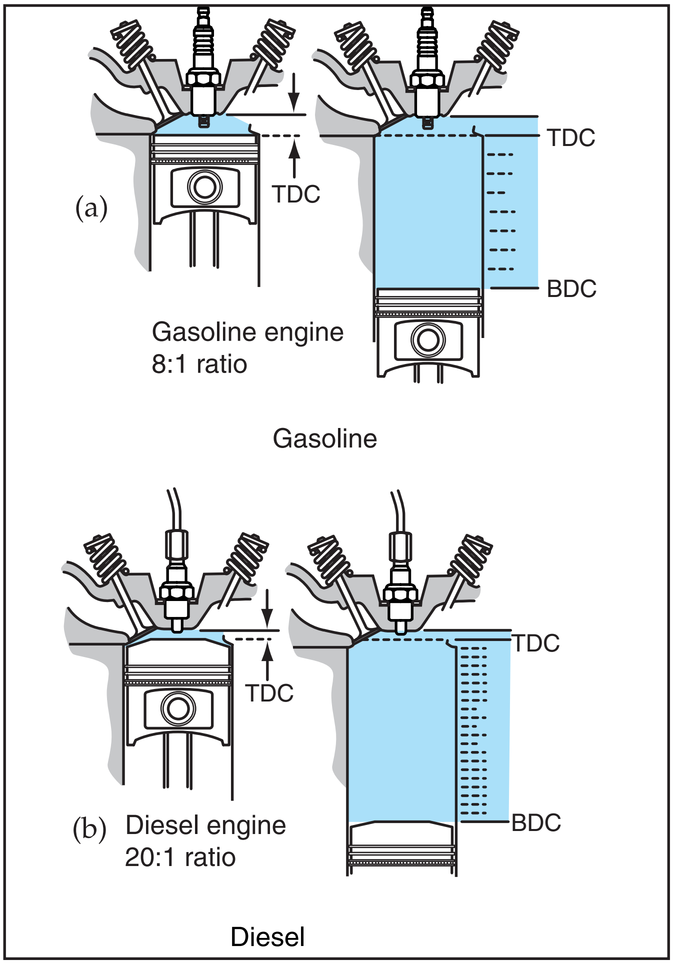


FIGURE 1.43 Comparison of gasoline and diesel compression ratios.

Diesel engines can run at very lean mixtures at idle and are generally about one-third more efficient on fuel, although they produce less power than a gasoline engine. In gasoline engines the amount of air entering the engine is changed to control speed and power. In a diesel, the amount of air remains the same while the fuel mixture is changed to control speed and power. The mixture can be as rich as 20:1 under load and as lean as about 80:1 at idle.

Problems with older diesel engines were their high particulate emissions (soot) and the high temperature of combustion, which produces high levels of NO_x emissions. Diesels also have starting problems in cold weather and require more frequent oil changes and other maintenance.

Modern diesel engines have been mandated to have exhaust emissions that are nearly free of particulates. Engine manufacturers have been able to accomplish this using computerized engine controls with altered engine designs. *Common rail direct injection* diesels first appeared in the mid-1990s.

A tube or passage called a *common rail* connects the fuel injectors with diesel fuel under very high pressure of nearly 20,000 psi (1360 BAR). The fuel system injects a small amount of high-pressure fuel before and after the main fuel charge. High pressure in the common rail thoroughly atomizes the diesel fuel, mixing it with air. This results in less unburned fuel and cleaner exhaust gas. Electronic piezoelectric injectors precisely control the fuel. Direct injection engines have lower emissions, are very responsive, and get better fuel economy than the old diesel engines.

Two Stroke Cycle

Two stroke engines have been used for years in diesel engines, outboards engines, chainsaws, and motorcycles. Other than a basic explanation of their operation, two stroke engines are not covered in this text. Future automobile engines might use the two stroke cycle because it has several advantages. A two stroke engine can be made smaller and lighter than a four stroke engine of comparable displacement. Theoretically, a two stroke engine only requires half of the displacement of a four stroke engine.

A two stroke engine has a power stroke every crankshaft revolution. The two stroke cycle begins with the piston at TDC on the power stroke. The cylinder has intake and exhaust ports, which are openings in the side of the cylinder (**Figure 1.44**). As the piston reaches the bottom of the power stroke, the exhaust port is opened to release exhaust gases. Shortly after the exhaust port opens, the intake port opens to force the air-fuel mixture to enter the cylinder. This action also helps to push the exhaust out. As the piston moves up on its compression stroke, both the intake and exhaust ports are covered.

Most nonautomotive two stroke engines use a mixture of oil and gasoline for lubrication. The oil and fuel mixture lubricates the **lower end** (crankshaft and bearings) as it flows through the crankcase on its way to the cylinder. New direct injected two stroke engines use fuel injectors to put fuel into the combustion chamber. Air is pushed into the cylinder using a supercharger. The crankcase is pressure-lubricated in these engines just like in four stroke engines.

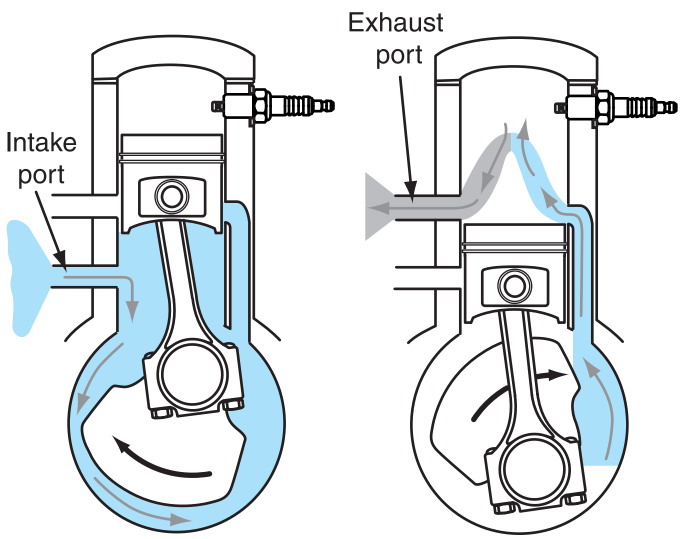


FIGURE 1.44 Two stroke cycle engine operation.

PUTTING IT ALL TOGETHER

- Most of today's cars and light trucks are powered by Otto-cycle engines. During one four stroke cycle, the intake, compression, power, and exhaust strokes are completed. This action takes 720°, or two crankshaft revolutions.
- In a simple one cylinder engine, the reciprocating (up-and-down) motion of the piston is changed to usable rotary motion by the connecting rod and crankshaft. A flywheel gives momentum to the crankshaft between power strokes. Valves control the engine's intake and exhaust.
- Cylinders are arranged in-line, in a V, or opposed to each other. The most popular automotive engines have four, six, or eight cylinders.
- The camshaft controls the opening and closing of the valves and, thus, the way that the engine breathes. Different cam grinds provide better low-speed or better high-speed operation.
- The camshaft is driven by a chain, a belt, or gears.

REMEMBER:

The sprocket or gear on the crankshaft has half as many teeth on it as the cam sprocket or gear. This is because the camshaft turns 360° (one turn) during one four stroke cycle, whereas the crankshaft turns 720° (two turns).

- Cylinder rows, called banks, are determined from the flywheel end of the engine. A complete engine assembly including the heads is called a long block; without heads it is called a short block.
- The crankcase houses the crankshaft and bearings. It is enclosed by the oil pan. The crankshaft has a flywheel on one end and a vibration damper or pulley on the other end. The part that the bearing rides against is called the main or rod bearing journal. Crankpins on four cylinders are offset from each other by 180°, in-line six cylinders by 120°, and V8s by 90°.
- Engine sizes are described by their cylinder displacement, usually in liters. Engine breathing determines the power that the engine develops.
- Camshafts are located either in the block (pushrod engine) or above the cylinder head (OHC). Pushrods are often found in V-type engines, whereas in-line engines are most often of the overhead cam design.

REMEMBER:

An engine running at 3000 rpm has to open and close a valve 25 times per second! Each spark plug must also fire at this same speed.

- Most crankshafts turn counterclockwise when viewed from the flywheel end of the engine. Engine cylinders are fired in one of several firing orders. Pairs of pistons that go up and down together but fire 360° from each other are called companions.
- Most engines have liquid cooling systems that use coolant to prevent rust and corrosion and provide additional protection against freezing and boiling.

HIGH-PERFORMANCE ENGINE TRIVIA

Top fuel dragster engines reach the upper end of their rev range somewhere between 7000 and 9000 rpm. Some Formula One engines approach 20,000 rpm. These are four stroke cycle engines, so the pistons must stop and start during every revolution of the crankshaft. At 18,000 rpm, each valve will have to open and close 150 times per second!

VINTAGE ENGINES

The vintage dragster engine shown in **Figure 1.45** is a "hemi." Note the spark plug cable terminations at the center of the cylinder heads, indicating the hemispheric combustion chamber design. The first automotive production hemi was a 180 HP model, introduced by Chrysler in 1951. By 1956, the Chrysler 300-B hemi had 340 HP. Hemi engines were popular in stock car racing and drag racing throughout the 1950s, 1960s, and 1970s. The four engine dragster shown in **Figure 1.46** has wedge cylinder heads.

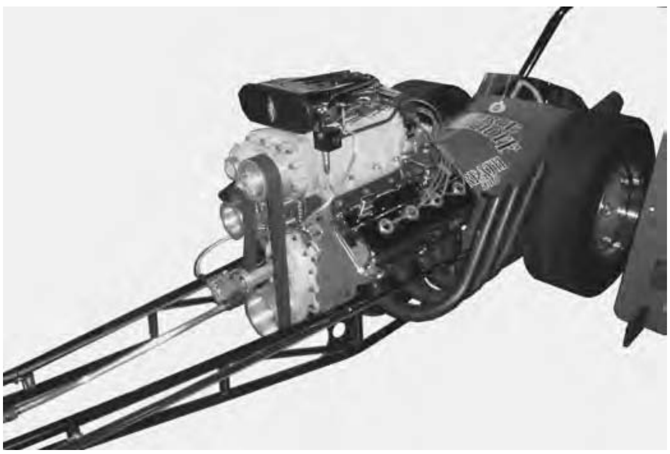


FIGURE 1.45 A vintage dragster with a hemi engine. *(Courtesy of Tim Gilles)*

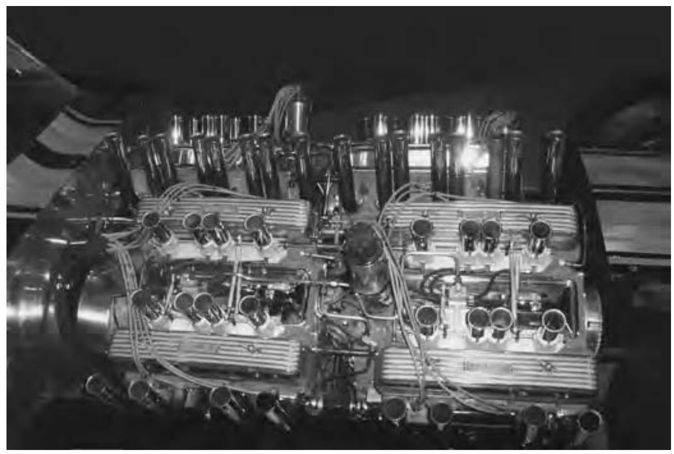


FIGURE 1.46 This vintage four engine dragster has wedge cylinder heads. *(Courtesy of Tim Gilles)*

KEY TERMS

BDC
bimetal engine
blowby
companion cylinders
compression ratio
displacement
firing order
lower end
TDC
transverse engine

STUDY QUESTIONS

1. What is the movement of the piston from top dead center (TDC) to bottom dead center (BDC) called?
2. What is the ratio called that compares the volume of the air space above the piston at TDC and BDC?
3. The crankshaft turns _____ as the camshaft.
   a. half as fast
   b. twice as fast
4. Where would an L-head engine be found today?

5. What does OHC mean?
6. How many times in 1 second will a valve open in an engine running at 6000 rpm?
7. What are four other names for a core plug?

   a.

   b.

   c.

   d.
8. What is a complete engine assembly called?
9. List three functions that a flywheel performs.

   a.

   b.

   c.
10. Do all engines use a vibration damper?
11. How many degrees are rod journals offset on the following engines?

    V8s _____ °

    in-line sixes _____ °

    in-line four cylinders _____°
12. What type of engine is a compression ignition engine?
13. What are the normal ranges of compression ratios for the following?

    Otto-cycle engine ______:1

    diesel-cycle _______:1
14. In a four stroke, four cylinder engine, how many degrees must the crankshaft turn before the next cylinder in the firing order is fired?
15. What causes ignition to occur in a diesel engine?

ASE-Style Review Questions

1. Technician A says that the Otto-cycle gasoline engine has four strokes per cycle. Technician B says that the crankshaft makes four revolutions during the four stroke cycle. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. Technician A says that the purpose of the flywheel is to control the twisting of the crankshaft. Technician B says that the purpose of the vibration damper is to help provide a continuous flow of power. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. Technician A says that an in-line six cylinder engine is usually longer and heavier than a V8 engine of the same displacement. Technician B says that there are twice as many teeth on the crankshaft sprocket as there are on the camshaft sprocket. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. An eight-cylinder engine has a 1 8 4 3 6 5 7 2 firing order. Technician A says that cylinder number 3 is cylinder number 1's companion. Technician B says that cylinder number 5 is cylinder number 8's companion. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. A six cylinder engine has a 1 5 3 6 2 4 firing order. Technician A says that after cylinder number 1 begins its intake stroke, the crankshaft will have to travel 240° before cylinder number 3 begins its intake stroke. Technician B says that when cylinders number 3 and 4 are at TDC,

cylinders number 5 and 2 are at BDC. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

6. Technician A says that diesel engines have compression ratios that are about twice as high as those found in gas engines. Technician B says that diesel engines require less maintenance than gasoline engines. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that "blowby" consists of gases that leak past the valves. Technician B says that blowby reduces the pressure in the crankcase. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says that the intake and exhaust valves are both closed during most of the power stroke. Technician B says that the intake and exhaust valves are both closed during most of the compression stroke. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Two technicians are discussing the part installed on the front of the crankshaft to control its twisting. Technician A says that it is called a harmonic balancer. Technician B says that it is called a vibration damper. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Technician A says that the crankshaft turns 720° during one four stroke cycle. Technician B says that the camshaft turns 360° during one four stroke cycle. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 2

Engine Shop Safety

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Use shop tools and equipment safely.
- Determine whether a chemical is safe to use.
- Locate and read a material safety data sheet.

Introduction

An engine shop has many tools, pieces of equipment, and chemicals. This chapter deals with their proper uses and safe shop practices. The number one priority of any business should be the health and safety of its employees. Those safety issues are covered here first, followed by a safety test at the end of the chapter. The information provided will help you understand how to protect yourself from hazards in the workplace. You will also gain insight regarding the impact of safety laws on your employer.

As you read this chapter, realize that the situations described can and do occur, sometimes often. Case histories presented throughout this book are true. Pay extra attention to the safety precautions detailed with each piece of equipment. Chemical safety is covered in this chapter as well.

GENERAL SHOP HEALTH AND SAFETY

When an accident occurs in an automotive shop, it is perhaps because safety considerations are not as obvious when repairing automobiles as they are in other trades like roofing or carpentry. This is sometimes the reason why people get hurt. Accidents are often caused by carelessness resulting from a lack of experience or knowledge. Often someone other than the one who has been injured causes the accident and suffers from the guilt of knowing the harm that he or she has caused.

In the event of an accident, inform your instructor or supervisor, who will know what procedures to follow to ensure your safety. Injured persons often suffer from shock. When an injury does not appear to be serious enough to call an ambulance, another person should be sent with the injured person to seek professional help. Every shop should have someone trained to handle emergencies. The American Red Cross offers thorough first-aid training.

General Personal Safety

A first-aid kit (**Figure 2.1**) contains items for treating some of the small cuts and abrasions that occur on a regular basis. Fires and accidents involving equipment like lifts and battery chargers happen occasionally in automotive shops. However, the most common injuries involve the back or the eyes, which are injuries that are largely preventable.

Eye Protection

Eye injuries are one of the most common injuries in an automotive shop, so continual use of

FIGURE 2.1 A first-aid kit.

glasses is recommended. Eye protection is emphasized for your own good, so use common sense. Several types of eye protection are shown in **Figure 2.2**.

Safety glasses or a face shield must be worn when using equipment. Face shields are convenient because they can be stored with each piece of equipment. They are also easily adjustable to your head. Using a hydraulic press or pounding with a hammer can cause parts to explode and rotating tools can throw pieces of metal or grit, causing eye injuries. Prescription safety glasses are an advantage because the user always wears them.

Wearing eye protection will prevent most eye injuries. Eye protection must be worn:

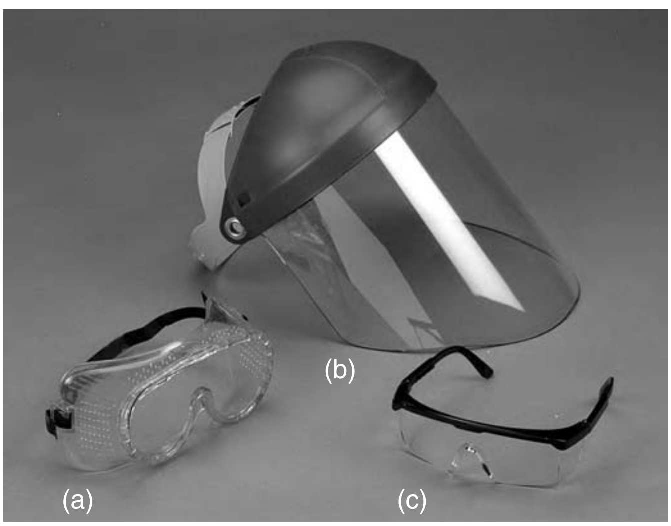


FIGURE 2.2 Eye protection. (a) Goggles. (b) Face shield. (c) Safety glasses.

- whenever working around moving parts and machinery.
- when blowing off parts with compressed air.
- when working on air conditioning. Refrigerant contained in the air-conditioning system will instantly freeze anything with which it comes into contact. If it gets into your eyes, blindness can result.

Additional cautions about skin and eye protection are covered throughout this book.

Back Safety

Protect your back when lifting. Following safe lifting procedures will prevent most back injuries. The normal tendency is to think that items are not that heavy, so you do not ask somebody for help. Be sure to get help when moving heavy items. If something is in an awkward position for lifting, leverage and the position your back is in can make it easier for an injury to occur. Before moving a heavy item, plan the route that the item will be carried and how you will set it down when you get there.

- If an item is too heavy to lift, use the appropriate equipment.
- Lift slowly.
- Do not jerk or twist your back. Shift your feet instead.
- Bend your knees and lift with your legs, not your back (**Figure 2.3**). Also, keep your lower back straight when lifting. Think about thrusting your stomach out.

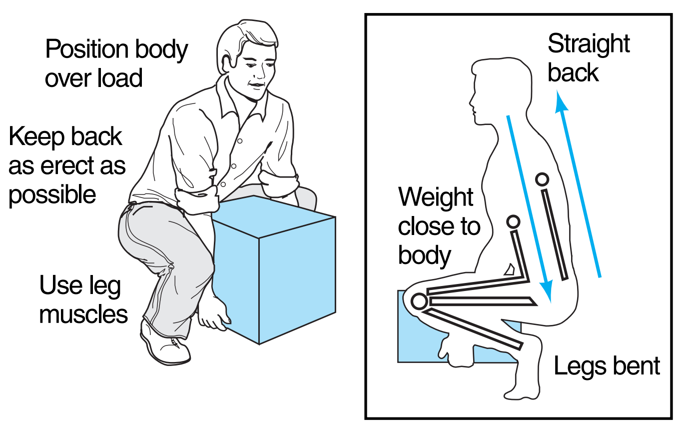


FIGURE 2.3 Lifting precautions.

CASE HISTORY

A machinist lifted a crankshaft out of the trunk of a car. As he reached forward and tugged the crankshaft up and out of the trunk, he felt a small pop in his lower back. The result was a herniated disk in this lower back, which is an injury that will affect him for the rest of his life.

Ear Protection

Damage to your hearing happens when you are exposed to loud noise over a period of time. A good rule of thumb is "if you feel any discomfort from noise, you are probably hurting your hearing." When loud machinery and air tools are used, ear protection should be worn.

NOTE

Your hearing will not recover once it has been damaged.

Clothing and Hair Protection

Clothing or hair that hangs out can get caught in moving machinery or under a creeper. Keep long hair tied back or tucked under a cap. Shirttails should be tucked in, or coveralls can be worn over the shirt.

Shoes or Boots

Leather shoes or boots offer much better protection than tennis shoes or sandals. Some soles are resistant to damage from petroleum products, and the tread can be designed to resist slipping. Boots and shoes that have the toe reinforced with steel inserts are widely available. An additional incentive is that safety footwear is often deductible from a technician's or machinist's income taxes.

SHOP CLEANLINESS

Good housekeeping practices are essential when cleaning engine parts and should be carried out throughout the rebuilding process and engine installation. A clean, orderly shop is vital for impressing on the public that your professional repair facility is thorough and competent. Of even more importance, however, is the health and safety of anyone in the shop area.

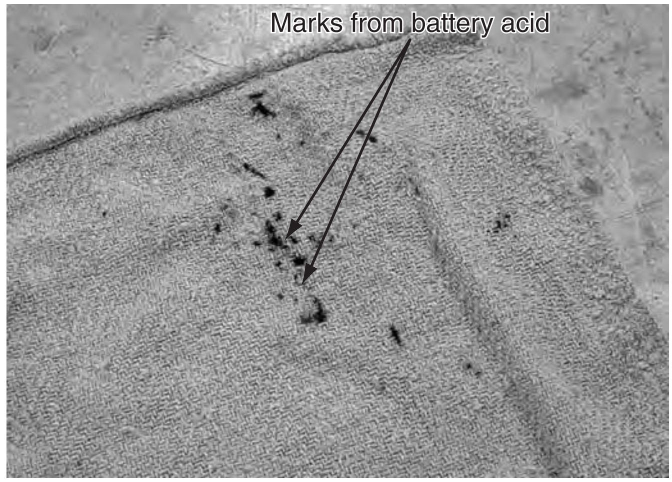


FIGURE 2.4 This shop towel has been contaminated with battery acid. The repair shop will have to purchase it from the linen supplier. *(Courtesy of Tim Gilles)*

Shop Towels

A shop is cleaner if its technicians use shop towels when working. Greasy, oily tools and hands should be wiped clean, preventing the mess from being spread around the rest of the shop. Most shops have linen service for uniforms and shop towels. Shop towels are often dyed red so the linen company can tell when they have come into contact with battery acid, which leaves blue marks on red towels (**Figure 2.4**).

SHOP TIP

You can save the shop some money by using a shop towel that has already been partly soiled but is not yet saturated.

SAFETY NOTE

Be very careful before wiping your hands, arms, or face with a shop towel. It is not uncommon for a shop towel to have metal chips hidden in its fibers (**Figure 2.5**).

Spills and Oil Leaks

Slippery floors are dangerous. To avoid the possibility of a dangerous slip and fall, immediately clean up slippery spills like coolant, solvents, glass

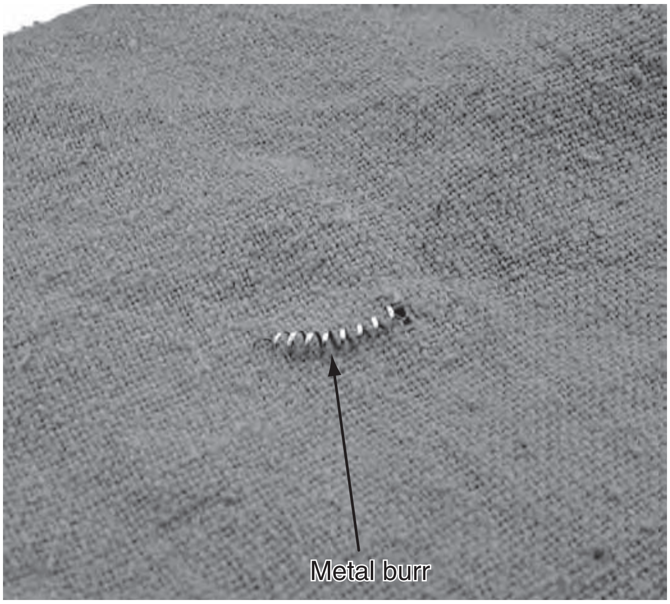


FIGURE 2.5 Be careful when wiping your hands, arms, or face with a shop towel. *(Courtesy of Tim Gilles)*

beads, or steel shot. Preventing spills from occurring in the first place is best, but when spills do occur, they must be dealt with immediately.

- Cleaning up a mess will prevent it from spreading around the shop.
- Parts that are wet with solvent should be blown off *into* the solvent tank (**Figure 2.6**) or allowed to air dry before being moved.
- Wet parts can be carried from the solvent tank in a drain pan to prevent solvent from dripping onto the floor (**Figure 2.7**).

FIGURE 2.6 When drying parts with compressed air, blow solvent back into the solvent tank.

FIGURE 2.7 To avoid dripping solvent on the floor, carry wet parts in a drain pan.

- An engine should be drained of oil and coolant before removing it from the vehicle. The oil filter holds oil, so it should be removed, too. The oil and filter will need to be disposed of properly in accordance with governmental requirements.

SHOP TIP

A spill often occurs when an engine block mounted on a stand is turned upside down during disassembly. There is usually some coolant remaining in the block. Position a drain pan under the engine before turning it upside down to catch a potential spill. After rinsing a block it should be turned over and drained in the cleaning area before moving it into the shop.

Absorbing Spills

To prevent someone from slipping, clean oil spills immediately with **greasesweep** (**Figure 2.8**), an already soiled shop towel, or absorbent mats or pads. Greasesweep is an absorbent material like rice hull ash or kitty litter. It is swept up and reused until it becomes too wet. In fact, it works better when slightly wet because the dust that results when using new greasesweep is avoided.

SHOP TIP

Coolant spills are best cleaned with a squeegee. Mixing water and coolant with oily greasesweep makes a muddy mess.

FIGURE 2.8 Cleaning an oil spill with greasesweep. *(Courtesy of Tim Gilles)*

Greasesweep becomes a hazardous material after it is used to soak up used motor oil or spilled fuel. Bioremedial oil-absorbent products are newer materials sometimes used instead of greasesweep. These products have microbes that "eat" oil or fuel, converting them to harmless carbon dioxide (CO_2) and water. Concrete floors cleaned with this material are left clean and slip resistant. A major advantage to this method is that the need for hazardous disposal is reduced or eliminated.

Superabsorbent cloths are available from waste disposal companies for soaking up spills. The disposal company collects the soiled cloths for proper treatment. There are also nontoxic water-based degreasers.

FIRE PREVENTION

Some common sense is important when dealing with fires. If the fire is burning so dangerously that your personal safety is jeopardized, withdraw from the area immediately and call for help. But if you can safely remove the source of fuel to a fire, do so. This might include shutting off fuel to a fuel fire or disconnecting the electrical source from an electrical fire.

Fire Extinguishers

A fire extinguisher is a portable tank that contains water or foam, a chemical, or a gas (**Figure 2.9**). There are four kinds of fires, each calling for a different type of fire extinguisher (**Figure 2.10**).

FIGURE 2.9 Fire extinguishers.

- A Class A fire is one that can be put out with water. Such things as paper and wood make up these kinds of fires.
- A Class B fire is one in which there are flammable liquids such as grease, oil, gasoline, or paint.
- A Class C fire is electrical.
- A Class D fire involves a flammable metal such as magnesium or potassium.
- Either CO_2 or a dry chemical fire extinguisher can be used on Class B and Class C fires.

SAFETY NOTE

Be sure to have a large enough fire extinguisher on hand. An engine compartment fire often requires a larger extinguisher, depending on how far the fire has progressed.

A popular fire extinguisher is the 2-A:10-B:C. You can find this information on the label. For car fires, fire officials recommend an extinguisher no smaller than this. An extinguisher with the number 1-A:5-B:C would be one-half as big.

The 1 is the size for the A (water) type of that extinguisher. The 5 is the size for Class B (flammable liquids) and C (electrical parts fires). This extinguisher does not work on Class D fires.

Locate and check the type of fire extinguisher(s) in your shop. They should not be located in a place where a fire is likely to start. For instance, do not mount a fire extinguisher right over the welding bench or next to the solvent tank. If a fire began in either of these places, you would not be able to get to the fire extinguisher.

	Class of Fire	Typical Fuel Involved	Type of Extinguisher
Class A Fires (green)	**For Ordinary Combustibles** Put out a class A fire by lowering its temperature or by coating the burning combustibles.	Wood Paper Cloth Rubber Plastics Rubbish Upholstery	Water*[1] Foam* Multipurpose dry chemical[4]
Class B Fires (red)	**For Flammable Liquids** Put out a class B fire by smothering it. Use an extinguisher that gives a blanketing, flame-interrupting effect; cover whole flaming liquid surface.	Gasoline Oil Grease Paint Lighter fluid	Foam* Carbon dioxide[5] Halogenated agent[6] Standard dry chemical[2] Purple K dry chemical[3] Multipurpose dry chemical[4]
Class C Fires (blue)	**For Electrical Equipment** Put out a class C fire by shutting off power as quickly as possible and by always using a nonconducting extinguishing agent to prevent electric shock.	Motors Appliances Wiring Fuse boxes Switchboards	Carbon dioxide[5] Halogenated agent[6] Standard dry chemical[2] Purple K dry chemical[3] Multipurpose dry chemical[4]
Class D Fires (yellow)	**For Combustible Metals** Put out a class D fire of metal chips, turnings, or shavings by smothering or coating with a specially designed extinguishing agent.	Aluminum Magnesium Potassium Sodium Titanium Zirconium	Dry powder extinguishers and agents only

*Cartridge-operated water, foam, and soda-acid types of extinguishers are no longer manufactured. These extinguishers should be removed from service when they become due for their next hydrostatic pressure test.

Notes:

(1) Freezes in low temperatures unless treated with antifreeze solution, usually weighs over 20 pounds (9 kg), and is heavier than any other extinguisher mentioned.

(2) Also called ordinary or regular dry chemical. (sodium bicarbonate)

(3) Has the greatest initial fire-stopping power of the extinguishers mentioned for class B fires. Be sure to clean residue immediately after using the extinguisher so sprayed surfaces will not be damaged. (potassium bicarbonate)

(4) The only extinguishers that fight A, B, and C classes of fires. However, they should not be used on fires in liquefied fat or oil of appreciable depth. Be sure to clean residue immediately after using the extinguisher so sprayed surfaces will not be damaged. (ammonium phosphates)

(5) Use with caution in unventilated, confined spaces.

(6) May cause injury to the operator if the extinguishing agent (a gas) or the gases produced when the agent is applied to a fire are inhaled.

FIGURE 2.10 Guide to fire extinguisher selection.

A gauge on the top of the fire extinguisher tells whether it is fully charged or if the charge pressure has leaked off. Fire extinguishers in business establishments are routinely inspected by the local fire department.

Flammable Materials

Greasesweep and shop towels soaked in oil or gasoline should be stored in covered metal containers (**Figure 2.11**). Keeping oil materials separated from air prevents them from self-igniting, a process

FIGURE 2.11 Keep combustibles in safety containers.

called **spontaneous combustion.** Used greasesweep is kept in a flammable storage container because it is reused until it becomes saturated (wet). Flammable materials that are not in approved containers must be stored in a flammable storage cabinet (**Figure 2.12**).

Fuel Fires

Gasoline is a major cause of automotive fires. Liquid gasoline is not what catches fire. Rather, it is the vapors that are so dangerous. Gasoline *vapors* are heavier than air, so they can collect in low places in the shop. They can be ignited by a spark from a light switch, the motor, electrical wires that have been accidentally crossed, or a dropped shop light.

Two kinds of shop lights are acceptable. One has a fluorescent bulb enclosed in a plastic tube. The other uses a special spark-proof incandescent bulb.

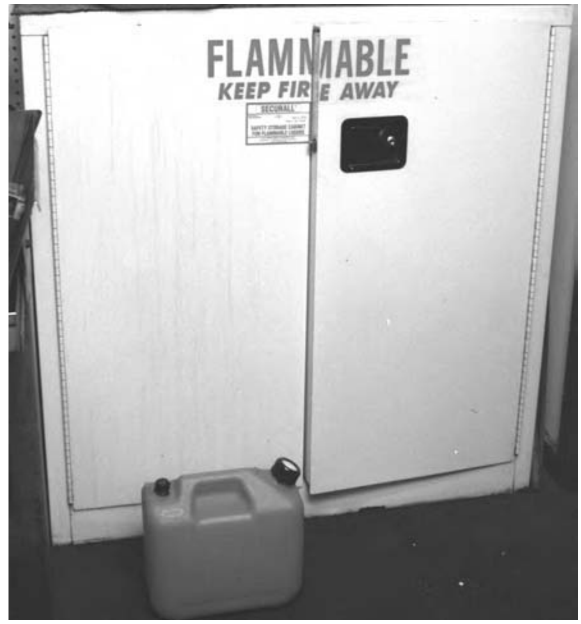


FIGURE 2.12 An approved flammable storage cabinet.

CASE HISTORY

A technician was removing an engine from a Volkswagen. When the fuel hose was disconnected, gasoline dripped on the floor. The technician accidentally dropped his shop light before the gasoline spill was cleaned up. The bulb in the shop light caused the gasoline to catch fire. The resulting fire destroyed the business.

SAFETY NOTES

- Gasoline should be stored in an approved safety container and never in a glass jar.
- Never use gasoline to clean floors or parts. Stoddard solvent has a higher flash point than gasoline so it is safer to use. A flammable liquid's **flash point** is the lowest temperature where it can produce vapors, which can ignite or explode. The flash point of gasoline is –45°F (–43°C). This means that liquid gasoline produces explosive vapors at almost any temperature you will ever encounter. Diesel fuel is safer than gasoline. The flash point of diesel fuel is 125°F (52°C), which is one of the reasons why diesel engines are popular in boats and ships.
- Careless cigarette smoking or failing to immediately and thoroughly clean gasoline spills can contribute to a dangerous situation. People become used to working around

gasoline and then begin to ignore how dangerous it can be.
- Do not attempt to siphon gasoline with your mouth. Accidental breathing of gasoline into the lungs can be fatal.

Electrical Fires

Electrical fires are prevented by disconnecting the battery before working on the electrical system or around electrical components, such as the starter or alternator. Disconnect the battery ground cable first (**Figure 2.13**). This prevents the possibility of a spark occurring when a wrench completes a circuit between a "hot" cable and the ground cable.

NOTE

The ground cable is the one bolted to the engine block. Do not assume that ground is the negative cable. On some older vehicles the positive cable is ground.

If there is an electrical fire, the battery must be disconnected as fast as possible so the fire can be put out. Another advantage to removing the ground cable is that an electric cooling fan cannot accidentally turn on while working near it.

CASE HISTORY

An apprentice was beginning the process of removing an engine from a car. After unbolting a few accessories, he raised the vehicle on the lift and began to remove the starter motor while the battery was still connected to the circuit. He did not attempt to disconnect the wiring, which was in an inaccessible location on the top of the starter. When the unbolted starter came loose, bare electrical terminal ends became wedged against grounded metal and a major electrical fire began. The master technician working in the next work area rushed over and cut the battery cable with a bolt cutter. Damage to the vehicle was limited to a wiring loom and the alternator. The apprentice went to the emergency room to be treated for burned hands and respiratory irritation resulting from the inhalation of noxious smoke when the insulation on the wires caught fire.

FIGURE 2.13 Remove the battery ground cable first.

Fuel Fires

Shop personnel should be knowledgeable about fire extinguishers so they can use them in an emergency. A fuel fire must first have its source eliminated if it is to be extinguished. Firefighters cool and extinguish a fuel fire by cutting off its oxygen using a fogging attachment at the end of a fire hose. Water from a garden hose will cause a fire to spread, however. Do not attempt to douse a fuel fire with water from a hose.

CASE HISTORY

A rebuilt engine was installed in a vintage car. The carburetor float was stuck and shortly after starting the engine for the first time, gasoline began to pour out of the carburetor. The engine hiccupped, popping back a flame out of the intake system, lighting the gasoline on fire. An apprentice grabbed a nearby hose and attempted to douse the fire but the water only served to spread the flames. The result was a total loss of the vehicle.

NOTES

- **Backfire** is a term for combustion that occurs in the vehicle's exhaust (after it leaves the cylinder).
- **Popback** is a term for combustion occurring in the fuel induction system (before it enters the cylinder).

Electric Shock

Twelve-volt direct current (DC) electrical systems like the ones used in automobiles are not capable of inducing serious electrical shock, unless the engine has a distributorless ignition or is a high-voltage hybrid. Shop equipment, however, is powered by either 110-volt or 220-volt alternating current. Electric shock hazards can be minimized when using electrical tools by not standing in water. To prevent a spark from jumping from the outlet to the plug, be sure that a tool is not in the "on" position before you plug it into the outlet.

Three-wire electrical tools are the best choice for commercial work. The extra terminal is connected to ground (**Figure 2.14**). If you use a homeowner-type tool with a two-wire plug, it should be double insulated. Traditional automotive wiring color is black for ground and red for positive, but in commercial wiring the green wire is for ground.

CASE HISTORY

An electrical plug on a drill with a metal housing was damaged, requiring replacement. A mechanic bought a new three-wire plug, cut and stripped the wires and installed it on the cord. He had been working on cars for many years and was used to the color code used around automotive batteries. When he connected the black wire to the ground terminal, he was actually connecting one of the hot leads to ground (also the housing of the metal drill). When he plugged the drill into the wall, he was holding it in his hand and received a dangerous electrical shock. Luckily he was not seriously injured.

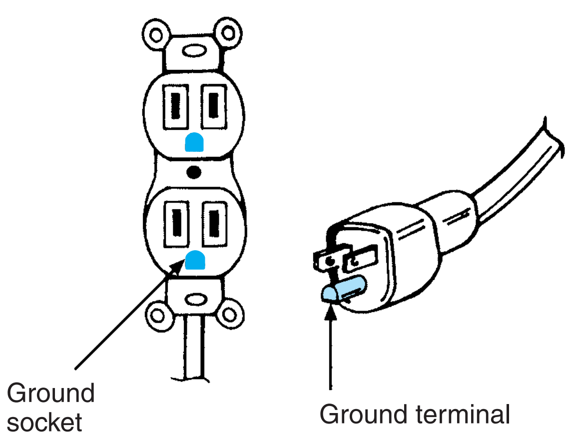


FIGURE 2.14 The third wire terminal is for ground.

General Hybrid Safety

If you ever work on a hybrid electrical system, your life will depend on knowing what and when something is safe to touch. Voltage can range up to 650 volts and 60 amps instantly. This can be deadly. All hybrid manufacturers provide ample information on the Internet to allow fire departments and other emergency personnel easy access for training. Toyota emergency information is available at the following Web site: http://techinfo.toyota.com.

SAFETY NOTE

Orange means high voltage. Do not forget this! **Figure 2.15** shows typical orange-colored high-voltage connections in a hybrid vehicle.

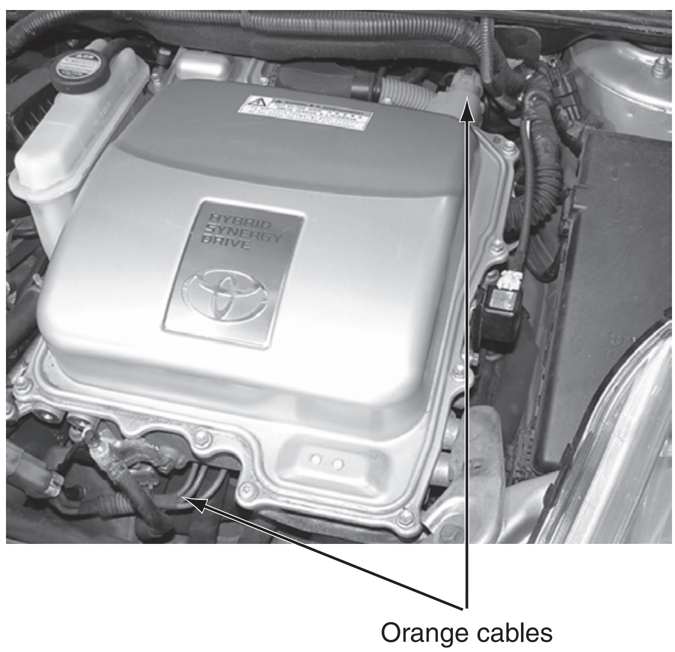


FIGURE 2.15 High-voltage cables on hybrid vehicles are orange. Accidental contact can kill you! *(Courtesy of Tim Gilles)*

FIGURE 2.16 Squeeze the top hose before attempting to remove the radiator cap. *(Courtesy of Tim Gilles)*

Coolant Burns

The most likely way to be burned in an automotive shop is with superheated engine coolant. Opening the radiator on a hot engine can be very dangerous. Always squeeze the top radiator hose before opening a radiator cap (**Figure 2.16**). If the hose is hard and feels like it is full of coolant, the coolant level is acceptable. If the hose collapses, there is no pressure on the coolant but steam can still cause a burn, so exercise extreme caution when opening the cap.

CASE HISTORY

A student had just started working in a repair shop. A customer asked him to check the radiator coolant level. When the student opened the radiator cap, he turned it one-half turn. The coolant boiled out into the coolant overflow tank, where it escaped, burning him and wasting the coolant (Figure 2.17). The radiator cap maintains pressure on the coolant when the engine heats up. Coolant's boiling point is higher when it is under pressure. Loosening the cap removes the pressure, causing the coolant to boil instantly and violently.

Cooling Fans

The fan that draws cool air into the radiator can be belt driven or electric. Rotating fans can be dangerous.

FIGURE 2.17 These burns resulted when a radiator cap was opened on a hot engine. *(Courtesy of Tim Gilles)*

SAFETY NOTES

- Disconnect electric cooling fans when working around them (**Figure 2.18**).
- Visually inspect fan blades for damage. A damaged fan blade will probably be out of balance, making it prone to flying apart.
- Keep hair and clothing away from fans and drive belts.

One of the most common farm injuries is lost fingers because farm machinery has many belts. Fingers are often cut off when they are caught between a belt and pulley. Before attempting a fan belt adjust-

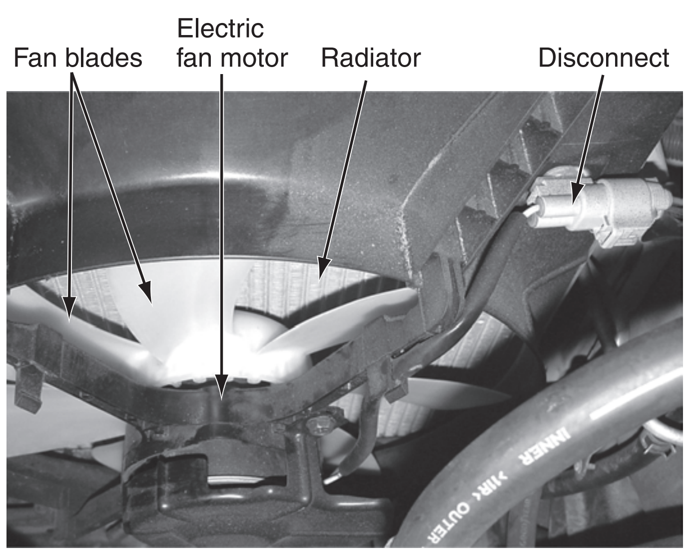


FIGURE 2.18 Disconnect the power to an electric cooling fan before working on it. *(Courtesy of Tim Gilles)*

ment, be sure that the keys are out of the ignition. If someone cranks the engine over, fingers can be cut off. Be certain that a helper understands what you are asking him or her to do. Assuming that your helper understands can result in an accident.

Safety Check before Test Drive

Before driving a customer's car, remember to check the operation of the brakes and condition of the tires. Do not test drive a car with obvious safety hazards until they have been corrected. It makes no sense to test drive a car with dangerous brakes.

TOOL AND EQUIPMENT SAFETY

Hand tools and equipment are essential to automotive technicians and machinists. Items related to the safe use of tools and equipment are covered in this chapter. The use of specialized pieces of engine rebuilding equipment is covered in their respective chapters in the text.

Hand Tool Safety

Hand tools must be kept in safe condition. The following are some hand tool safety considerations:

- Pounding on chisels will result in the top of the chisel folding over in the shape of a mushroom. Do not use a **mushroomed chisel** until it has been reground.
- A file has one pointed end called a tang. To prevent hand injuries, install a handle on the end of a file.
- When loosening a fastener, pull toward you rather than pushing away.
- Do not use a pipe to increase leverage when tightening the handle of a vise. This can break the vise.

Puller Safety

Many types of pullers, ranging from small to large, are used in automotive work. Pullers are used to remove or install pressed-fit gears, bushings, bearings, or other parts from shafts. Specific uses of many of the pullers discussed here are covered in later chapters. When using pullers:

- Wear eye protection.
- Be sure the pressure screw is clean and lubricated before using an impact wrench.
- Be sure the removable point is installed on the puller.
- Be sure the puller is aligned so it is perpendicular to the part being pulled.
- Do not use a puller with damaged or worn parts.
- Use the correct size puller so overloading is avoided.
- Use a three-jaw puller instead of a two-jaw puller when possible.
- When heating a part to help free it, do not heat the jaws of the puller. This could change the temper of the metal.

Press Safety

There are many special-use press fixtures available. For press work, a bearing separator plate is often used. Be sure to support it where the bolt holds the two halves of the tool together (**Figure 2.19**). If the separator is installed in the press 90° to the correct position, the bolts will be bent and the tool can be damaged.

SAFETY NOTE

Presses can be very dangerous because parts being separated are under such pressure that they may explode. Common automotive presses develop hydraulic force in the range of 20–40 tons (40,000–80,000 pounds). Bearings have been known to explode, injuring the user with shrapnel.

- Be sure to use common sense.
- Use applicable safety guards.
- Wear face protection.

Air Tool Safety

Air tools are great time-savers for technicians. In addition to blowguns, there are many air-operated tools, including air drills, air valve seat grinding motors, air-operated valve spring compressors, and air hydraulic jacks.

An air compressor provides air at a regulated pressure of 90 to 150 psi (pounds per square inch). For the best performance and reliability, air tool manufacturers recommend regulating air pressure

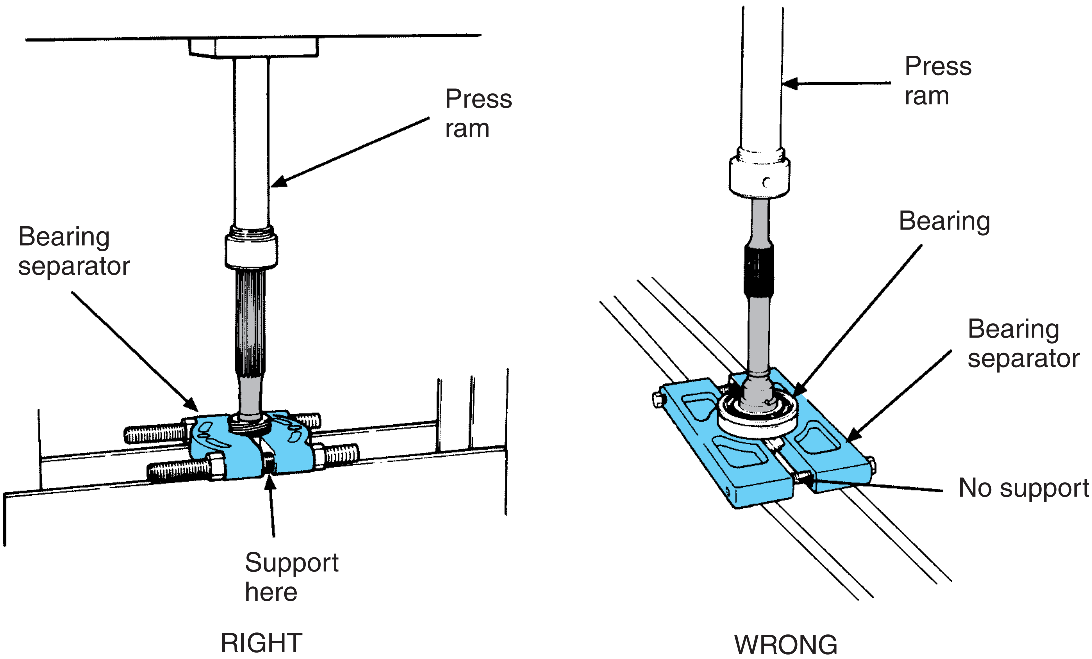


FIGURE 2.19 Support the bearing separator under the bolts so the tool is not damaged.

to 90 psi to get the longest life from air tools. Compressed air is very useful to a technician, but it can be dangerous when used improperly.

Horseplay has no place in a shop! A blast of air can break an eardrum. Blowing compressed air into an orifice of a person's body can result in death. Observe the following safety precautions when using air tools:

- Always wear eye protection when blowing off parts. Pieces of debris can be blown into your eyes. Always blow down and away from yourself.
- Do not blow air against your skin; the high-pressure compressed air used in auto repair shops can penetrate skin. Pressurized grease from a chassis grease gun can penetrate skin also.
- Hold onto an air hose when uncoupling an air line so it does not fly through the air. When possible, bleed off the air from an air line before uncoupling an air hose.

There are two basic types of blowguns (**Figure 2.20**). Blowguns designed for blowing off parts are regulated to produce no more than 35 psi. Rubber-tipped blowguns, used to blow into fluid passageways or engine oil galleries, do not have this safety feature. A worker should not use these tools until proper instructions on their safe use are given.

FIGURE 2.20 An OSHA-approved safety blowgun (top) and a rubber-tipped high-pressure blowgun (bottom). *(Courtesy of Tim Gilles)*

Impact Wrenches. The air impact wrench is a favorite technicians' tool.

A ½" drive impact wrench is used to loosen large, very tight bolts. Special, extra thick impact sockets must be used with the impact wrench (**Figure 2.21a**). Regular sockets can crack or explode (**Figure 2.21b**). Follow these precautions when using an impact wrench:

- Be careful of loose clothing or hair that might become tangled in the tool.

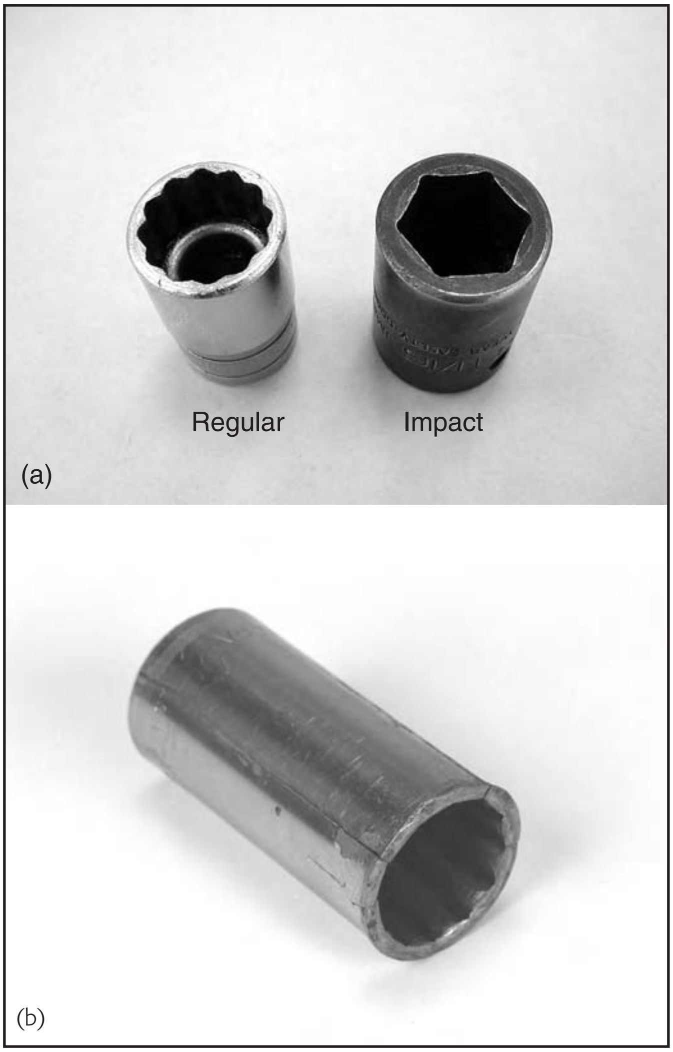


FIGURE 2.21 (a) Regular (left) and impact (right) sockets. *(Courtesy of Tim Gilles).* (b) Using a regular chrome socket on an impact wrench can result in a broken socket.

- Use approved impact sockets, not chrome sockets.
- Be sure that the socket is secured to the air tool. A clip at the end of the tool's square drive can become worn so that it no longer holds the tool.
- When the impact wrench fails to loosen a fastener, use a large breaker bar.
- When using a wobble socket, do not turn on the impact wrench unless it is installed on a nut or bolt. The socket can fly off the impact wrench, possibly causing an injury.

Air Chisel. An air chisel is a miniature jackhammer (**Figure 2.22**) often used to drive valve guides in and out of cylinder heads. There are many attachments available for a variety of uses. When using an air chisel:

- Before pulling the trigger, be sure to have the tool bit against the workpiece. Otherwise the tool might fly out of the gun.
- Be sure to wear eye protection.

Die Grinder. Air-powered die grinders turn at very high speeds, often in excess of 20,000 rpm. Be certain that an abrasive disk or grinding wheel used with the die grinder is rated at sufficient rpm.

Electric Machinery

Much of the machinery in a shop is powered by electricity. Electric machinery includes anything with a motor. Motors that power large machines usually run at a constant speed. Many pieces of machinery have different-sized belt-driven pulleys or another means of adjusting the speed of the machine to fit the application.

General Machinery Safety

- To the eye, swiftly rotating machinery can at times appear not to be moving. Lights powered by ordinary alternating current flicker 60 times per second. This can produce a strobe effect on moving machinery. Be cautious when working around a running engine or rotating machinery. Fingers can be severed by a moving belt and pulley.

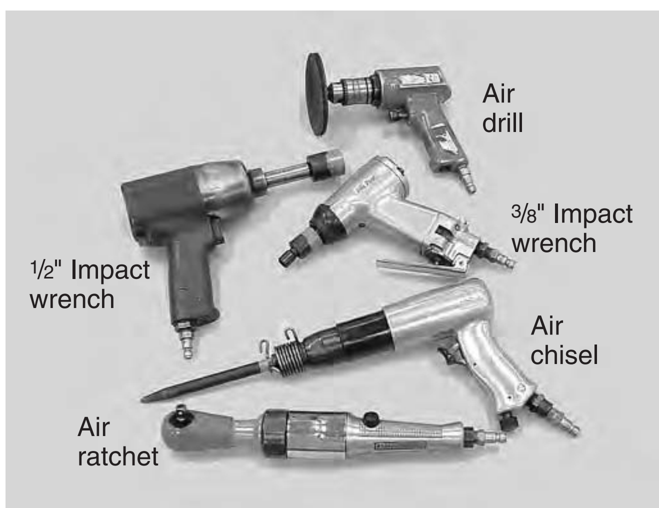


FIGURE 2.22 Miscellaneous air tools. *(Courtesy of Tim Gilles)*

- Do not talk to someone who is operating a machine; do not talk to someone when you are operating a machine.

Drill Safety

- Always wear eye protection.
- Release pressure occasionally to allow chips to break off before they become too long and dangerous.
- A drill bit may catch when it starts to break through the bottom of the work being drilled. Be sure that sheet metal is clamped to the worktable. Let up the pressure on the bit as it starts to break through the bottom of the hole.
- If the drill grabs the work, shut off the drill. Never grab the moving work.
- Never stand in water when drilling. Standing in water increases the danger of electrical shock.
- Be sure to remove the chuck key from the chuck before drilling.

Grinder Safety

- Stand to the side when starting the motor. The grinding wheel is more likely to explode during startup because of the inertia of the wheel.
- Wear face protection.
- Position the tool rest as close to the wheel as possible, so that nothing can get trapped between the wheel and the tool rest (**Figure 2.23**).
- Do not grind on the side of the grinding wheel.

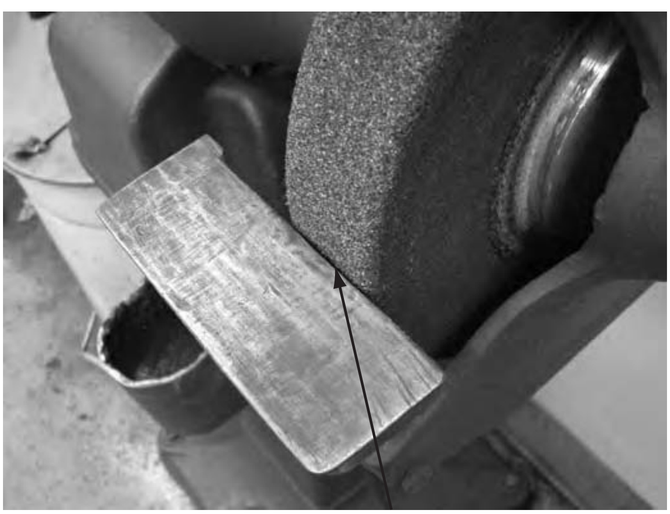


FIGURE 2.23 Position the tool rest as close to the grinding wheel as possible. *(Courtesy of Tim Gilles)*

LIFTING EQUIPMENT

Automotive repair work includes lifting heavy items like engines, transmissions, and entire vehicles. Safe lifting practices will prevent accidents and injuries.

Hydraulic Jacks

A hydraulic floor jack (**Figure 2.24**) is used to raise and lower the vehicle and to help position heavier components, such as engines and transmissions.

Position the jack under the vehicle frame, or at one of the correct lift points shown in the service literature (**Figure 2.25**). Many vehicles are built

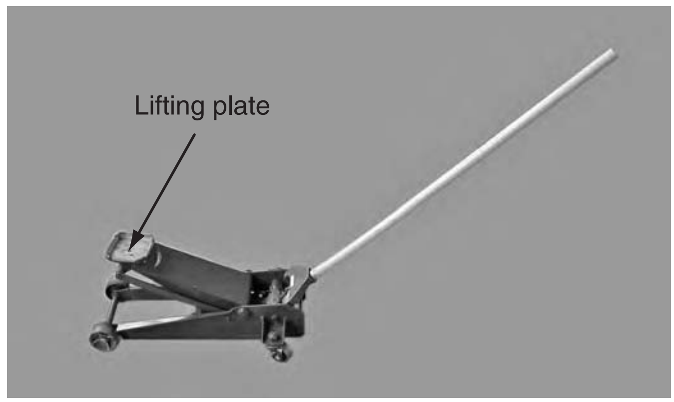


FIGURE 2.24 A hydraulic floor jack. *(Courtesy of Tim Gilles)*

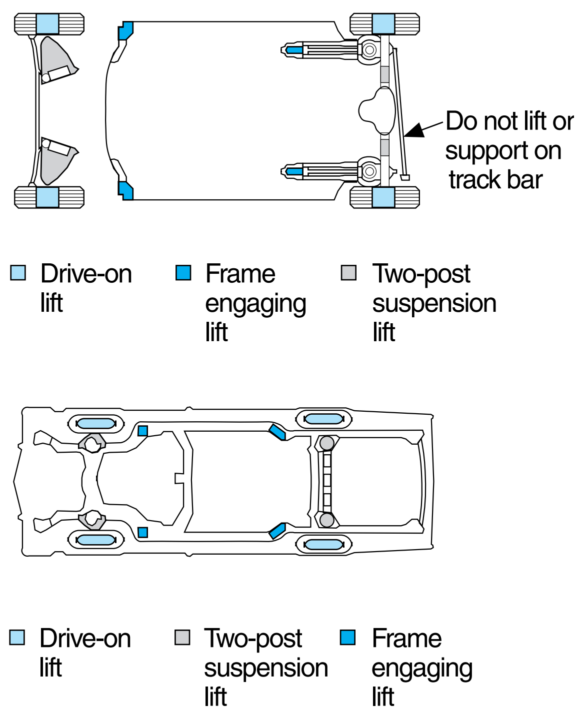


FIGURE 2.25 Check the service manual for the correct lift points for a particular vehicle.

without frames and may be damaged if lifted improperly. Do *not* jack under the vehicle floor pan or under suspension and steering linkages that can be bent.

SAFETY NOTES

- Position the jack so that its wheels can roll as the vehicle is lifted. Otherwise, the lifting plate may slip on the frame, or the jack may tip over.
- Use a jack only to raise and lower a vehicle. Cars are often serviced while raised on a jack, but this is a dangerous practice. Vehicles have fallen and crushed people who used jacks that failed.
- A car should always be positioned on safety stands (jack stands) when it is jacked up for service.

CASE HISTORY

An apprentice was working on a vehicle that was supported only by a hydraulic jack. The master technician he was working with told him to go get a pair of jack stands to support the vehicle. While he was getting the jack stands, the jack failed. Had he been under the car, he would have been crushed.

Safety Stands/Jack Stands

There are several types of safety stands, also called jack stands. One type is shown in **Figure 2.26**.

FIGURE 2.26 Jack stands.

Using safety stands when a vehicle is raised frees up the floor jack for use by someone else, but more importantly it provides a proven safety advantage. It is foolish to crawl under a vehicle that is not resting solidly on safety stands.

CASE HISTORY

A California auto shop student was killed when the truck he was working on fell off its jack stands while he was adjusting the clutch.

- **Be certain that jack stands are positioned in the recommended location on the frame.**
- **Shake the vehicle to be certain it is firmly placed before going under it.**
- **Only use jack stands on a level concrete surface. The leg can dig into asphalt on a hot day and cause an accident. Place a piece of plywood ¾" or larger under a jack stand that is used on asphalt.**

A tall safety stand is used to support the engine, transmission, or front suspension components when a vehicle is raised in the air on a lift (**Figure 2.27**). This type has a screw top to permit adjustment.

FIGURE 2.27 A tall jack stand is used when the car is raised on a lift. *(Courtesy of Tim Gilles)*

SAFETY NOTE

Be careful not to raise the vehicle off the lift when raising the adjustment on the jack stand.

Frame-Contact Lifts

Frame-contact lifts have adapters at the end of adjustable *lift arms*. The lift adapters contact the vehicle frame at the manufacturer's specified lift points, at the rocker panels or on a section of the frame (see Figure 2.25). Be sure to check the service literature before attempting to lift a vehicle. When lifted improperly, body, suspension, or steering components can be bent. The windshield might even pop out or the vehicle might fall.

In 1992 the Society of Automotive Engineers (SAE) adopted a standard (SAE J2184) for vehicle lift points. Some manufacturers label their vehicles with decals depicting the recommended lift points. These are located inside the passenger side front door. Permanent markings on the underside of the chassis also mark the lift points. These markings can include a hole, a boss, or a ¾" depression of a triangle.

Some adapters, sometimes called *foot pads*, flip up. These adapters are adjustable to several positions to accommodate different heights between the lift points in the front and rear of the vehicle and to provide clearance between the rocker panel and the lift arm (**Figure 2.28**). Some foot pads have screw threads that allow them to be positioned higher or lower (**Figure 2.29**). Some adapters have rubber pads. Be sure that they are in good condition and that they are not covered with oil or grease, which could make them slippery.

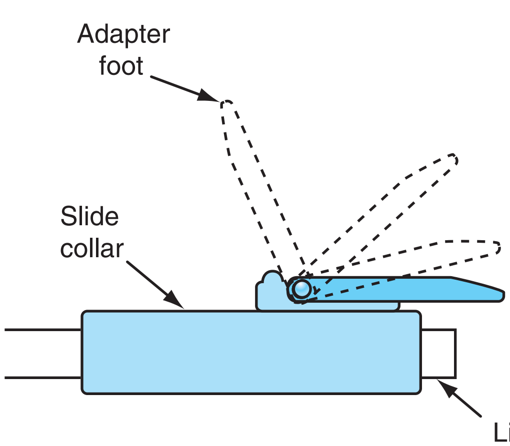


FIGURE 2.28 Adapters flip up to accommodate different frame heights.

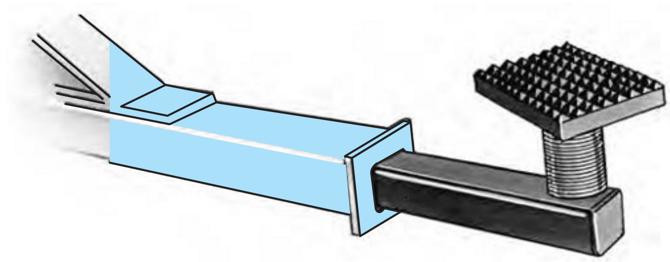


FIGURE 2.29 Some adapters have a screw adjustment. *(Courtesy of Automotive Lift Institute, www.autolift.org)*

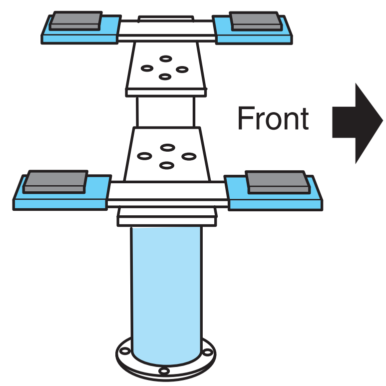


FIGURE 2.30 A rocker panel (pad) lift.

Unibody/monocoque vehicles are lifted at points on the rocker panel (just under the bottom outside edge of the car body). Special rocker panel lifts, called pad lifts (**Figure 2.30**), can be used for these cars and cars with perimeter frames. Do not use pad lifts for trucks.

SAFETY NOTE

Adapters must be placed at the manufacturer's recommended lifting points and set to raise the vehicle in a level plane or else the vehicle will be unstable.

Special Auxiliary Adapters/Extenders. Sometimes extenders are used on the adapters (**Figure 2.31**). If the lift points on the vehicle are covered with undercoating, a special rubber adapter might be needed when using a lift that has steel adapters. Damaging the undercoating can void the vehicle's rust protection warranty. Some sport-utility vehicles, light trucks, and vans require special adapters to provide clearance between the lift arm and the

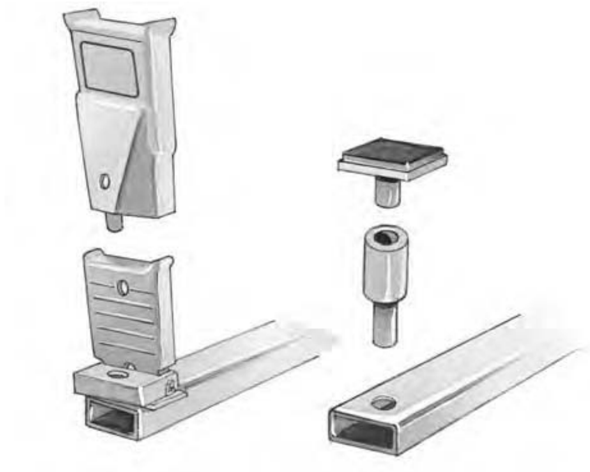


FIGURE 2.31 Extenders can be used with pickup trucks and vans. *(Courtesy of Automotive Lift Institute, www.autolift.org)*

rocker panel. Most lift manufacturers make these available. Do not use makeshift extenders.

Wheel-Contact Lifts. A wheel-contact lift is one in which all four of the vehicle's wheels are supported.

When driving a car onto one of these lifts, be sure that the tires are an equal distance from the edges of the ramps. Wheel-contact lifts have secondary stops for roll-off protection at the front and rear. After spotting the vehicle, always use manual wheel chocks to prevent the car from rolling.

Wheels-Free Jacks. On a wheel-contact lift, the wheels are supported unless a *wheels-free* jack is used (**Figure 2.32**). These jacks, which are air or hydraulic powered, are used to raise either end of the car for wheels-free work. After the vehicle is raised, the jack is lowered onto a mechanical safety latch. When using one of these jacks, keep hands clear and be sure to extend each of the lift arms an equal amount to avoid uneven loading. Be sure that a wheels-free jack is lowered all of the way before driving into or out of the lift.

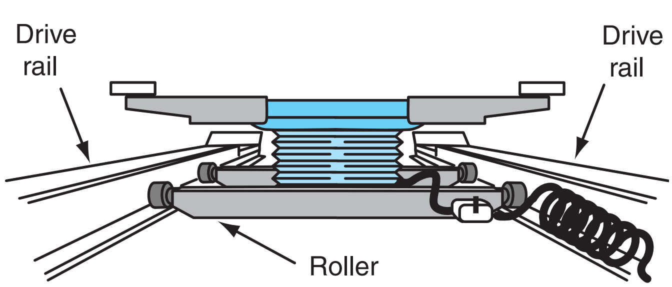


FIGURE 2.32 A wheels-free air jack.

NOTE

The vehicle may be raised safely even without the engine in it. Trying to lift a vehicle can be dangerous on a frame-contact lift, because the unbalanced vehicle might tip off the lift.

SAFETY NOTE

When using a wheels-free or transmission jack with a car raised on a frame-contact lift, be careful not to raise the car off the lift pads as you raise the transmission.

Center of Gravity

Find the center of gravity of the vehicle and position it over the posts of the lift. The center of gravity is the point between the front and the rear wheels where the weight will be distributed evenly. Different positions are used for front-wheel drive and rear-wheel drive vehicles (**Figure 2.33**). On one or two post lifts, position the vehicle's center of gravity over the posts. On four-post models, position the car equally between the front and rear.

- Rear-wheel drive (RWD) center of gravity is below the driver's seat.
- Front-wheel drive (FWD) center of gravity is below the steering wheel in front of the driver's seat.

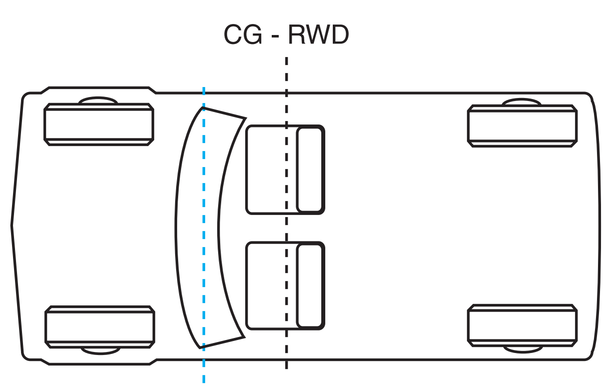


FIGURE 2.33 Center of gravity (CG) positions for front-wheel drive (FWD) and rear-wheel drive (RWD) vehicles.

REMEMBER:

You are lifting a vehicle that weighs several thousand pounds. The car must be correctly spotted on the lift so that the center of gravity is correct.

CAUTION

Do not position the vehicle to the front or rear of the posts on an aboveground hoist just so the door can be opened easier.

Lift Safety

Lifts have an excellent safety record but, unfortunately, vehicles occasionally fall off them. When a vehicle comes down by accident, this is usually due to carelessness, misuse, or neglected maintenance. Training in the use of the lift is mandatory before attempting to lift a car.

The American National Standards Institute (ANSI) and the Automotive Lift Institute (ALI) have set the standard for automotive lifts. This standard (ALOIM-1994), which lists safety requirements for operation, inspection, and maintenance of lifts, requires annual inspection of each automotive lift by a qualified lift inspector to ensure that it remains in safe operating condition.

- If you notice a problem with a lift, do not use it. See your supervisor immediately. Do not take chances.
- When lifting, first raise the vehicle until its wheels are about 6'' off the ground. Then, jounce the vehicle and double-check the contact between the adapters and the frame to be sure that the vehicle is safely engaged.
- Be certain that all four lift pads are contacting their lift points and bearing a load. It is not unusual for three lift arms to be touching the vehicle while the fourth one is free to move. If a lift arm can be moved after the car is in the air, the car is unevenly loaded.
- If a lift arm is positioned incorrectly, lower the vehicle slowly to the ground and reposition the arm.
- Some lifts have swing arm restraints that hold the unloaded arm in position to prevent accidental movement. These restraints are not designed to prevent the car from falling if it is not properly positioned.
- When performing vehicle repairs on a vehicle on a frame-contact lift do not use a large prybar or do anything else that might knock the vehicle off the adapters. When tight bolts are encountered, it is best to use an air impact wrench on them.
- Be sure that the lift contact points beneath the vehicle are in good condition with no oil or grease on them.
- Some lifts have different length arms in the front than they do in the rear. These are called asymmetrical arms. Be sure to consult the manufacturer's instructions before using this type of lift.
- Some lifts have a safety locking device that holds the post should a hydraulic failure occur. Be sure it is engaged. If the lift is not raised high enough for it to engage or if the lift is not equipped with a safety device, use four tall safety stands.
- The lift area should be clean. There should be no grease or oil on the floor. Hoses, extension cords, and tools should be in the places where they belong.
- Do not allow customers to drive their own cars onto the lift. Insurance companies usually prohibit customers from being in the lift area.
- Be sure that the lift has the adequate capacity to lift the weight of the vehicle. If the vehicle has any loads in the back seat, in the trunk, or in the bed of a pickup, the center of gravity will be affected and the vehicle will be unsafe to lift.
- Be sure that the lift is all of the way down before attempting to drive a car onto or off it.
- Before lowering a vehicle, alert anyone standing nearby and be certain that no tools or equipment are positioned beneath the car. All of the car's doors should be closed.

Engine Hoist Safety

When the engine is removed from the car, it is usually raised 3 or 4 feet off the ground to clear the radiator grilles. *It is very dangerous to move the engine hoist with the center of gravity at this height*. Let the engine down close to the ground, and then roll the hoist in as straight a line as possible to avoid tipping it over. This precaution is especially critical when the engine and transmission have been removed at the same time.

CASE HISTORY

An apprentice had just removed an engine and transmission from an RWD pickup. The engine was still in the high position that was required to clear the front grille and radiator mount. He attempted to move the engine and transmission without first lowering them close to the ground. As he tried to push the engine hoist over a ledge at the entrance to the service bay, the balance of the hoist was upset and the engine came crashing to the ground. Luckily the only damage was to the transmission oil pan and extension housing. One of the legs of the engine hoist was bent so badly that it had to be taken out of service.

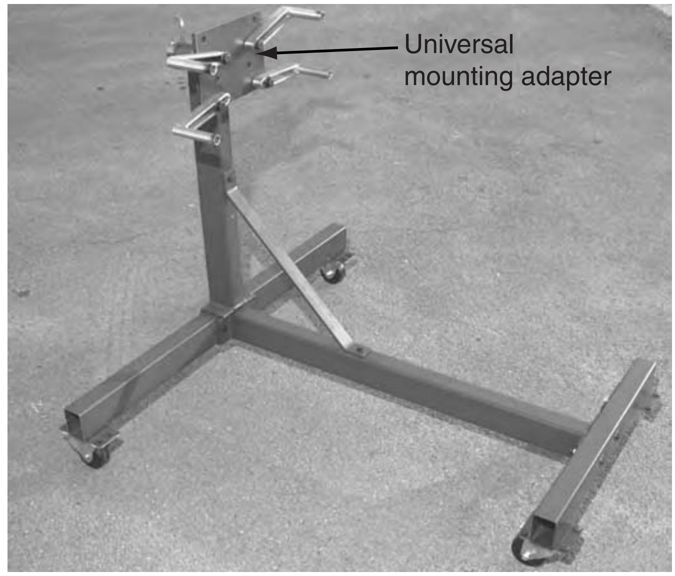


FIGURE 2.35 A universal engine stand.

Engine Lifting Sling

An engine sling (**Figure 2.34**) is used to connect the engine hoist to the engine block. The sling must be tightened securely against the block, because the holding bolts can be overly stressed and break.

Be careful that the sling does not contact the distributor or fuel injection or carburetor, which can be damaged during engine removal.

SAFETY NOTE

The bolts should go into the block to a depth at least one-and-a-half times the diameter of the bolt.

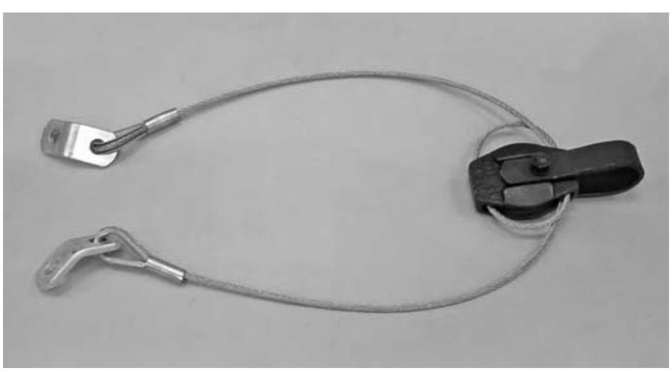


FIGURE 2.34 An engine sling. *(Courtesy of Tim Gilles)*

Engine Stand

The engine stand provides a convenient means of turning the engine over for disassembly and reassembly (**Figure 2.35**). The engine stand universal head, which is designed to fit almost any engine, is bolted to the rear of the engine in place of the bell housing or automatic transmission converter housing.

It is a good idea to mount the engine on an engine stand immediately after removing it from the car.

SAFETY NOTES

- Inexpensive engine stands are widely available. Be sure to purchase one that is designed to carry the maximum load that you might encounter. Do not use a light-duty stand for a heavy engine.
- It is not safe to work on an engine that is hanging from an engine hoist. An engine stand provides a margin for safety as well as convenience.
- First, mount the universal mounting adapter to the engine. Then install the engine and mounting head on the engine stand.
- Be sure that the bolts extend into the thread for at least one-and-a-half times the bolt diameter.

CASE HISTORY

After bolting the universal head to a complete engine assembly, a student worker lifted the engine with the hoist and mounted it to the engine stand. A few minutes later the engine came crashing to the ground. Luckily no one was hurt. Three rows of thread were pulled from each of the four bolt holes in the block. A corner broke off the block, but it was repairable by welding.

For more information on engine stands, see Chapter 4.

OTHER SHOP EQUIPMENT SAFETY

Creepers

A *creeper* has small wheels and saves wear and tear on the body when working in uncomfortable positions or working under a vehicle resting on safety stands.

FIGURE 2.36 Stand a creeper on end or push it under a vehicle when not in use. *(Courtesy of Tim Gilles)*

SAFETY NOTE

Stand a floor creeper on end or push it under a car when not in use so no one accidentally steps on it (**Figure 2.36**).

Battery Charger

A battery charger is used to charge batteries or to help a discharged vehicle battery start the engine. Some battery chargers have instructions that recommend against using the unit for jump-starting a car. Be sure to check the instructions for the unit you are using and be sure that the cables are clamped to the proper battery terminals (**Figure 2.37**).

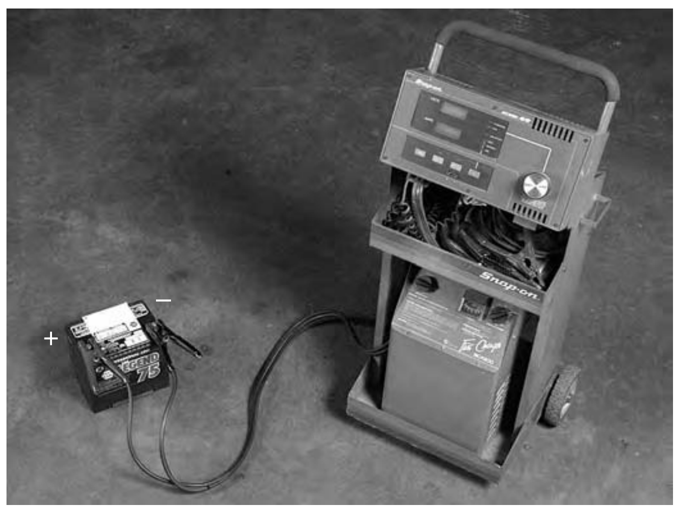


FIGURE 2.37 Be sure to connect the battery charger clamps to the correct battery terminals.

Batteries occasionally explode. A battery explosion can cause damage to skin (from acid thrown by the explosion), permanent or temporary hearing loss, and blindness (**Figure 2.38**). When a battery is being charged, hydrogen gas vapors are given off. Hydrogen gas is the same gas that was used in the *Hindenburg*, the passenger blimp that exploded mid-air in the 1930s. Sparks must be avoided around batteries. Be sure to wear eye protection and unplug the charger before connecting or disconnecting it.

The most common cause of battery explosions is when someone disconnects a battery charger without turning it off.

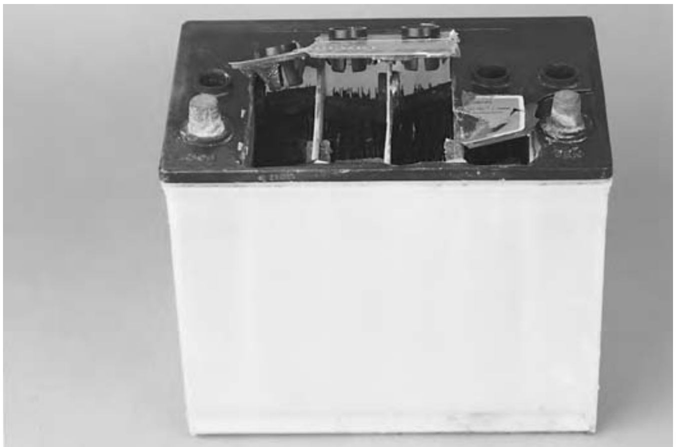


FIGURE 2.38 Careless use of the battery charger caused this battery to explode. *(Courtesy of Tim Gilles)*

SAFETY NOTES

- Always wear eye protection when working around batteries. When jump-starting a car, follow the proper procedures and wear eye protection.
- A good safety practice is to unplug the battery charger before disconnecting any of the cables.
- Shut off the battery charger before unplugging it, or a spark could result when the electricity tries to jump (arc) from the outlet to the plug.

Battery Acid

Battery acid (electrolyte) is a chemical combination of sulfuric acid and water. Baking soda neutralizes battery acid.

SAFETY NOTE

Battery acid can harm skin, eyes, and clothing. Immediately wash any spills with water for at least 15 minutes.

After carrying or servicing a battery, keep hands out of pockets. Your pockets will develop holes when you wash your clothes because the outside of a battery is usually coated with acid deposited by misting from the vent caps during charging.

Electronic Engine Analyzers

Engine analyzers, scan tools, or digital storage oscilloscopes are useful in diagnosing engine problems and verifying correct operation after an engine rebuild. These tools can help diagnose compression problems, uneven balance between cylinders, worn timing chains, and air leaks. Observe the following safety precautions when working with these tools:

- Sometimes you will need to work around a running engine. Be sure to keep the cables away from the fan and accessory drive belt(s).
- Be sure that the parking brake is firmly applied, and try to stand to the side of a running vehicle as much as possible.
- Exhaust gas can contain large amounts of carbon monoxide. Protect yourself and others from exhaust gas by using an exhaust ventilation system (**Figure 2.39**).

Welding Safety

Most machine shops and some repair shops use welding equipment. Observe the following safety precautions when welding:

- Arc welding produces ultraviolet rays. A helmet with the appropriate shade of lens must be used to prevent damage to the eyes.
- Welding can result in splatter of molten metal. Be sure to wear appropriate protective gear.
- Bystanders must have appropriate protective gear, too.
- Cutting with a torch can result in a great deal of flying molten metal. Be sure that flammable materials are not in the area and that molten metal does not burn through the hoses.

FIGURE 2.39 Use an exhaust ventilation system when working around a running engine. *(Courtesy of Tim Gilles)*

- When welding on a vehicle, protect electronic devices by disconnecting the battery by removing the ground cable.

HAZARDOUS MATERIALS

In the United States, materials that can harm workers and the environment are regulated by three agencies.

- The Environmental Protection Agency (EPA) protects the land, air, and water from hazardous materials.
- The Occupational Safety and Health Administration (OSHA) manages the protection of workers from unsafe workplace hazards, including hazardous materials.
- The Department of Transportation (DOT) oversees the transportation of hazardous materials.

Types of Hazardous Materials

Some shop chemicals may be dangerous to your health. In addition, many chemicals are skin irritants. A material is considered *hazardous* if it causes illness, injury, or death; or pollutes water, air, or land. Some of the hazardous substances that engine rebuilders and technicians sometimes come into contact with include cleaning chemicals, used oil, and heavy metals from engine bearings.

The EPA characterizes hazardous waste in two ways and has developed a list of over 500 specific hazardous wastes. A material is a hazardous waste if it is on this list, or if it exhibits a characteristic from one of four categories: ignitability, corrosivity, reactivity, or toxicity.

- *Ignitable wastes* burn readily. These materials have a flash point of less than 140°F. Automotive products like cleaning solvents, paint solvents, degreasers, and gasoline are examples of ignitable materials.
- *Corrosive wastes* burn the skin or corrode metals or other materials. They have a pH lower than 2 or higher than 12.5. Examples include rust removers, acid or alkaline cleaning liquids, and battery acid.
- *Reactive wastes* are unstable and react rapidly or violently with water or other materials. Hardly any reactive wastes are used in the automotive industry, although acetylene (used in gas welding) is an example of a reactive substance.
- *Toxic materials* include the carburetor or brake cleaner sprays commonly used in most automotive repair facilities. Some of these products contain chlorinated compounds and most contain various toxic organic chemicals, such as methyl ethyl ketone (MEK), acetone, methylene chloride, trichloroethane, toluene, or heptane. Some are hazardous air pollutants (HAPs). **Chlorinated solvents** are a threat to the earth's protective ozone shield. Other automotive pollutants on the EPA's air contaminant list include carbon monoxide from vehicle exhaust and chlorofluorocarbons (CFCs) from older air-conditioning refrigerants.

Petroleum-based solvents can cause nervous system damage. Some are also carcinogens, which means they potentially cause cancer. Wastes are also toxic if they contain certain heavy metals, such as chromium, lead, or cadmium.

Personal Protective Equipment

Hazardous materials can enter your bloodstream through the lungs by breathing fumes. They can also be ingested (by eating or drinking contaminated food and beverages). Your skin protects the bloodstream from most toxic liquids. However, the molecules of some toxic liquids are smaller than the membrane of human skin that allows sweat to escape. These liquids can, and do, penetrate skin and enter the bloodstream. Always wear protective gloves to protect yourself.

Gloves and respirators are called personal protective equipment (PPE) (**Figure 2.40**). Be certain

FIGURE 2.40 Personal protective equipment includes gloves, a respirator, and ear protection. *(Courtesy of Tim Gilles)*

that the gloves provide the necessary level of protection. Some gloves will allow the penetration of the same materials that can penetrate your skin. Also be aware that materials can enter your bloodstream if you have a cut or scrape.

Dermatitis. Automotive technicians and machinists sometimes experience chronic exposure to cleaning materials. Cleaning parts by hand in solvents without using gloves is one example. Years of this abuse can result in a painful condition called dermatitis, in which hands are cracked and often bleed and the skin peels off. Using the wrong soap for the parts being cleaned can also result in dermatitis. Some hand lotions and creams are formulated to correct or prevent dermatitis. Be sure to wash your hands thoroughly before applying a lotion or cream.

Respirators. A respirator is not a guarantee of protection from breathing all materials. Some smaller materials can pass through a typical respirator. Asbestos is one example. Its fiber is so small that a special filter, called a high-efficiency particulate air (HEPA) filter, is required for breathing protection.

If your employer provides you with PPE, you are *required* to use it. Eye protection is one example. OSHA Regulations Section 29 CFR 1910.133 (a) (1) says: "Each affected employee shall use eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation (like arc welding)." In the United States, the EPA regulates disposal of hazardous materials, and the EPA's Hazard Communication Standards outline these regulations.

Companies must develop a hazardous waste policy, and each hazardous waste generator must have an EPA identification number. When waste is transported for disposal, a licensed waste hauler must transport and dispose of the waste. The shop must keep a copy of a written EPA form called a manifest.

The Hazard Communication Program requires chemical manufacturers to publish information about the chemicals they produce and distribute. The employer then provides information by labeling materials and training employees in their proper uses. The label on a hazardous material must include the product manufacturer's name and address, its chemical name and trade name, and safety information about the chemical.

Material Safety Data Sheets

The employer must make available to employees a material safety data sheet **(MSDS)** for each dangerous substance used (**Figure 2.41**). An MSDS provides details of the composition of a chemical, lists possible health and safety problems, and gives precautions for its safe use. A supplier of a chemical is required by law to provide an MSDS (upon request). In addition to your local parts supplier, the Internet is a source of easy access to this information. Typical shop practice is to obtain pertinent MSDS and keep them in a binder where employees can access them. An MSDS must include any hazardous materials contained in a product. It lists the percentage of the product made up of each of the product's hazardous ingredients. For instance, a typical carburetor cleaner spray might be made up of 45% toluene, 20% acetone, and so on.

The MSDS also lists the permissible exposure limit (PEL) and the threshold limit value (TLV) of various vapors, dusts, and fumes. Exceeding the limit can result in illness or injury. Short-term exposure limits (STEL) are also included. The STEL is the maximum amount of exposure during a 15-minute period in one 8-hour workday.

NOTE

The smaller the exposure limit on the MSDS, the more toxic the chemical is. The National Institute of Occupational Safety and Health (NIOSH) lists an exposure limit called Immediately Dangerous to Life and Health (IDLH). Be aware that exposure limits are simply estimates of danger for short-term exposure. There is no guarantee that you will not suffer long-term damage if you are regularly exposed to a chemical at a level that is less than the STEL.

Flammable limits for a material are also listed on an MSDS. LEL is the *lower explosive limit* of a material. This represents the lowest vapor concentration of a material that will ignite. Leaner mixtures than the LEL will not burn. UEL stands for the *upper explosive limit*. Concentrations richer than the UEL will not burn. Some chemicals list LFL and UFL standards. These are the same, except they mean *lower flammable limit* or *upper flammable limit*.

```
HEXANE
==========================================================
MSDS Safety Information
==========================================================
Ingredients
==========================================================
Name: HEXANE (N_HEXANE)
% Wt: >97
OSHA PEL: 500 PPM
ACGIH TLV: 50 PPM
EPA Rpt Qty: 1 LB
DOT Rpt Qty: 1 LB
==========================================================
Health Hazards Data
==========================================================
LD50 LC50 Mixture: LD50:(ORAL,RAT) 28.7 KG/MG
Route Of Entry Inds _ Inhalation: YES
Skin: YES
Ingestion: YES
Carcinogenicity Inds _ NTP: NO
IARC: NO
OSHA: NO
Effects of Exposure: ACUTE:INHALATION AND INGESTION ARE HARMFUL AND MAY BE FATAL.
INHALATION AND INGESTION MAY CAUSE HEADACHE, NAUSEA, VOMITING, DIZZINESS, IRRITATION
OF RESPIRATORY TRACT, GASTROINTESTINAL IRRITATION AND UNCONSCIOUSNESS. CONTACT
W/SKIN AND EYES MAY CAUSE IRRITATION. PROLONGED SKIN MAY RESULT IN DERMATITIS (EFTS
OF OVEREXP)
Signs And Symptions Of Overexposure: HLTH HAZ:CHRONIC:MAY INCLUDE CENTRAL
NERVOUS SYSTEM DEPRESSION.
Medical Cond Aggravated By Exposure: NONE IDENTIFIED.
First Aid: CALL A PHYSICIAN. INGEST:DO NOT INDUCE VOMITING. INHAL:REMOVE TO FRESH AIR. IF
NOT BREATHING, GIVE ARTIFICIAL RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN.
EYES:IMMED FLUSH W/PLENTY OF WATER FOR AT LEAST 15 MINS. SKIN:IMMED FLUSH W/P LENTY
OF WATER FOR AT LEAST 15 MINS WHILE REMOVING CONTAMD CLTHG & SHOES. WASH CLOTHING
BEFORE REUSE.
==========================================================
Handling and Disposal
==========================================================
Spill Release Procedures: WEAR NIOSH/MSHA SCBA & FULL PROT CLTHG. SHUT OFF
IGNIT SOURCES:NO FLAMES, SMKNG/FLAMES IN AREA. STOP LEAK IF YOU CAN DO SO W/OUT
HARM. USE WATER SPRAY TO REDUCE VAPS. TAKE UP W/SAND OR OTHER NON_COMBUST MATL &
PLACE INTO CNTNR FOR LATER (SU PDAT)
Neutralizing Agent: NONE SPECIFIED BY MANUFACTURER.
Waste Disposal Methods: DISPOSE IN ACCORDANCE WITH ALL APPLICABLE FEDERAL, STATE AND
LOCAL ENVIRONMENTAL REGULATIONS. EPA HAZARDOUS WASTE NUMBER:D001 (IGNITABLE
WASTE).
Handling And Storage Precautions: BOND AND GROUND CONTAINERS WHEN TRANSFERRING LIQUID.
KEEP CONTAINER TIGHTLY CLOSED.
Other Precautions: USE GENERAL OR LOCAL EXHAUST VENTILATION TO MEET
TLVREQUIREMENTS. STORAGE COLOR CODE RED (FLAMMABLE).
==========================================================
Fire and Explosion Hazard Information
==========================================================
Flash Point Method: CC
Flash Point Text: _9F,_23C
Lower Limits: 1.2%
Upper Limits: 77.7%
Extinguishing Media: USE ALCOHOL FOAM, DRY CHEMICAL OR CARBON DIOXIDE. (WATER MAY BE
INEFFECTIVE).
Fire Fighting Procedures: USE NIOSH/MSHA APPROVED SCBA & FULL PROTECTIVE
  EQUIPMENT (FP N).
Unusual Fire/Explosion Hazard: VAP MAY FORM ALONG SURFS TO DIST IGNIT SOURCES & FLASH
BACK. CONT W/STRONG OXIDIZERS MAY CAUSE FIRE. TOX GASES PRDCED MAY INCL:CARBON
MONOXIDE, CARBON DIOXIDE.
==========================================================
```

FIGURE 2.41 A material safety data sheet.

Solvents

Solvents are used for cleaning automotive parts. A solvent is a liquid organic chemical compound used to dissolve solid substances. Most are made of petroleum or synthetic materials. Solvents can dissolve plastics and resins like those used in gaskets and sealers. They also evaporate quickly, leaving relatively little residue. Evaporation rate is important to the application. Gasket cements and paints must dry quickly, so solvents used in them have high evaporation rates.

Solvents are popular in the workplace because they work very well and make jobs go much faster. Used correctly, solvents can be very handy tools, but all solvents are toxic to a certain extent and must be used with caution. Always read the MSDS. The following paragraphs are intended to provide you with some important background material that can help you make informed decisions regarding your personal safety.

There are several chemical classes of solvents, including alphatic, aromatic, and chlorinated hydrocarbons; alcohols; esters; and ketones. Most solvents are flammable, and some can explode or create a different hazardous material when they react with other substances or heat. Chlorinated solvents are not flammable. However, when exposed to flame they can become phosgene gas, which is the nerve gas that killed so many soldiers in World War I.

- Acute symptoms of solvent exposure are those that show up immediately.
- Chronic conditions are those that arise later.

Acute symptoms include rashes and burns, nausea, and headaches. Solvents can cause irritation and damage to your skin, eyes, and respiratory tract, including the nose and throat. Continued irritation can result in chronic bronchitis and other lung diseases, called *local effects*, because the harm is caused at its original point of contact.

All organic solvents can cause skin problems. Repeated contact causes the skin's protective fats and oils to dissolve. When the skin's protective barrier is removed, it becomes dry and cracked, leaving it vulnerable to absorption of toxic materials. Some solvents, like MEK, can be absorbed through the skin. When a chemical enters the body this way, the exposure is called *systemic* and it can travel to other organs such as the liver, kidneys, muscles, heart, and brain. Liver and kidney damage can result from systemic chemical exposure.

Chronic effects, also called latent effects, can be due to repeated exposure over time or can result from a single exposure. Latent effects can take weeks or even years to show up and are often irreversible. These include cancers, heart disease, blood disease, and the inability to bear healthy children. Symptoms of chronic exposure to dangerous chemicals are documented over time. For instance, heart damage was linked to solvents during a 5-year period where more than 100 people died from sniffing solvents.

Benzene, heptane, trichloroethylene, and methylene chloride are some of the chemicals that can cause arrhythmias. *Arrhythmia* is a term that applies to abnormal patterns in the heart's pumping cycle. Tetrachloroethylene (also called perchloroethylene or perc) and toluene have been implicated as spontaneous abortion risks to fetuses fathered by male technicians who have been exposed to it in the workplace.

Some solvents can cause neurological symptoms, such as narcosis. Central nervous system involvement can result in narcosis (unconsciousness), dizziness, headaches, fatigue, and nausea. At high concentrations, symptoms can mimic drunkenness, followed by death.

The most common solvents in the automotive industry include hexane, mineral spirits, xylene, toluene, heptane, and petroleum naphtha. Hexane is found in gasoline, rubber cements, and some spray products. Check the label on the container (**Figure 2.42**) and read the MSDS. Hexane can affect the central and peripheral nervous systems.

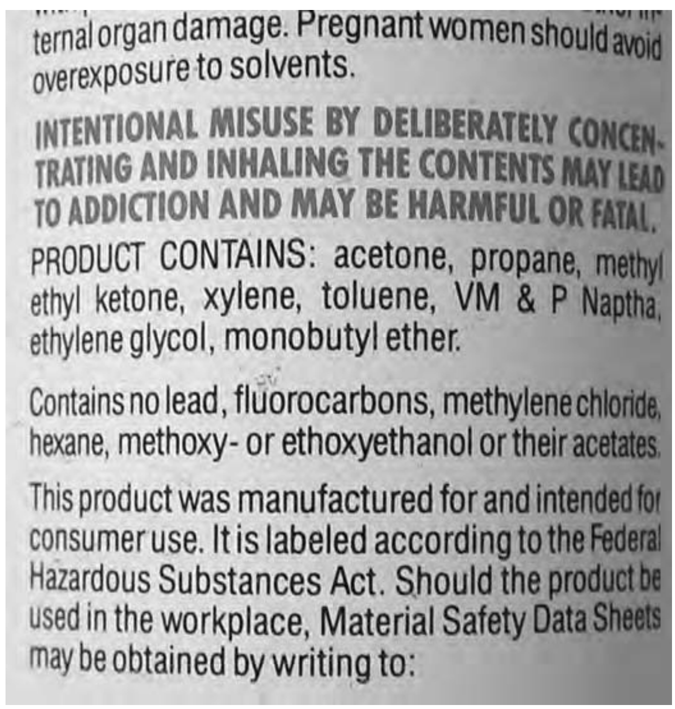


FIGURE 2.42 Hexane and other hazardous materials are sometimes contained in spray products. Check the label on the container. *(Courtesy of Tim Gilles)*

Peripheral nervous system involvement causes peripheral neuropathy, which is a slowing of the speed of nerve impulses from your spine to your arms and legs, accompanied by numbness, weakness, or paralysis. Symptoms can be similar to multiple sclerosis. Another disorder of the peripheral nervous system is polyneuropathy. Symptoms include muscle spasms, pain and weakness in the legs, and tingling in the arms. Solvents that have been implicated as possible causes include benzene, n-hexane, n-heptane, and toluene.

Heptane is a central nervous system depressant. Dizziness and loss of coordination are the result of short-term exposure (2000 parts per million for 4 minutes). Long-term exposure can result in minimal peripheral nerve damage.

Sometimes two or more toxic substances react with one another and become more hazardous. This is called synergism. Here are some examples:

- A higher instance of health problems exists among asbestos workers who also smoke.
- Severe nerve damage can result when MEK is combined with n-hexane.
- Carbon tetrachloride causes serious liver damage, especially when combined with alcohol.

NOTE

The effects of these chemicals vary by individual. Some individuals can be affected at lower levels than the number listed on an MSDS.

Carcinogens and Mutagens. Some solvents are known to cause cancer in humans and animals. These are called carcinogens. Benzene, found in gasoline, can cause leukemia. Experts suspect that chlorinated solvents (those whose names include "chloride" or "chloro") might cause cancer. Twenty-one human carcinogens are regulated by OSHA, and there are hundreds of other suspected carcinogens under investigation. Some chemicals, called mutagens, can affect genetic material in human cells, prevent conception, cause a miscarriage, or damage a fetus. When dealing with hazardous materials the most prudent course of action is to avoid contact altogether. If a part can be cleaned in a contained tank without dangerous contact to you, use this method whenever practical.

Protection from Chemicals. Many technicians and machinists now routinely wear blue nitrile gloves on their hands at all times. This provides some measure of protection from skin damage and penetration through the skin by the solvents.

Employee training requirements are controlled by both state and federal agencies. Always be aware of the materials you are dealing with.

REMEMBER:

No one will be more concerned for your safety and health than you!

Asbestos. Asbestos, which is found in some clutches and cylinder head gaskets, is dangerous to breathe. Do not use a regular vacuum on asbestos dust because asbestos will go right through it. A special vacuum, called a **HEPA vacuum,** can handle asbestos without allowing it to escape through the vacuum bag.

CAUTION

You could be exposed to asbestos when cleaning head gaskets from head and block mating surfaces with a high-speed rotating disk.

KEY TERMS

backfire	greasesweep	mushroomed chisel
chlorinated solvent	HEPA vacuum	popback
flash point	MSDS	spontaneous combustion

Engine Shop Safety Test

Use the terms in the following word list to fill in the blanks:

freeze	disconnected	impact	hydraulic jack
back, eyes	electrical	pipe	picker
B	gasoline	air	smaller
fire	water	wrench	drilling
legs	ground	corrosive	1½
reground	asbestos	grinders	explosions
toxicity	material	drill	end
squeezing	green	side	instructor
vapor	handle	talk	water
spontaneous	air	hydraulic	charger
eye or face	blowguns	6 inches	jack
professional	manual	jack	
flash	systemic	rest	

1. The most common injuries in an automotive shop involve the _____ and _____.
2. If refrigerant from an air-conditioning system contacts your skin or eyes it will _____ them.
3. Lift with your _____, not your back.
4. If a _____ is burning out of control, leave the area immediately and call for help.
5. A flammable liquid fire is called a Class _____ fire.
6. Keep oily materials separated from air to prevent _____ combustion.
7. What form of gasoline is the most dangerous, liquid or vapor? (Circle one.)
8. Never use _____ to clean floors or parts.
9. The temperature at which a flammable liquid's vapors will ignite when brought into contact with an open flame is called the _____ point.
10. Disconnect the battery's _____ cable before working on a vehicle electric system.
11. Before a(n) _____ fire can be extinguished, the battery or power source must be disconnected.
12. Do not attempt to put out a gasoline fire with _____.
13. A HEPA vacuum is a special vacuum for _____.
14. The color of the wiring for ground on household electrical wiring is _____.
15. Electric cooling fans should be _____ before working around them.
16. Before opening a radiator, test for pressure in the system by _____ the top radiator hose.
17. Neat and clean work habits show a _____ attitude.
18. Mushroomed punches or chisels should be _____ before use.
19. Always wear _____ protection when using hammers, chisels, pullers, batteries, air-conditioning machinery, compressed air, and other hazardous equipment.
20. Always use a _____ on the tang of a file.
21. Compressed _____ can penetrate skin and must be used cautiously.
22. Rubber-tipped _____ work at full shop air pressure.
23. When using an air impact wrench, be sure to use an extra thick socket, called a(n) _____ socket.

24. When an air impact _____ is used with a wobble socket, it can fly off and hit something if the tool is turned on when the socket is not on the bolt.
25. When using a(n) _____ chisel, be sure to have the tool bit against the workpiece before you squeeze the trigger.
26. Die _____ turn at speeds of up to 20,000 rpm. Be sure to use wheels that are rated for at least that speed.
27. Do not use a _____ on the handle of a vise or it might break.
28. Do not distract or _____ to someone who is operating a machine.
29. A _____ bit has a tendency to grab the work when it just begins to cut through the metal.
30. When _____ sheet metal or large pieces of metal on the drill press, make sure that they are clamped to the worktable.
31. Stand to the _____ when starting the grinder.
32. Position the tool _____ as close to the grinding wheel as possible.
33. Because they can develop force of from 20 to 40 tons, _____ presses can cause parts to explode.
34. Locate the correct lift points in a service _____ before using a hydraulic jack or hoist.
35. Use a _____ _____ to raise and lower a vehicle only.
36. A raised-up vehicle should be placed firmly on _____ stands.
37. When lifting a vehicle on a frame-contact hoist, place the lift pads at the specified locations and raise the vehicle about _____. Then shake it to see that it is firmly placed.
38. Bolts that attach an engine sling or engine stand adapter to the block should enter the block at least _____ times the diameter of the bolt.
39. When moving an engine that is hanging from an engine _____, be sure that the engine is lowered as far as possible to keep the center of gravity low.
40. When using a transmission _____ on a car that is on a frame-contact lift, be careful not to raise the car off the lift pads as you raise the transmission.
41. When a floor creeper is not in use, it should be stood on _____ or pushed under a car so it is not accidentally stepped on.
42. The most common cause of battery _____ is when someone unhooks the battery charger without turning it off.
43. Shut off and unplug the battery _____ before disconnecting any of the cables.
44. If acid gets on skin or eyes, immediately flush with _____ for at least 15 minutes and seek medical attention as soon as possible.
45. If you become injured while working in the shop, inform your _____ immediately and seek medical attention as soon as possible.
46. The four categories under which the EPA categorizes waste are ignitability, corrosivity, reactivity, and _____.
47. Wastes that have a pH lower than 2 or higher than 12.5 are _____.
48. MSDS stands for _____ safety data sheet.
49. A chemical with a _____ exposure limit is more toxic.
50. When a chemical enters the body and travels to other organs, this is called a _____ effect, rather than a local effect.

CHAPTER 3

Diagnosing Engine Problems

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Use engine diagnostic tools and equipment safely and properly.
- Diagnose engine and related problems and determine the proper repair procedure.

Introduction

This chapter focuses on how to troubleshoot problems on a running engine. Also discussed are some of the external causes of engine problems that can result in a repeat of a previous engine failure, if allowed to continue unresolved. Internal engine parts are shown here to illustrate some of the causes and results of these problems. Internal problem diagnosis after disassembly is also covered in more detail in subsequent chapters.

It is very important that you diagnose the cause of a problem before performing a repair. It is not unusual for an inexperienced technician to spend many hours of work only to discover that the repair was unnecessary.

Five major diagnosis areas are covered:

- Possible reasons for oil consumption
- Causes of rough running or a loss of engine power
- Engine noises
- Oil pressure problems
- Cooling system problems

There are many causes of engine problems. Some are the result of normal wear and tear or a lack of maintenance. Engine problems also might be due to previous work on the engine. Problems that appear to be engine-related can also be caused by other automotive specialty areas, such as the transmission or emission controls. Sometimes a problem with a system causes an engine to fail. If the problem is not taken care of, the failure will recur.

VINTAGE ENGINES

In the past, gasoline stations provided underhood service, and most of them had an adjoining service facility. Today many of the service facilities have been converted to mini-markets. One result of self-service is that engines are suffering from a lack of maintenance.

FIGURE 3.1 This damaged starter motor was the cause of a "frozen" engine. The starter was repaired, and the engine ran fine. *(Courtesy of Tim Gilles)*

This chapter should serve as a reference for future problems. The descriptions of various problems are listed in the index at the back of the book. More in-depth training in engine diagnosis comes under the overlapping specialty area of engine performance.

DIAGNOSING PROBLEMS BEFORE A REPAIR

An engine should be correctly diagnosed before disassembly for two reasons. It should be determined that an overhaul is really necessary. The damaged starter motor drive frame shown in **Figure 3.1** resulted in a diagnosis of catastrophic engine failure. Failed belt-driven accessories can also lead you to believe that there is a **seized engine**.

The exact location of a problem should be determined while the engine is running. A thorough discussion of the problem with the owner of the vehicle is also helpful. Sometimes an owner's driving habits or maintenance procedures can be the cause of the problem.

OIL CONSUMPTION

Piston rings are usually the first thing a customer suspects when a car starts to use oil, even though oil can be lost through a variety of other conditions. Oil loss can be due to either external leakage or internal oil consumption. Excessive internal oil consumption can sometimes be spotted as an oily coating on the inside of the exhaust pipe. Black soot at the exhaust pipe often indicates an overly rich air-fuel mixture, not oil consumption.

The rate of normal oil consumption depends on such things as the size of the engine, the weight and shape of the vehicle, the viscosity and service rating of the oil, engine rpm and load during use, engine temperature, and the amount of oxidation and dilution of the oil. Information about oil is covered in detail in Chapter 14.

From time to time an owner will complain of an occasional rapid oil loss. This might be a normal condition that sometimes occurs after 1000 or more miles of city driving followed by a highway trip. City driving can result in extra fuel and water dilution in the oil. Before leaving on a long vacation trip, the customer checks the oil and the dipstick registers "full." But when the diluted oil becomes thoroughly heated, evaporation of the pollutants gives the appearance of rapid oil consumption as the oil level drops a quart in a few hundred miles.

Bad Valve Guides or Seals

The cause of internal oil consumption is often worn valve guides or defective valve guide seals. There might be exhaust smoke during deceleration because of oil leaking into the combustion chamber through the intake valve guides. Deceleration causes very high engine vacuum, which pulls oil into the combustion chamber.

A spark plug that is oil fouled on only one side indicates leaking valve guide seals. Carbon deposits on the necks of the intake valves are another indication (**Figure 3.2**). Look for carbon deposits when disassembling the cylinder head.

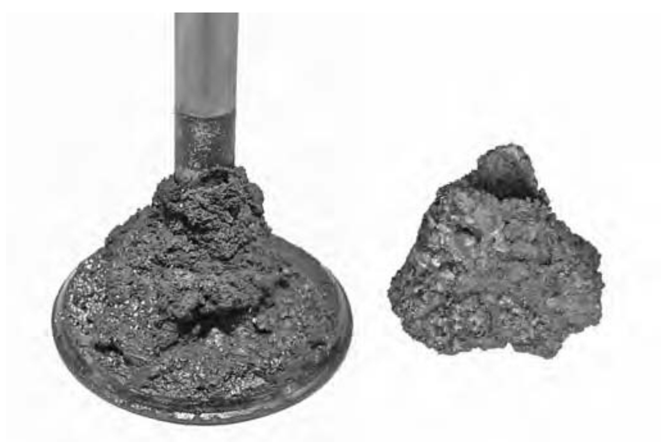


FIGURE 3.2 Carbon on the neck of a valve. *(Courtesy of Tim Gilles)*

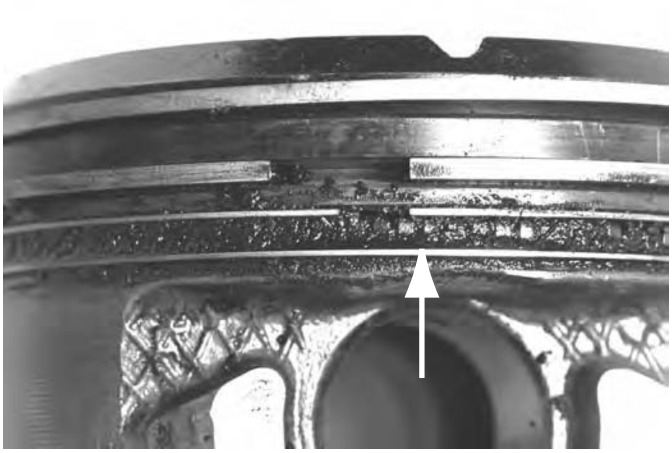


FIGURE 3.3 A Plugged oil control ring.

Different types of valve guide seals are described in detail in Chapter 7. Valve guide seals should always be replaced during a valve job while the heads are disassembled. Chapter 7 includes a procedure for replacing valve guide seals without removing the heads from the engine.

Oil Consumption from Piston Rings

When oil is consumed past piston rings, one common cause on high mileage engines is lack of ring tension resulting from cylinder wall and ring wear. A record of poor engine oil maintenance contributes greatly to an increased wear factor. An engine that suffers from a lack of regular oil changes will often have plugged oil control rings (**Figure 3.3**). The piston's oil-control rings need to be able to scrape oil from the cylinder walls and return it to the crankcase through the underside of the piston (**Figure 3.4**).

NOTE

According to the Ford Motor Company, there are approximately 36,500 drops of oil in 1 quart. If the engine consumed as little as 1/1100 of a drop of oil on each stroke, it would use 1 quart of oil in 1000 miles. So you can see the fantastic job that the oil rings do the majority of the time and the major problem created when they become restricted.

Oil Consumption from Worn Compression Rings

Combustion pressure leaks past the piston rings when compression rings become worn, resulting in higher pressure in the crankcase. Remember from Chapter 1 that this is called blowby (see Figure 1.10). During the intake stroke, there is higher engine vacuum in the cylinder above the piston, but there is also higher pressure in the crankcase below the piston rings. Therefore, oil takes the path of least resistance and migrates up the cylinder wall into the combustion chamber, resulting in oil consumption. In extreme cases, exhaust smoke can be visible either during acceleration or deceleration.

When looking for the cause of excessive oil consumption, technicians will often do a compression test (covered later in this chapter). Although this procedure might locate worn or broken compression rings, it does *not* check the condition of oil control rings.

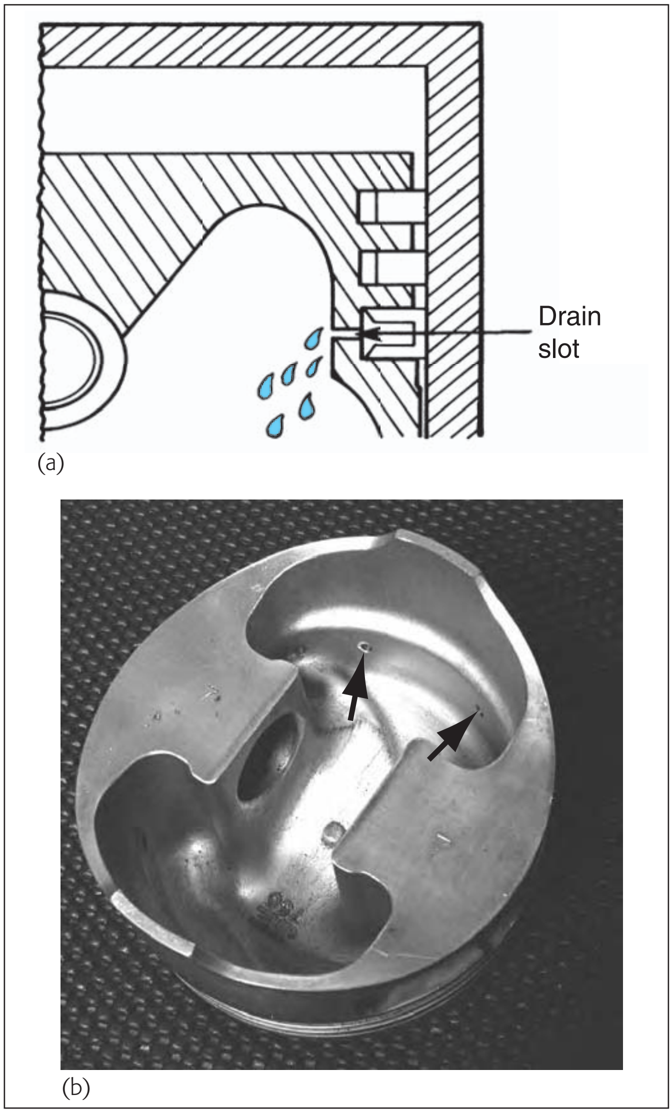


FIGURE 3.4 Oil ring drainback. Slots (a) or holes (b) in the oil groove return oil to the crankcase as the piston moves down.

A spark plug deposit test can check for internal oil consumption. During this test:

- The engine's initial spark timing is retarded to 10° after top dead center (ATDC).
- The engine is idled at 500 rpm for 15 minutes.
- Next, the spark plugs are examined for oil wetting.
- The engine should not be run above idle speed until the timing is returned to specification because it will overheat.

NOTE

Retarded timing can cause exhaust valves to run dangerously hot.

Spark plugs provide a window to conditions in the cylinder because they extend into the combustion chamber. **Figure 3.5** shows abnormal spark plug conditions associated with oil consumption.

Increased Oil Consumption after a Valve Job

Consider the condition of the entire engine before doing a valve job. If the rest of the engine is worn, sometimes an engine starts to consume oil after a valve job. The valve job increases *compression*, but it also increases engine vacuum. This can result in more oil being sucked past the worn piston rings into the combustion chamber.

When cylinder heads are removed for a valve job, look at the tops of the pistons to see if oil consumption might be caused by worn or stuck piston rings (see Figure 4.107).

FIGURE 3.5 Examples of oil-fouled spark plugs. *(Courtesy of Tim Gilles)*

Excessive Rod Bearing Clearance

A high mileage engine will probably have worn crankshaft bearings. Excessive bearing-to-crankshaft journal oil clearance can result in low oil pressure at idle. Oil consumption can increase at higher engine rpm as oil leaks out between the connecting rod journal and the rod bearing. At higher engine speeds, this can result in too much oil being thrown onto the cylinder walls, overwhelming the oil rings, which cannot return all of the oil to the crankcase (**Figure 3.6**). Whatever oil enters the combustion chamber will be burned with the air-fuel mixture. Even with normal rod bearing clearance, high-speed driving can cause increased oil consumption due to extra oil thrown from the rods. In one test, an engine run at 70 mph used seven times the oil that it used at 40 mph.

Incorrect Engine Oil Dipstick

It is especially important to make sure that the correct oil dipstick is used after an engine change or short block installation. Manufacturers often install the same engine in different vehicle models. Depending on the vehicle, the engine can be equipped with a different oil pan, which sometimes

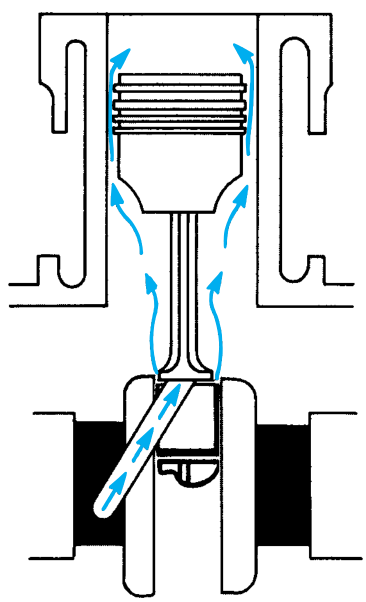


FIGURE 3.6 Increased oil clearance causes more oil to be thrown onto cylinder walls.

VINTAGE ENGINES

Automatic transmissions on many older vehicles use a vacuum modulator. It senses engine load by using **intake manifold vacuum** to tell the transmission when to shift. If the diaphragm in the modulator leaks, transmission fluid will be sucked into the intake manifold. This can produce smoke that might be confused with engine oil smoke, even though the engine may be in perfect condition. One clue is when the spark plugs nearest the vacuum tap on the intake manifold become oil-fouled with automatic transmission fluid (**ATF**). A leaking modulator diaphragm can also cause rough engine idle because it allows air to leak into the intake manifold. Harsh, late transmission shifts, or no upshifts, are other symptoms.

Be sure to question the vehicle owner thoroughly. The combination of any or all of these symptoms can lead an owner to believe that an engine overhaul is needed. The key to diagnosing a faulty vacuum modulator is that the engine is probably consuming ATF and the level drops consistently.

requires a different length oil dipstick. Excessive oil consumption can result from too short a dipstick. Every time the owner mistakenly adds a quart of oil to the crankcase, the crankshaft throws the oil on the cylinder walls and the overfull engine burns off the excess.

Plugged Cylinder Head Drainback Holes

When engine oil has not been changed often enough, thick sludge can plug the oil return holes in the cylinder head. These *drainback holes* allow rocker arm oil to return to the crankcase (**Figure 3.7**). The problem can be temporarily solved by cleaning out the holes, but it is a symptom of a poorly maintained engine and major service will soon be needed. The oil remains in the valve cover area instead of returning to the crankcase; it floods the valve guide, making the valve stem seal ineffective.

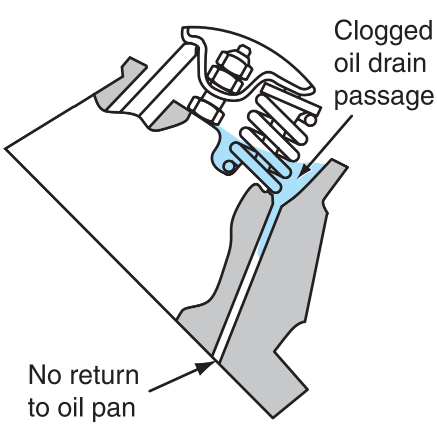


FIGURE 3.7 Plugged oil drainback holes will cause exhaust smoke.

Leaking V-Type Intake Manifold Gasket

Intake manifold vacuum can draw oil into the intake ports from the lifter-valley area under some intake manifolds (**Figure 3.8**). This is a tough problem to find. A smoke test is a good way of finding an intake manifold leak. A cranking vacuum is another way to test for internal air leaks before the engine is disassembled. These procedures are covered later in this chapter. When removing an intake manifold, always visually inspect for the possibility of previous intake gasket leakage.

V-type engines equipped with an exhaust gas recirculation (**EGR**) valve on the intake manifold often experience oil-fouling of the spark plugs that are closest to the EGR valve. This is caused when the intake manifold warps or the manifold gasket fails. Replace the gasket with one designed for high temperature applications.

Crankcase Pressure

Normally, there is a slight vacuum in the crankcase. One possible reason for excessive oil leakage is a positive crankcase ventilation (PCV) valve that

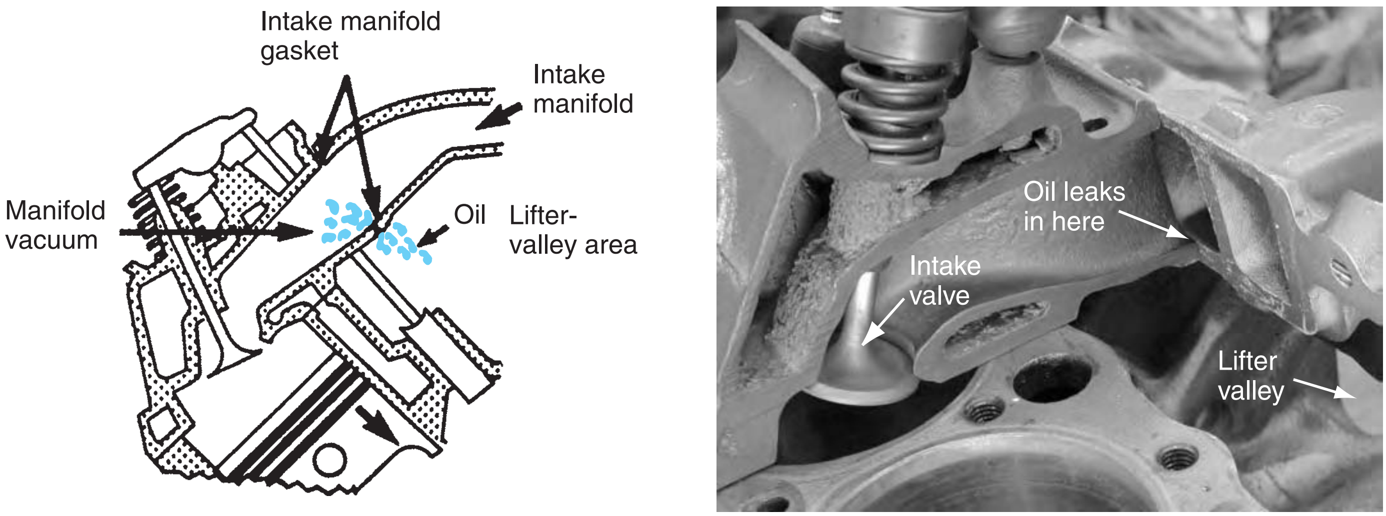


FIGURE 3.8 Oil can be drawn into the intake manifold past a faulty manifold gasket. *(Courtesy of Tim Gilles)*

is plugged. This can cause pressure to build up in the crankcase at low rpm. Crankcase pressure can result in increased internal oil consumption, too.

NOTE

The operation of the PCV valve is covered in detail in Chapter 14.

To see if the **PCV** valve is working properly:

- Pinch the line that leads to it, or cover the end of the PCV valve with your thumb.
- With computer idle speed adjust disabled, if the PCV valve is good, idle speed should drop.

Blocking the flow of air to the PCV valve enriches the air-fuel mixture.

REMEMBER:
A leaner air-fuel mixture means a higher idle speed.

SHOP TIP

Here is another simple test to see if there are any leaks in the crankcase:

- Remove the hose from the valve cover to the air cleaner (at the air cleaner side).
- With the engine idling, put your thumb over the end and wait for a couple of seconds. If the crankcase ventilation system is working correctly, vacuum should be felt in the hose.

Be sure to check for a restricted filter or a kink in the breather line from the valve cover to the air cleaner. This can result in oil leakage caused by crankcase pressure.

NOTE

Under high load, low vacuum conditions, the PCV valve does not work as well. Any blowby that can cause crankcase pressure must be able to escape through the hose to the air cleaner.

VINTAGE ENGINES

If oil is leaking from the breather hole of a mechanical fuel pump, be sure to inspect for excessive crankcase pressure.

If the PCV system is to be effective, the entire crankcase must remain sealed. A leaking or misplaced gasket can cause enough air leakage to result in failure of the PCV system. This includes the timing cover, oil pan, valve cover gaskets, and crankshaft seals. If the engine is not airtight, suction from the PCV valve will not create sufficient vacuum in the crankcase. An oily air cleaner, or oil in the hose to the air cleaner, often points to a crankcase pressure problem.

NOTE

With the correct amount of suction in the crankcase, slight leakage from a gasket or seal should result in outside air leaking *into* the crankcase, rather than oil leaking out.

CASE HISTORY

A motor home was using excessive oil and leaking from the rear main crankshaft seal. A technician replaced the crankshaft seal, but the new seal continued to leak. After performing some of the tests, the owner of the repair shop determined that the crankcase ventilation system was not working correctly. Motor homes experience extremely high under-hood temperatures. The valve covers are located directly over the exhaust manifolds and are exposed to extreme heat. A valve cover gasket had developed a leak on the intake manifold side. Oil was not leaking out, but air was leaking in, causing the PCV system to be inoperative. Compounding the problem, the hose to the air cleaner was supposed to be a molded hose but someone had installed a piece of heater hose instead. The hose had become kinked and did not allow blowby to escape at highway speeds. The combination of these two problems caused internal oil consumption and leakage from the crankshaft seals.

SHOP TIP

To check for suspected excessive crankcase pressure:

- Remove the oil dipstick.
- Put a pressure/vacuum tester on the oil dipstick tube.
- With a long enough hose, the technician can drive the car while watching for pressure on the gauge.
- When running this test at idle, the breather should be plugged, but it should be unplugged during a road test.

A ring seal tester can be used to test an engine's amount of blowby. It measures airflow out of the crankcase in cubic feet per minute (cfm). Normal airflow is about 5–8 cfm. Above 8 cfm indicates that the rings are not sealing properly.

Unfiltered air allows dirt to enter the engine, causing engine wear. This can result from leaking vacuum hoses, vacuum control units, vacuum accessories, or manifold leaks. Crankcase pressure can also cause oil to migrate up the distributor shaft and into the distributor.

To locate a leak in the PCV system:

- Seal the breather and PCV valve.
- Use a smoke tester (covered later) or blow (lightly) into the dipstick tube with a rubber-tipped blowgun (regulated to no more than 2–3 psi). Listen for leaks, using a piece of hose or a stethoscope with the metal end pulled off.

A leak is often not readily apparent, especially at the top side of a valve cover gasket or where the intake manifold meets the block at the front or back. Oil might not leak out because of gravity and suction from the crankcase vacuum of the PCV system.

SAFETY NOTE

Fuel in the crankcase causes a dangerous condition to develop. A faulty mechanical fuel pump, fuel injector, or fuel pressure regulator will allow the crankcase to collect fuel. Also, fuel enters the crankcase when the engine has been flooded with raw fuel.

CASE HISTORY

A vehicle was brought into a shop for a tune-up. The technician decided that it would be easier to service the distributor if it was removed from the engine. Somehow the ignition switch was left in the "on" position. When the distributor was removed a spark resulted, igniting the air-fuel mixture in the crankcase and causing an explosion. The explosion blew the burning mixture out the ignition distributor hole, burning the technician and catching his clothing on fire.

VINTAGE ENGINES

Most older engines with carburetors had mechanical fuel pumps. A faulty mechanical fuel pump can be responsible for oil consumption and other problems. A break in the pump diaphragm will allow fuel to dilute the oil in the crankcase. The thinner oil that results leaks more easily past the piston rings, into the combustion chamber. Low fuel pump pressure and an oil dipstick that smells of gasoline are symptoms of the problem. Low fuel pump pressure can cause the vehicle to run out of fuel when partway up a grade. It can also cause vapor lock, which is when fuel boils in the line, temporarily depriving a carbureted engine of gas. Another problem from diluted crankcase oil is hydraulic valve lifters that become noisy because they leak down rather than opening the valves.

A mechanical fuel pump has an oil seal above its diaphragm spring. If oil leaks past this seal, it can result in an external leak as it comes out of the vent hole in the dry chamber above the diaphragm. The problem will be worse if crankcase pressure is excessive.

SAFETY NOTE

If you are working on a vehicle and your clothing catches fire, fall on the ground and roll around to smother the flames. Do not run.

OIL LEAKS

NOTE

A loss of one drop of oil every 30 feet results in a loss of about 3 quarts of oil every 1000 miles.

Oil that leaks through gaskets and seals is a common cause of oil consumption.

SHOP TIP

To test an engine for leaks:

- Clean the engine.
- Slide a piece of white newsprint or autobody masking paper under the vehicle while the engine idles.
- Fresh drops of oil on the newsprint indicate a leak.

Rear Crankshaft Seal Leaks

A rear main bearing seal leak can be identified when oil is found on the engine side of the flywheel or torque converter. Oil on the opposite side indicates front transmission seal leakage.

Oil that has been sprayed in a circular pattern is also indicative of a crankshaft seal leak. Most crankshaft seal leaks are caused by excessive crankcase pressure.

Oil leaks streaking down the block can be due to a leaking oil gallery plug, cam plug, or seal retainer block. The block could also be porous or cracked.

Black Light Testing. When **black light testing**, a 1-ounce bottle of fluorescent dye is added to engine oil to help locate leaks. When a black light is used, the source of the leak will be highlighted in bright yellow-green streaks. A mirror can be used to bounce the black light into hard-to-see areas. Washing the engine first is helpful but not necessary.

There are two types of ultraviolet (UV)-fluorescent lights available. The traditional black light type uses a vapor bulb powered by 110 volts. It requires a warm-up period of about 10 minutes. With the 110-volt lamp, yellow-green dye is easily visible in the leaking oil; oil without dye appears purple. Use care when handling the lamp. The bulb is fragile and is expensive to replace.

A different type of light system uses a high output 12-volt UV/blue lamp that comes on instantly and is used with yellow glasses (**Figure 3.9**). UV light can be damaging to your eyes, so use caution. With the 12-volt lamp and glasses, oil is yellow and oil with dye in it is a brighter yellow-green.

When a leak is minor it might not show up after just a short time, so the car might need to be driven

FIGURE 3.9 A UV light powered by the vehicle battery is used with yellow UV glasses, which prevent eye damage. *(Courtesy of Tim Gilles)*

for a day or so. After the leak is repaired, the engine is cleaned and rechecked with the black light. The fluorescent dye stays in the oil. The dye is not harmful and the manufacturer says that it dissipates within 300 miles of driving.

CASE HISTORY

A technician was attempting to repair an oil leak on a dual overhead cam six cylinder engine. He replaced the valve cover gasket but the leak continued and the unhappy customer returned to the shop. After pouring some leak detection fluid into the crankcase and taking the car on a test drive, he aimed the black light at the engine. Bright streaks of yellow oil were visible coming from behind one of the camshaft sprockets. He removed the valve cover, timing belt, and sprocket and replaced the semicircular rubber seal behind the timing sprocket (see Figure 3.15).

There are also special formulations of leak detection fluid for automatic transmissions, fuel systems, air-conditioning systems, and power steering leaks.

Miscellaneous Leak Detection Methods. Other methods of oil leak detection include adding red dye to oil or spraying foot powder on a clean area. When the oil leaks again, it will stain the white powder. Refer to Chapter 16 for more information on gaskets and seals.

FUEL MIXTURE PROBLEMS

Emission control and fuel system malfunctions sometimes mimic engine problems. Occasionally, important items are neglected during an engine job. Larger engine shops often employ specialists capable of diagnosing these complicated problems.

NOTE

A fuel or emission problem that resulted in an engine problem will probably cause the same failure again if it is not repaired.

An air-fuel mixture that is too lean (too much air/too little fuel) can cause burned internal engine parts.

Oil/Fuel Wash

An overly rich mixture (too much fuel/too little air) can cause *fuel wash* or *oil wash* (when oil is washed from cylinder walls, resulting in cylinder wall wear). Leaking fuel injectors can result in cylinder wall oil wash, too. They can also cause intake valve deposits that will affect engine idle and emissions. A bad vapor canister purge valve can also cause oil wash. When only one side of a piston is worn, this is often due to oil wash. The worn side will be the major thrust side. An explanation of piston thrust surfaces is provided in Chapter 13.

Many areas use reformulated gasoline (RFG) to lower air pollution. RFG does not cause problems with engine wear under normal conditions. But a richer than normal air-fuel mixture can result in accelerated engine wear because the alcohol or ether in RFG dilutes the oil on the bearings, cylinder walls, and piston rings. When mixed with the oil, it does not evaporate as easily and the diluted oil loses much of its lubricity. When a low mileage engine fails and there is no evidence of excessive dirt, abrasives, or machined material, diluted engine oil is a prime suspect.

Oxygen Sensor Problems

Modern engines use oxygen sensors in the exhaust to compare the oxygen content of the exhaust with that of the outside air. After a short warm-up period, it gives the computer information to control the air-fuel mixture. If the engine runs rough when cold, but the problem goes away after a short warm-up, the oxygen sensor could be masking an air leak.

Check to see that the sensor is not dirty. Dirt or undercoating can plug the sensor's outside air intake port, affecting the signal from the sensor. This can result in a richer than normal air-fuel mixture.

COMPRESSION LOSS

Compression loss, another reason for an engine overhaul, can be traced to two causes: compression leaks and engine breathing problems.

Compression Leaks

Compression can leak due to several causes: a blown head gasket (**Figure 3.10**), burned valves (**Figure 3.11**), worn or broken piston rings, a damaged piston (**Figure 3.12**), or a broken valve spring (**Figure 3.13**).

NOTE

A broken valve spring is nearly always accompanied by water in the crankcase. Acid is a by-product of combustion that accumulates in engine oil. When acid combines with water, corrosion accelerates and the resulting rust raises stress in the surface of the spring, causing it to break.

When *valve clearances are too tight* the valves cannot seal against their valve seats, resulting in a compression leak. Tight valves can result from wear to the valve faces (**Figure 3.14**) or valve seats, either of which allows the valve stem tips to move deeper into the cylinder heads. Closer valve clearance can also result when valves have been adjusted incorrectly.

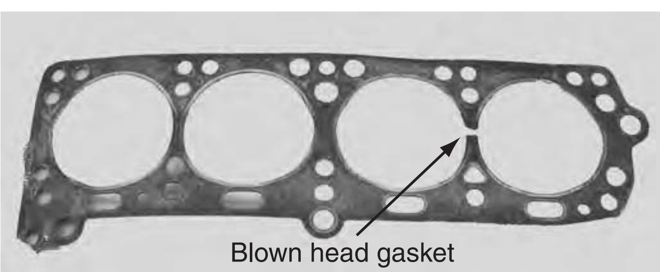


FIGURE 3.10 A blown head gasket. *(Courtesy of Tim Gilles)*

(a)

(b)

FIGURE 3.11 (a) A burned exhaust valve like this one causes lower or no cylinder compression pressure. (b) Severely burned valves. *(Courtesy of Tim Gilles)*

NOTE

A burned valve can result when an engine with an exhaust leak has been driven for a period of time without repair (**Figure 3.15**). The valve typically runs at temperatures in excess of about 1300°. When the relatively cold air in the engine compartment is sucked in through the exhaust leak, the valve suffers thermal shock.

Exhaust leaks make noise at ½ crankshaft rpm.

FIGURE 3.12 A damaged piston resulting from detonation. *(Courtesy of Tim Gilles)*

FIGURE 3.13 A broken valve spring. *(Reprinted Courtesy of Caterpillar Inc.)*

FIGURE 3.14 Valve face wear will cause the valve stems to move into the head, eliminating valve adjustment clearance. *(Courtesy of Tim Gilles)*

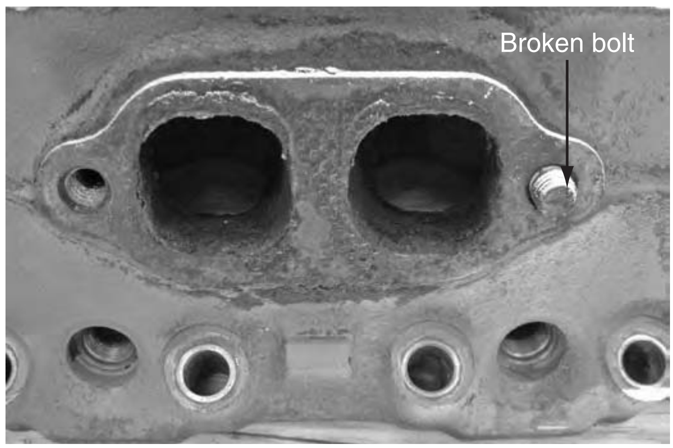


FIGURE 3.15 This broken exhaust manifold bolt resulted in a burned exhaust valve due to thermal shock. *(Courtesy of Tim Gilles)*

Breathing Problems

An engine that cannot breathe properly is suffocating and will not be able to develop sufficient compression. Engine vacuum will drop off, further lowering compression. Breathing problems can be traced to such things as worn camshaft lobes that do not open the valve far enough (**Figure 3.16**), or late valve timing (see Chapter 10). Valve timing can become retarded (late) when a timing chain becomes so worn that it skips a tooth.

SHOP TIP

Hard valve seats that are starting to burn can turn a spark plug blue because of cobalt deposits that flake off the valve seat.

NOTE

Late valve timing will cause poor low rpm performance although engine performance might be acceptable at higher rpm.

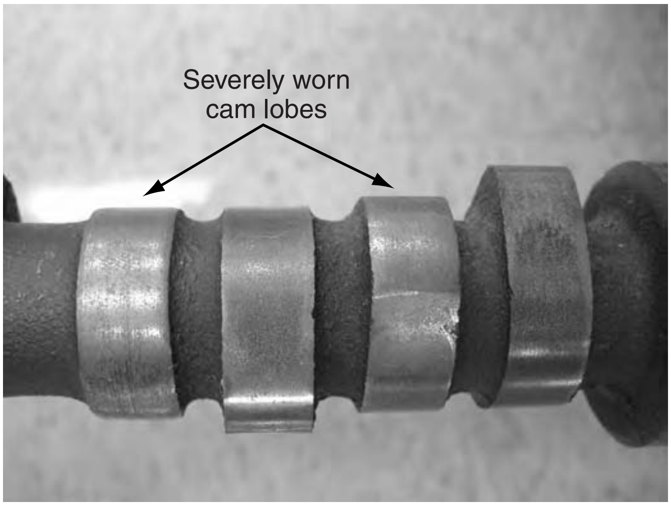


FIGURE 3.16 A severely worn cam lobe will not properly open a valve. *(Courtesy of Tim Gilles)*

If the timing chain has skipped and valve timing is retarded, suction will be felt at the exhaust pipe. This happens because the exhaust valve is still open during the piston's intake stroke.

Breathing problems can also be traced to carbon buildup around the neck of the valve (**Figure 3.17**) or to restrictions such as a dirty air cleaner or a blocked exhaust.

SHOP TIP

A blocked exhaust will be evident when the engine rpm is raised quickly. A roar will be heard on the engine side of the air cleaner.

NOTE

A collapsed laminated (two layer) exhaust pipe (**Figure 3.18**) will often cause a discoloration of the outside of the pipe at the point of restriction.

Catalytic converters in the exhaust system can become plugged after running for a prolonged period with an ignition system defect. A rich air-fuel mixture can also cause a converter to plug when it overheats and melts internally. OBD II vehicles (later than 1996) will go into limp-in mode when the computer senses a catalyst damaging misfire.

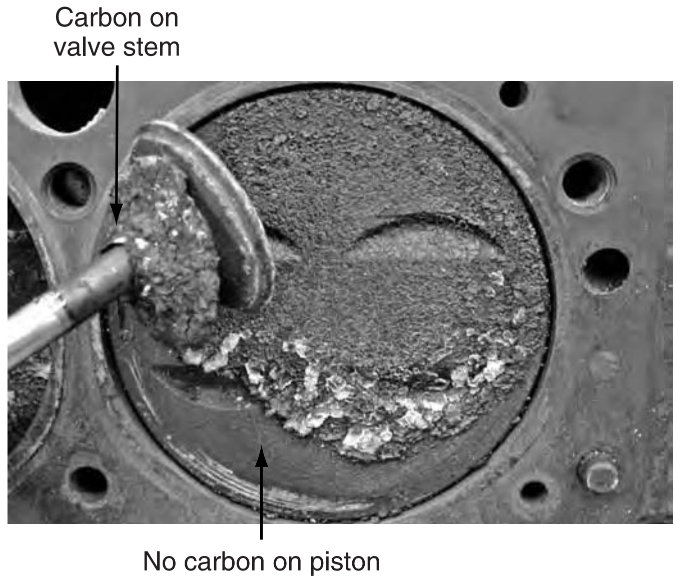


FIGURE 3.17 A lack of carbon formation on the top of the piston, beneath the intake valve, indicates oil leakage through the valve guide. The valve in the photo was found when the head was disassembled. *(Courtesy of Tim Gilles)*

FIGURE 3.18 A collapsed laminated exhaust pipe causes breathing problems. *(Courtesy of Tim Gilles)*

SAFETY NOTE

A catalytic converter on a pre-OBDII vehicle can become so hot that it can start a fire if the vehicle is parked above dry grass.

An exhaust restriction can also cause an automatic transmission to shift harshly or late due to the resulting faulty vacuum signal or increased throttle pressure in the transmission.

Exhaust backpressure can be tested using a fuel pump vacuum/pressure tester connected to the smog pump lines into the exhaust manifold, or an adapter can be substituted for the EGR valve. According to TRW, removing the oxygen sensor to perform the test can give an inaccurate reading due to a venturi effect in the exhaust system. Specifications vary among manufacturers. As a general rule, pressure should not exceed 1.75 psi at wide-open throttle (WOT) under full load.

Breathing problems can also be found using a vacuum gauge (covered later in this chapter).

Testing for Compression Loss

For an engine to run, it must have three things:

- Sufficient compression
- Fuel (in a flammable ratio to air)
- Ignition (timed at the appropriate instant)

A quick way to check for uneven compression between cylinders is to disable the ignition system and crank the engine. An uneven cranking rhythm indicates unequal compression.

NOTE

If any of the following tests indicates a possible valve sealing problem, be sure to check the valves for correct clearance adjustment before proceeding with a repair.

SHOP TIP

A quick judgment of engine compression can often be made simply by cranking the engine with the ignition system disabled and listening for an uneven rhythm.

Compression Test

One of the most common and least expensive pieces of test equipment is the compression tester. A compression tester is simply a pressure gauge that is inserted into a spark plug hole.

There are two styles of compression testers. One is held in place while cranking the engine (**Figure 3.19a**). It is handy on in-line engines because it is fast and easy. The other type is the screw-in tester. Spark plugs use one of two thread sizes. The tester shown in **Figure 3.19b** has adapters to accommodate both thread sizes and different thread lengths. It has a Schrader valve, very similar to a tire valve, for saving the pressure in the gauge so that the technician can read it.

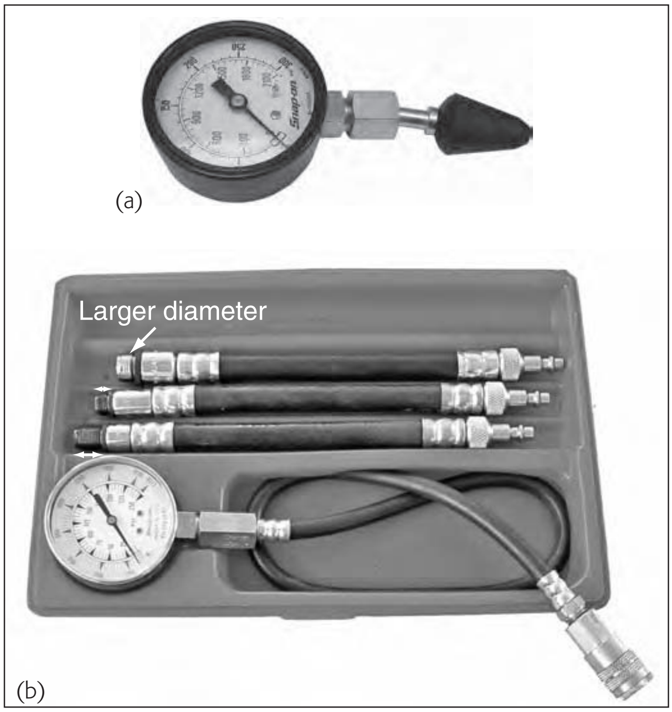


FIGURE 3.19 Compression testers. (a) This compression tester can be used when there is easy access to the spark plug holes. (b) A screw-in compression tester with adapters. The adapter shown on top is for larger-diameter spark plug threads. The two adapters beneath it are for different lengths (reaches) of the smaller spark plug thread size. *(Courtesy of Tim Gilles)*

The advantage of the screw-in tester is that it can be threaded into the plug hole, leaving the technician free to crank the engine.

NOTE

Ideally, the test is done with the engine at normal operating temperature. The battery must be fully charged for a compression test to be accurate.

Compression Test Procedure

- Use caution when removing secondary (spark plug) wires. First, twist the rubber boots to loosen them from the spark plugs.

FIGURE 3.20 A throttle depressor is used to hold the throttle open during the compression test. *(Courtesy of Tim Gilles)*

- Clean around all the spark plugs with compressed air. Then remove *all* spark plugs, so that the starter can crank the engine easily.
- Block the throttle in the wide-open position. This can be done with a throttle depressor (**Figure 3.20**).

SAFETY NOTE

Blocking the throttle open during a compression test prevents an engine with a carburetor from sucking fuel into the cylinders.

SHOP TIP

On some vehicles, when the starter is not easily accessible, a wire in an easy-to-reach location under the hood can often provide access to the starter circuit. Study the wiring diagram for the vehicle.

- Connect a remote starter between the S terminal on the starter solenoid and the ungrounded battery post.
- The compression test is done with the ignition switch in the "on" position to prevent damage to the electrical system on some vehicles. Disable the ignition system by pulling the battery-to-distributor wire on cars with electronic ignition. Follow the manufacturer's instructions.

CAUTION

If you crank the engine without disabling the ignition system and you have a spark plug wire disconnected, you can damage the ignition module or computer.

- Insert the compression gauge into a spark plug hole.
- Crank the engine through at least *four* compression strokes.
- Check and record each pressure reading.

The gauge will move four times, or with all the plugs removed you can hear each compression stroke as the compression in the cylinder being tested slows the engine.

CASE HISTORY

A group of students was performing a compression test on a teacher's car. During the compression test, the compression was checked repeatedly by several students (the throttle was not blocked open). After completing the compression test, they tried repeatedly to get the engine started. Finally a spark happened, fuel in the muffler of the flooded engine was ignited and a deafening explosion ripped the muffler apart.

Interpreting Compression Test Results. If all cylinders are performing equally and engine performance is acceptable, the engine passes the test. When compression test specifications are available, they are only an estimate. If specifications are not available, locate the compression ratio in the specification manual and use the following formula:

$$\begin{array}{cccc} \text{Compression Ratio} & \times & \text{Atmospheric Pressure} & + \\ \text{Atmospheric Pressure} & + & \text{5 (Volumetric Efficiency)} & \end{array}$$

For example, to figure out the approximate compression on an 8:1 engine at sea level (14.7 psi atmospheric pressure):

$$8.0 \times 14.7 + 14.7 + 5 = 137.3 \text{ psi}$$

Variations in compression among cylinders should be no more than 20%. When two cylinders next to each other have low compression, a blown head gasket is usually indicated. One or several cylinders with low compression and no apparent pattern of loss often indicates burned exhaust valves with rough idling as a symptom. At higher rpm, the rough running from the burned valve may disappear.

SHOP TIP

On an engine at idle, a burned exhaust valve will cause a piece of paper to be sucked repeatedly against the end of the exhaust pipe every time the bad cylinder's piston has an intake stroke.

Wet Compression Test. When cylinders show poor results, perform a wet compression test.

- Squirt about a tablespoon of oil into each low cylinder. The oil makes a seal around worn rings, boosting the compression reading.
- When cylinder readings are low but increase to normal during a wet test, a piston ring problem is indicated.

NOTE

Adding too much oil takes up volume and raises compression.

Running Compression Test

The running compression test, or *volumetric efficiency test*, is used when the cause of a cylinder misfire cannot be pinpointed or when an engine lacks power. First, perform a regular cranking compression test and record all of the results. Then install all of the spark plugs except for one and install a compression tester in that hole. Start the engine, and depress the release pin on the Schrader valve to allow the reading to stabilize.

NOTE

A typical running compression reading will be about one-half that of a cranking compression test. During cranking, intake manifold gauge pressure (vacuum) is zero and absolute pressure is about 15 psi. With the engine running, the intake manifold has around 15 inches of vacuum and 7.5 psi absolute pressure. At idle, the throttle plate is closed, the pistons are moving relatively fast, and the cylinder cannot fill as completely with air.

Snap Compression Test. The next step is to snap the throttle wide open and let the engine return to idle. When it is first snapped, the throttle plate is wide open while the piston speed is relatively low. This will result in a higher reading. The compression gauge will hold this reading until the Schrader valve is manually released.

Record your *snap compression test* readings. Typical readings will be around 80% of cranking compression readings. Lower snap readings mean that the intake system is restricted. Higher readings indicate an exhaust restriction. Problems in only one cylinder point to a worn cam lobe, broken valve spring, etc. Problems in all cylinders can be traced to a restriction in the air intake system or a plugged exhaust pipe or catalytic converter.

Cylinder Power Balance Test

To quickly locate weak cylinders, perform a power balance test. A compression test or leakage test (covered later) can be performed to pinpoint compression problems located by the power balance test.

Electronic Cylinder Power Balance Testing

Vehicles produced since the mid-1990s have sophisticated on-board diagnostics called OBD II. **Figure 3.21** shows a screen shot of a scan tool during an electronic power balance test. The scan tool disables fuel injectors rather than the ignition system. This eliminates the possibility of catalytic converter damage and oil dilution from raw fuel entering the crankcase during the test.

A cylinder that causes less drop than the others is not pulling its full load. Variations in rpm drop between cylinders should be less than 5%. A problem could be caused by the ignition system or fuel system, or the engine could have vacuum leaks or compression problems. Occasionally, rpm will *rise* as a cylinder is shorted out due to exhaust gas entering the intake manifold. This can be caused by an EGR valve that is open. (EGR should be closed at idle.) Like an air leak (also called a vacuum leak), EGR leaks cause a drop in manifold vacuum. But

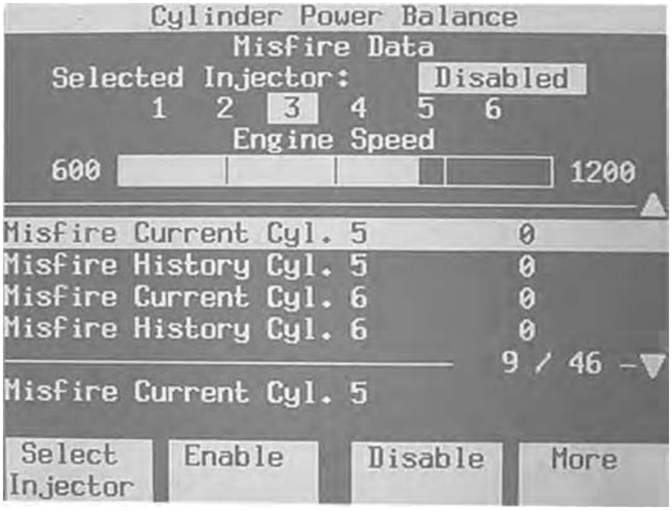


FIGURE 3.21 Electronic cylinder power balance. When an injector is disabled, engine rpm should drop. *(Courtesy of Tim Gilles)*

EGR leaks do not respond when you richen the mixture like air leaks do. The cylinder causing the rise in engine rpm is the one from which the exhaust gas for the EGR valve was picked up. Retest at cruise rpm and the problem will disappear.

CAUTION

Cylinders should be shorted for only a few seconds at most. Raw fuel entering the catalytic converter can cause it to overheat. Converter overheating can be minimized by disconnecting the smog pump during the test.

SHOP TIP

Using an oscilloscope when performing a power balance test allows the height of the firing lines to be observed. A poorly performing cylinder with a high firing line can indicate a lean air-fuel mixture; a low firing line can be indicative of low compression.

The cylinder power balance test can also be done with the engine running at higher speeds than idle. Compare results at low and higher speed.

An engine with a burned valve will perform poorly at low engine rpm but would improve at higher rpm. A leaking valve does not have as significant an effect at higher speed as it does at low speed because the air coming into the engine and leaving it is moving too fast and has a much higher volume.

A restriction in the intake, like that caused by a worn cam lobe, with hydraulic adjustment will result in little change in engine operation at idle. The problem will become gradually more pronounced as speed is increased.

VINTAGE ENGINES

Prior to OBD II, manual power balance testing was a routine procedure. On engines with contact point distributors, it was a common practice to disconnect each spark plug wire on an idling engine and note the rpm drop. You can perform a power balance test on cars equipped with electronic ignition electronically. Allowing the coil to produce ignition sparks while spark plug cables are disconnected can increase current flow in the coil to the point where the coil and ignition module can be ruined. Engine analyzers and hand-held scan tools have a feature that automatically shorts out cylinders, one at a time, without removing spark plug cables.

It is important that each cylinder be shorted for the same length of time and that the speed of the engine returns to normal before shorting the next cylinder. The test is most effective when done at the lowest engine speed possible (500–600 rpm).

Vehicles equipped with computer-controlled fuel systems will automatically raise the engine idle to compensate as each cylinder is grounded out. Disabling the computer's spark advance is required to perform this test. Consult service literature for the correct procedure.

Cylinder Leakage Test (CLT)

The cylinder leakage test can accurately pinpoint causes of leakage. Regulated compressed air is introduced into the cylinder through its spark plug hole (**Figure 3.22**). The piston is positioned at top dead center (TDC) on the compression stroke, ensuring that both valves are completely closed.

- It is better to perform a cylinder leakage test when the engine is warm and the rings are sealed with oil. Otherwise, a small amount of movement at TDC can allow the piston ring to move off its ring land, allowing leakage (see Chapter 11).
- An acceptable leakage reading on the tester's gauge is usually less than 10% to 15%, although vehicles with up to 30% leakage might still be performing to the owner's satisfaction. The owner might not notice the power difference until it is restored after an overhaul, because the loss in power has happened gradually.

If a cylinder shows high leakage, listen to locate the sound of the leaking air. The following lists cylinder leakage test results.

Here are some possible locations for leaking air and the likely causes:

- Oil filler = leaking rings or piston
- Manifold intake = leaking intake valve
- Exhaust pipe = leaking exhaust valve

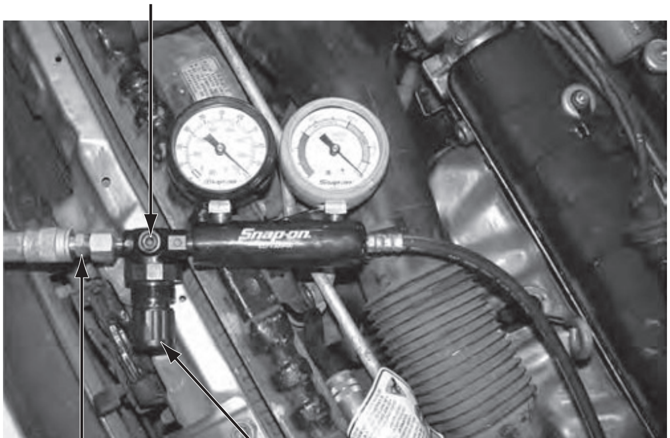


FIGURE 3.22 A cylinder leakage tester is connected to the cylinder through a hose to the spark plug hole. *(Courtesy of Tim Gilles)*

- Bubbles in the radiator = blown head gasket, or a crack in the head or block, which allows the regulated air to enter the cooling system

SHOP TIP

If leakage is past the piston rings, the PCV valve could allow air to travel into the intake manifold where it can cause the technician to mistakenly suspect a leaking intake valve. To avoid this situation, remove the oil filler cap, or disconnect the vacuum line to the PCV valve or pinch it with pinch pliers.

The leakage tester offers three advantages over a compression test:

1. The test can be performed on an engine that is removed from a car (such as an engine purchased at a salvage yard).
2. The exact source of leakage can be pinpointed before engine disassembly.
3. A racing camshaft will not affect the results of the test. It would cause lower readings on the compression test, however, because engine vacuum is lower at cranking speeds with a racing cam.

NOTES

- If a high mileage engine tests OK on the power balance test and has compression within expectations but has excessive cylinder leakage test results, carbon deposits in the combustion chamber could account for the relatively good compression, although the engine will probably have excessive blowby and may lack power.
- When a cylinder bore has considerable taper wear on the top, the reading can be improved if the piston is moved slightly past TDC into a less worn area.

Engine Vacuum

Intake manifold vacuum can be very useful in determining engine problems. Vacuum readings compare pressure in the intake manifold to atmospheric pressure. Vacuum is measured in either inches of mercury (in. Hg) or millimeters of mercury (mm Hg) or kilopascals (kPa). The vacuum gauge (**Figure 3.23a**) is connected to a manifold vacuum source (**Figure 3.23b**).

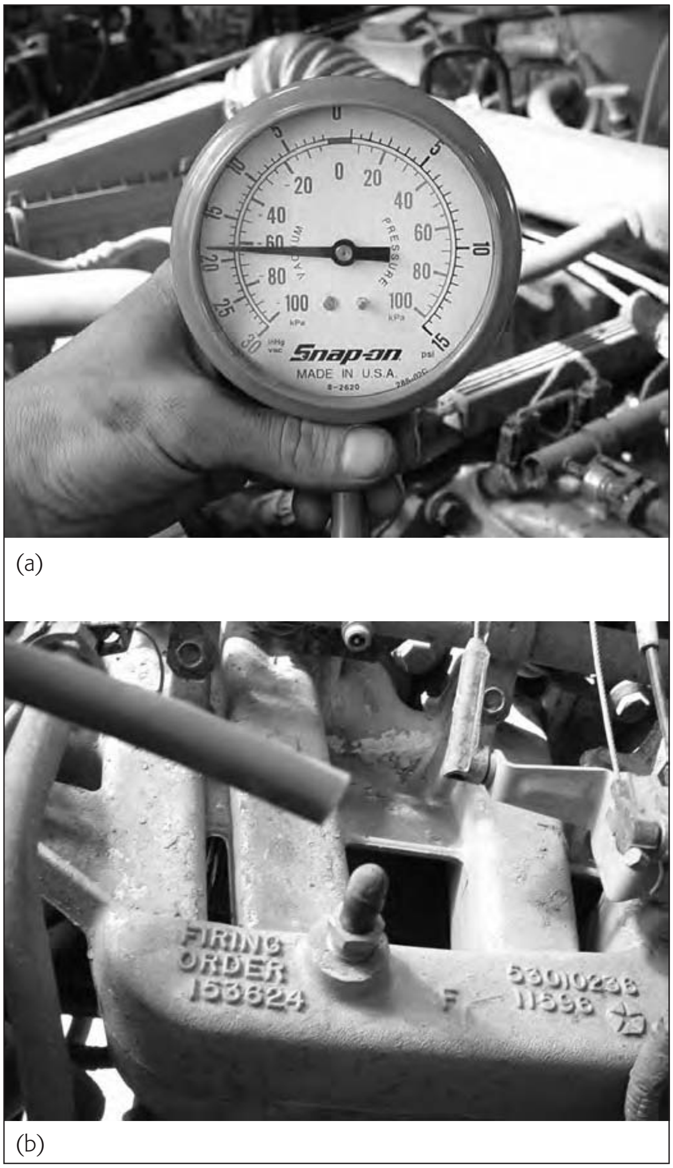


FIGURE 3.23 (a) A vacuum gauge reads pressure when the needle moves clockwise and "vacuum" when the needle moves counterclockwise. (b) Connect the vacuum gauge to an intake manifold vacuum source. *(Courtesy of Tim Gilles)*

Throttle plate opening controls the amount of air that can enter the engine. Movement of the accelerator pedal opens or closes the throttle plate, changing engine vacuum. For a stock engine, vacuum should range from 16 to 22 in. Hg at idle, and the needle should be steady (**Figure 3.24**). An engine has higher vacuum when it is operating under light load. Vacuum drops to zero under WOT.

- At idle, with the throttle plate nearly closed (**Figure 3.25a**), engine vacuum will be high.
- At medium throttle opening, when cruising (**Figure 3.25b**), engine vacuum will be in the neighborhood of 8 to 10 inches.
- At WOT (**Figure 3.25c**), engine vacuum is zero.

NOTE

Vacuum readings will drop approximately 1 inch for each 1000 feet above sea level.

A leaking intake manifold gasket can cause an engine to idle rough, especially when cold, before oxygen sensor feedback begins. The oxygen sensor can compensate for small vacuum leaks to a certain extent. At speeds above idle, symptoms of a leaking

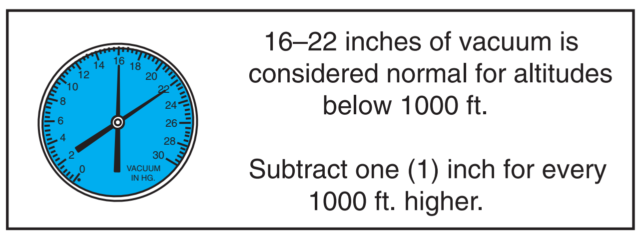


FIGURE 3.24 Normal engine vacuum.

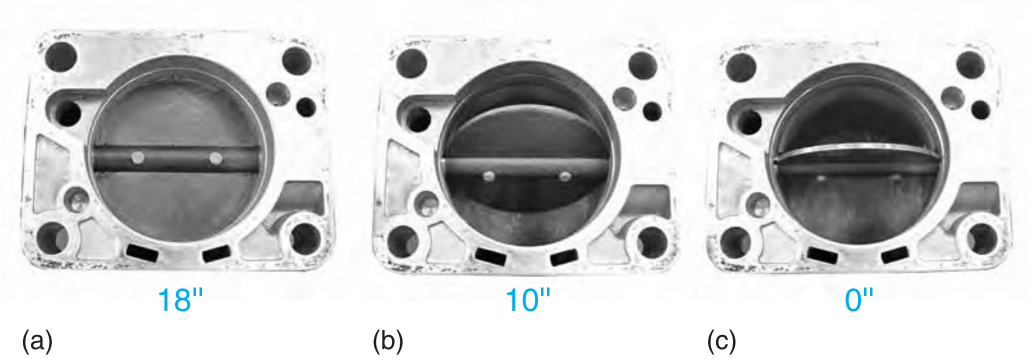


FIGURE 3.25 (a) Idle vacuum is high. (b) Cruise vacuum is moderate. (c) At wide-open throttle, vacuum is zero. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Ignition timing is adjustable on engines without computer controls. When low, steady vacuum is found, check the ignition timing. Late/retarded ignition timing can cause an engine to run hot. If the timing is retarded a great deal, check the camshaft timing (see Chapter 10). Excessive timing chain slack can allow the timing chain to skip a tooth on its sprocket. Because the distributor is usually driven by the camshaft, this shows up as late ignition timing during an ignition timing check.

intake manifold diminish because the size of the leak is proportionally less as the engine breathes more air.

A leaking intake manifold gasket can result from sloppy cleanup of gasket surfaces during manifold installation, from failing to clean out bolt holes, or from bottoming out bolts that are too long.

A car with an oxygen sensor feedback fuel system can run rough when cold but run fine after warm-up when the computer responds to the oxygen sensor signals by compensating with a richer air-fuel mixture.

One vacuum test for a manifold gasket leak is to pinch off the two PCV valve hoses—the one to the intake manifold and the breather hose to the air cleaner—then run the engine. If there is vacuum at the oil filler opening, an intake manifold-to-crankcase vacuum leak is indicated.

NOTE

Low vacuum at idle is normal for an engine with an aftermarket high-performance camshaft. Vacuum will increase as rpm is raised. This is caused by valve overlap, which is discussed in Chapter 10.

To test for *weak piston rings* (**Figure 3.26**):

- Raise the engine speed to about 2000 rpm.
- Snap the throttle closed and watch for an increase of 2 to 6 inches of vacuum above normal.
- Worn rings will not increase vacuum sufficiently during deceleration. Generally, the higher the rise, the better the condition of the rings.

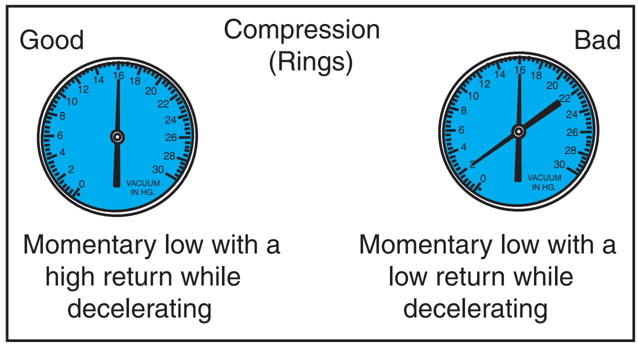


FIGURE 3.26 Vacuum readings for weak piston rings.

Sticky valves are indicated when the needle drops quickly or drifts. This could be because valves are hanging up in their guides rather than closing freely (**Figure 3.27**). The movement will have no apparent rhythm.

Leaking valves (**Figure 3.28**) are indicated when the needle drops at regular intervals. A power balance test will pinpoint the low cylinder.

Bad Valve Springs. Sometimes valve springs that are too short or too weak have been installed by accident. Otherwise, valve springs weak enough to cause this problem are rare.

To test for weak valve springs with a vacuum gauge (**Figure 3.29**):

- Raise engine rpm slowly to 2000.
- Look for rapid fluctuations of the needle as speed increases.
- An exhaust analyzer will have a good hydrocarbon (HC) reading at idle but bad under acceleration.

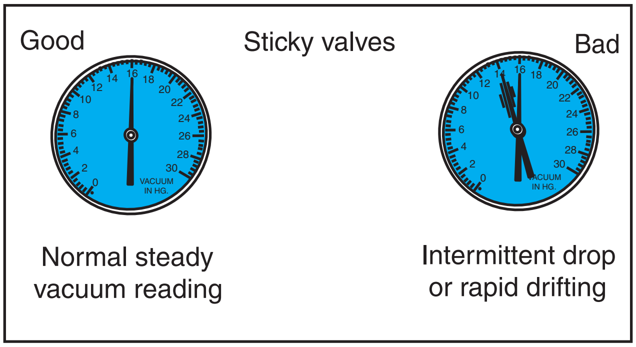


FIGURE 3.27 Vacuum reading for sticky valves.

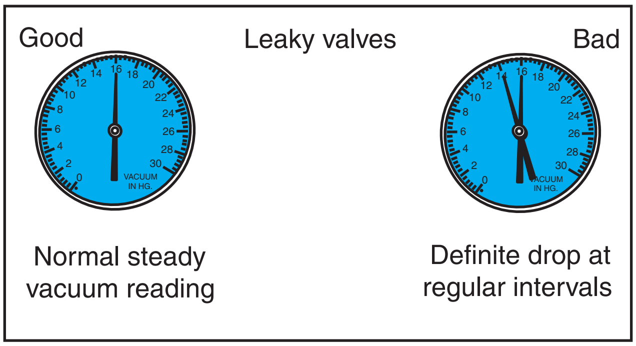


FIGURE 3.28 Vacuum reading for leaking valves.

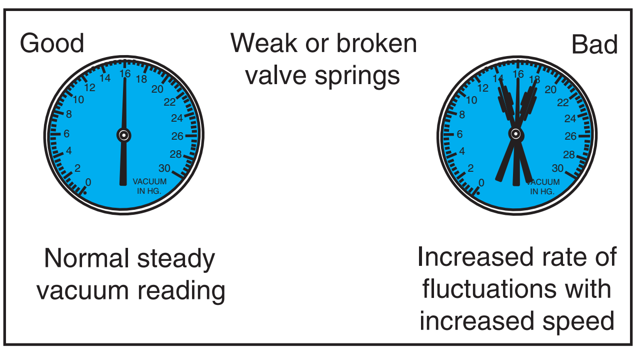


FIGURE 3.29 Vacuum reading for bad valve springs.

When an engine with weak valve springs is accelerated, hydraulic lifters can overfill (pump up). There is no noise, but the engine will run rough when it returns to idle.

According to one Auto Engine Rebuilders Association (AERA) bulletin, incorrect valve spring tension can result in a rough idle that is only apparent on initial cold startup. OBD II engine computer systems sometimes sense this misfire and cause the malfunction indicator lamp (MIL) on the dash to illuminate.

Restricted Exhaust. To test for a *restricted exhaust* (**Figure 3.30**):

- Raise the engine rpm quickly to 2000 to cause the vacuum reading to go momentarily low and then release the throttle quickly.
- Vacuum should return smoothly and quickly to higher than normal levels.
- A slow, hesitating return can indicate a breathing restriction.

Other Causes of Low Vacuum. Port fuel injected engines use O-rings to seal each individual fuel injector where it enters an intake port (**Figure 3.31**). When an O-ring leaks, the resulting vacuum leak and lean air-fuel mixture in that cylinder cause a rough idle (**Figure 3.32**).

If an engine is equipped with an air pump for emission control, be sure that it does not have a

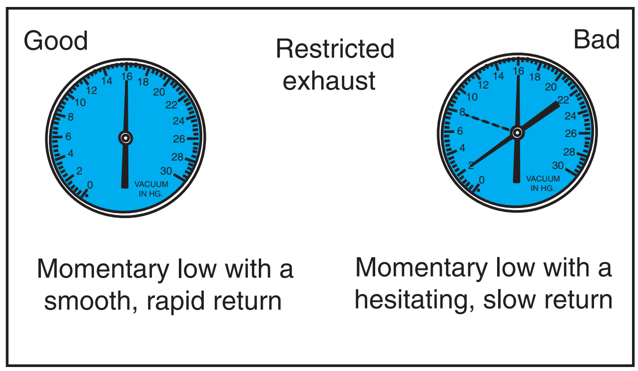


FIGURE 3.30 Vacuum reading for restricted exhaust.

FIGURE 3.31 O-rings seal the fuel injectors where they enter the intake ports. *(Courtesy of Tim Gilles)*

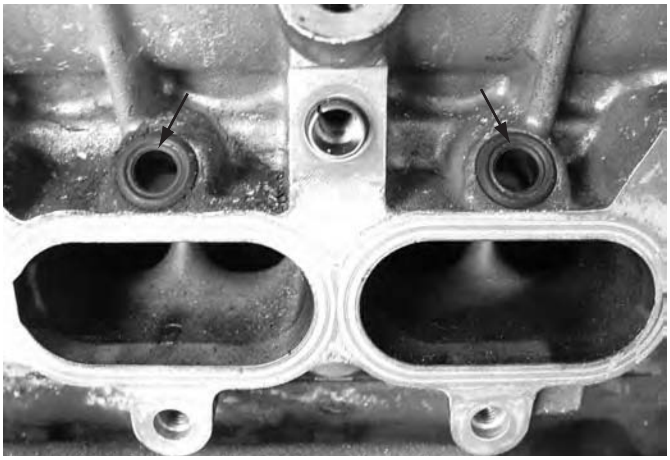


FIGURE 3.32 Fuel injection O-rings can become hard and brittle with age, resulting in a rough idle, especially during open-loop operation when the engine is first started and the computer is not receiving feedback from the oxygen sensor. *(Courtesy of Tim Gilles)*

defective anti-backfire valve, which can cause low vacuum.

Cranking Vacuum Test

A **cranking vacuum test** looks for internal air leaks. The engine must be sealed off for the test to be effective. The throttle plate must be all the way closed and the crankcase ventilation system must be plugged off.

To perform the test:

- Close the throttle all the way.
- Plug the breather hose to the air cleaner.
- Disable the ignition system.
- The engine should produce a minimum of 3 inches of vacuum while cranking. Most engines will produce far more cranking vacuum than this.

During cranking, the needle on the gauge should be steady. The steadiness of the needle is often more important than the amount of vacuum on the gauge.

SHOP TIP

Pull the PCV and cover its opening with your thumb. Cranking vacuum should rise. If it does not, there is a problem with the PCV system.

Pressure Transducer Testing

Engine condition can be tested electronically using a pressure transducer and a digital storage oscilloscope. Cylinder pressures can be monitored electronically with a pressure transducer attached to the spark plug hole using a compression tester adapter (**Figure 3.33**). Exhaust pressure wave testing is also possible using a pressure transducer attached to the exhaust pipe with a dual venturi adapter that measures the pressure wave in both directions.

Propane Enrichment Tester

A propane enrichment tester can provide *false fuel* to the intake manifold so the engine can be started and run when the fuel system is not working. A propane bottle is used with a special attachment (**Figure 3.34**) to meter propane through a hose

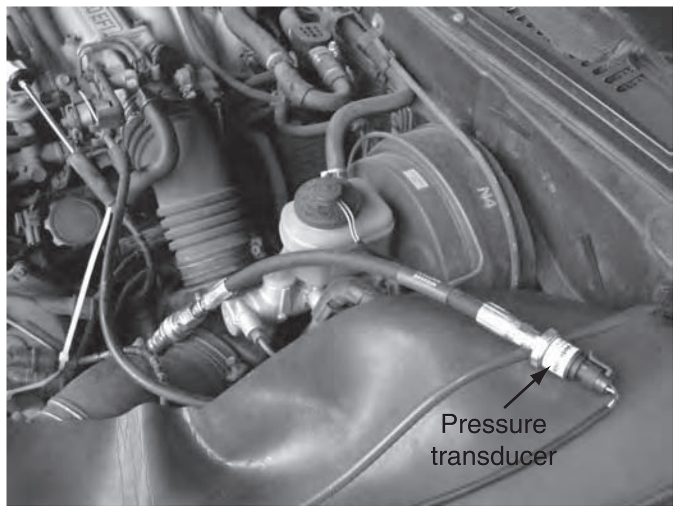


FIGURE 3.33 A hose threaded into the spark plug hole is connected to a pressure transducer so pressure waves can be observed on a digital storage oscilloscope. *(Courtesy of Tim Gilles)*

FIGURE 3.34 A propane bottle is used with this attachment to meter propane into the intake manifold, providing *false fuel*. *(Courtesy of Tim Gilles)*

into the intake manifold. Propane enrichment can also be used to test for an intake manifold leak. Close off all of the PCV system hose and see if engine idle changes when propane or acetylene gas is put into the oil filler. This means the gas is getting in through an intake manifold leak and changing the way the engine operates.

In rare instances, if the transmission manual shift valve has become disconnected during an engine swap, an automatic transmission malfunction can cause symptoms mimicking engine breathing problems.

CASE HISTORY

A technician removed an engine from a Cadillac to replace it with a rebuilt short block. While he was waiting for the replacement engine to come, the vehicle was moved to a parking spot to free up the work area for another job. After the new engine was installed, it would not accelerate beyond about 1800–2000 rpm (stall test speed). After numerous tests were performed (cam timing, valve adjustment, cylinder leakage, fuel injection, etc.), the company that rebuilt the engine suggested that the technician remove the engine and swap it with another. Luckily, the technician still did not believe that the engine was at fault. The car was on the hoist so he tried to accelerate the engine while it was in *Drive range* with the parking brake disconnected. The problem disappeared and the engine ran fine. The technician disconnected the torque converter from the flexplate and ran the engine to double check. It turned out that the transmission had been recently rebuilt. A locating pin in the manual valve had been left out. There probably would never have been a problem had the engine not been removed and the vehicle moved. When the transmission was shifted without the engine in place, it tilted and became engaged both in park and a gear range at the same time.

In the preceding case, had the already rebuilt engine been exchanged, the repair shop would have been liable for the cost because nothing was wrong with the original unit. Needless to say, this is a very rare occurrence. But rare instances do occur and diagnostic ability is extremely important to a shop's profit margin.

Smoke Testing

Smoke testers are popular diagnostic devices for finding vacuum, oil, cooling, and exhaust leaks (**Figure 3.35**). A smoke machine generates thick, white smoke (**Figure 3.36**) at a pressure of 1–1.5 psi. In the event of an increase in pressure above that amount, the machine vents off the excess smoke. A refillable smoke chamber allows for 200–300 tests. Some machines also use UV dye that can leave a tell-tale trace that can be located using a black light.

FIGURE 3.35 A smoke tester can be used to pinpoint vacuum, oil, and exhaust leaks. *(Courtesy of Tim Gilles)*

FIGURE 3.36 This smoke was generated by a smoke tester. *(Courtesy of Tim Gilles)*

Finding Vacuum Leaks. Vacuum leaks are located while the engine is off with the throttle closed. Disconnect the vacuum hose from the PCV valve and pump smoke into the PCV hose. Sometimes it is easier to disconnect the hose from the power brake booster and use that as an access point. An engine can be filled with enough smoke for a thorough check in about a minute to a minute and a half.

Finding Exhaust Leaks. For exhaust leaks, a soft cone adapter is used (**Figure 3.37**). An exhaust system takes about 2 minutes to fill with smoke. The smoke machine can even detect smaller exhaust leaks before they can be heard. Manifold leaks can also be tested using smoke and a mirror. Smoke from cracks show up better when the engine is cold.

Finding Coolant and Oil Leaks. Finding coolant leaks with smoke can be done with the cooling system drained. Potential oil leak locations can be found by putting smoke in through the dipstick tube. First, seal the crankcase and pinch the PCV hose so smoke does not leak back through the intake manifold.

Oscilloscope Tests. The use of the oscilloscope is not discussed in detail in this book. This section is included to augment the oscilloscope skills of those familiar with its use. The scope may be used to help find breathing problems. A leaner air-fuel mixture causes a higher resistance to spark, which raises the height of the spark plug firing lines in response to increased voltage.

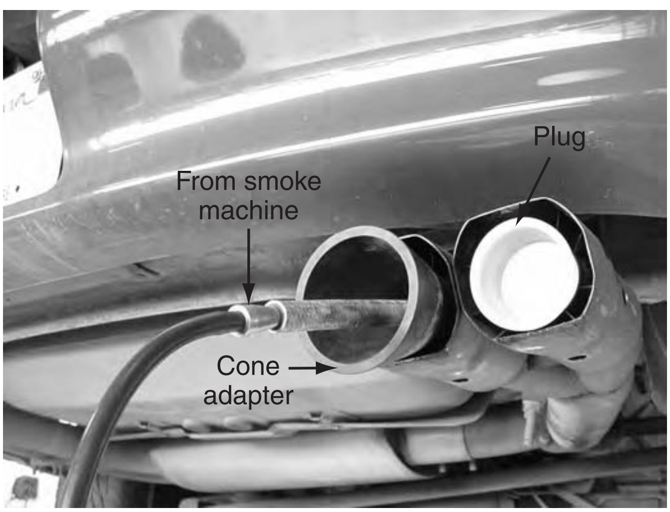


FIGURE 3.37 A cone adapter and plug used with a smoke machine for locating exhaust system leaks. *(Courtesy of Tim Gilles)*

A scope reading can also reveal a worn timing chain in engines without timing chain tensioners. When slack develops in the chain, erratic changes appear in the dwell section of a scope pattern with the engine idling. If the engine is momentarily accelerated, the problem disappears. Further investigation will be required because this can also be due to worn distributor bushings.

A loose timing chain can also show up during an ignition timing check. When the timing mark is moving erratically on the vibration damper at idle, it will stabilize as engine speed is raised and slack is removed from the drive side of the timing chain.

Bore Scopes and Video Inspection Devices

A bore scope or video inspection device can be used to view inside the cylinder. The spark plug is removed and the scope is inserted to view the combustion chambers, the valves and valve deposits, and the condition of the top of the piston and cylinder walls.

Emission Analyzer Test

Shops that do engine performance and emission control work have an infrared exhaust gas analyzer (**Figure 3.38**) that can be used to check for a collapsed piston skirt or piston ring or cylinder damage. If an engine has a PCV valve, remove it from the valve cover or other crankcase entry point and insert the analyzer probe. With the engine idling, individually short out each cylinder and record the HC reading. The HC reading should increase as each cylinder is shorted out, but a significantly higher reading indicates a problem cylinder.

ENGINE NOISES

Noises can be located by listening through a stethoscope (**Figure 3.39**). The end of a large screwdriver, a piece of hose, and a long wooden dowel are other listening tools to help pinpoint noises. An amplified stethoscope is very effective as well (**Figure 3.40**).

SHOP TIP

When checking for exhaust leaks, remove the metal end of the stethoscope and listen at the end of the hose.

FIGURE 3.38 A five-gas infrared analyzer. *(Courtesy of Vetronix Corp.)*

FIGURE 3.39 A stethoscope.

It is important to try to determine the location of noises before disassembling the engine. There have been cases where engines have been disassembled, inspected, and rebuilt, and when reinstalled in the car, still had the same problem. Pinpointing the origin of the noise might have resulted in more careful scrutiny of the offending part while the engine was apart.

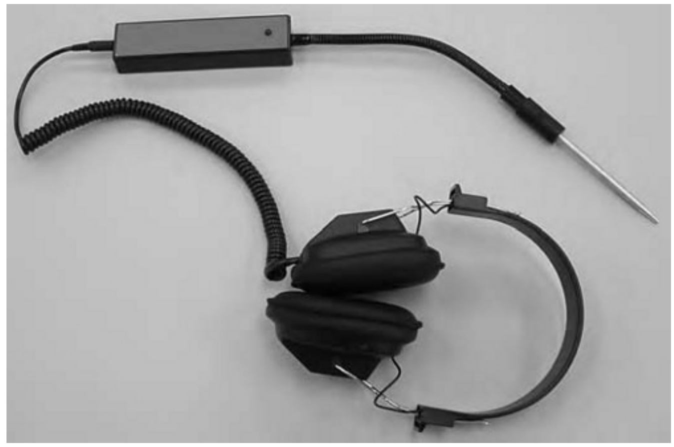


FIGURE 3.40 An amplified stethoscope. *(Courtesy of Tim Gilles)*

SAFETY NOTE

Both the stethoscope and screwdriver are electrical conductors. They should be used *with caution* around electrical connections such as those located on the back of the alternator.

Accessory Noises

Noises are often transmitted from their origins to other locations and can be difficult to locate.

Accessories often cause noises that can be mistaken for other problems. Be sure to check alternators, smog pumps, air-conditioning compressors, and coolant pumps carefully.

Belts are a common source of noise. If you suspect a belt of making noise, disconnect the belt and run the engine for a short time, or spray soapy water on the belt while the engine runs to see if the noise changes.

A fan clutch on the coolant pump can cause a serious-sounding noise that is hard to pinpoint. A stethoscope cannot be used to listen to the noise because the fan is spinning when the engine runs. Sometimes the extra looseness in the fan clutch can be felt when the engine is off. To isolate the problem, remove the drive belt and run the engine.

Crankshaft Noises

Crankshaft noises can be caused by a variety of things. They are generally deeper in pitch than other engine noises. It is important to isolate the source of the noise so that an accurate diagnosis can be made.

- *Front Main Bearing Knock*. Excessive front main bearing clearance results in a heavy knock when the engine warms up. The knock is generally most pronounced at 1500–2500 rpm. Loosening accessory drive belts will often reduce the intensity of the knock.

CASE HISTORY

A technician working in a dealership repaired an engine that had a worn crankshaft. The crankshaft was removed and sent to a machine shop for regrinding. After the job was completed, the engine had a minor knock that was diagnosed as a front main bearing. The technician pulled the oil pan and measured all of the crankshaft clearances with Plastigage. The front crankshaft bearing had 0.0025" clearance, enough to make noise. He cleaned the main bearing cap and lightly sanded the parting surface with very fine sandpaper to remove the film of dirt that had accumulated there during the cleaning process. When he rechecked the clearance it was 0.0015, which was within specifications. After reassembly the noise was gone. In the future, he always checked crankshaft clearances carefully during initial assembly. Some manufacturers have bearing shells that have a 0.0005" thinner bearing back. These can be combined with a standard shell to adjust the bearing clearance more precisely.

- *Thrust Bearing Knock*. End thrust is movement of the crankshaft in a forward and backward direction (see Chapter 12). The crankshaft has a machined surface that controls end thrust. It can be worn, allowing the crank to move back and forth. Excessive end thrust will cause a clunk to happen when the vehicle leaves a stop sign. This is usually more pronounced on vehicles with standard transmissions.
- *Rod Knock*. Excessive clearance at a connecting rod journal causes a rod knock. During a cylinder power balance test, the intensity of the knock will diminish, or disappear altogether, as the offending cylinder's spark plug is grounded out. This condition is sometimes accompanied by low oil pressure, especially at idle.

Related Noises. A loose flywheel, torque converter, or vibration damper can cause a very serious-sounding noise. Torque converter flexplates sometimes crack, causing a serious-sounding sharp knock. To test for this:

- Run the engine at fast idle about 2000 rpm.
- Turn the key off and then on, listening for a knock as the engine restarts.
- Shut off the engine and use an inspection mirror (**Figure 3.41**) to look for a crack in the flexplate.

SHOP TIP

Shining a flashlight into the mirror will bounce the light onto the flexplate so you can look in hard-to-see locations.

Figure 3.42 shows a cracked flexplate. A broken flexplate often results from misalignment with the engine, either sideways or in height. Sideways misalignment can be caused by uneven mounting of the flexplate to the crankshaft or by dirt or a burr between the engine and transmission.

When access is available from the bottom, an effective test for height misalignment is to use a dial indicator mounted to the crankshaft. Rotate the crankshaft to sweep the indicator against the bore where the automatic transmission pump mounts. A machinist can correct this using eccentric sleeves that fit over the alignment dowels. The transmission housing is drilled oversize to match.

Bent Oil Pan. A bent oil pan can cause a deep sound when the connecting rod hits the dented spot. Complete engines can weigh several hundred pounds. It is not uncommon for engine sheet metal, such as an

FIGURE 3.41 An inspection mirror. This one telescopes and has a replaceable mirror on a pivoting head.

FIGURE 3.42 A cracked flexplate. *(Courtesy of Tim Gilles)*

oil pan or valve cover, to become dented when the engine is removed or replaced in the vehicle.

CASE HISTORY

A student completed a complete engine rebuild on an in-line six cylinder engine. After installing the engine and priming the lubrication system, he started it up. The engine had a very serious knock that could be heard with a stethoscope as coming from the oil pan. The student was very discouraged and wanted to remove the engine from the vehicle to repair the problem. The instructor noticed an indentation in the oil pan and suggested that the student remove the pan to inspect it. Examination of the inside of the oil pan showed a shiny spot where the crankshaft had been hitting it. Knocking out the dent fixed the problem.

Rod Side Clearance. Excessive clearance on the sides of connecting rods can sometimes cause a ticking sound that resembles a valvetrain noise but comes from the crankcase. The noise can go away during a power balance test. To correct this problem, General Motors supplies connecting rods that are 0.010″ wider than stock for a few engines. Spark knock (discussed later in this chapter) can intensify noise caused by excessive rod side clearance.

EGR Valve Knock. When there is a low-speed knock, check the EGR valve by manually opening the valve and accelerating the engine to about 2000 rpm to see if the noise disappears. If it does, replace the EGR valve.

Piston Noises

There are several types of piston noise, including cracked pistons, piston slap, piston pin noise, and others.

SHOP TIP

Retarding the spark timing will often reduce the intensity of a piston noise. On the other hand, grounding out the plug during the power balance test can increase the noise. A bad connecting rod reacts to ignition grounding in the opposite way, making less noise.

Cracked Piston. A cracked piston is sometimes the source of noise (**Figure 3.43**).

- The noise is a higher pitched noise than a crank-related noise and can be confused with a valvetrain noise, except that it occurs at a faster rate.
- Cracked pistons are often the result of a broken timing chain or incorrect valve timing, which can allow a valve to strike a piston (see explanation on interference engines in Chapter 9).

Piston Slap. Piston slap is caused by excessive clearance between the piston skirt and the cylinder wall.

FIGURE 3.43 A cracked piston. *(Courtesy of Tim Gilles)*

- Sometimes the noise gets louder during acceleration and goes away when the engine warms up.
- Piston slap at TDC and bottom dead center (BDC) causes oval wear as the piston rings scrub the sides of the cylinder.
- Look for worn or collapsed piston skirts when excess oval cylinder wall wear is found.

Piston Pin Noise. Noise from excessive piston pin clearance makes a "double click" sound at idle or fast idle that usually diminishes or goes away when the engine warms up.

- Pin noise can become more intense after the installation of new piston rings. The noise will gradually diminish as the rings wear.
- With the engine running at the speed where the most noise occurs, grounding the spark plug wire can increase the noise even more. The noise level might not increase, but it will not decrease.

  Piston inertia is what causes the noise, which is why the noise does not go away when the spark plug is shorted out.

Other Piston Sounds

- *A broken ring* can rattle during acceleration.
- A cylinder ring ridge that is not removed when new rings are installed can cause a clicking sound when the square edge of the new ring hits against the rounded edge of the ring ridge (**Figure 3.44**). This can also force a ring land down on the second ring (**Figure 3.45**). The result is a stuck second compression ring or a broken ring or ring land.

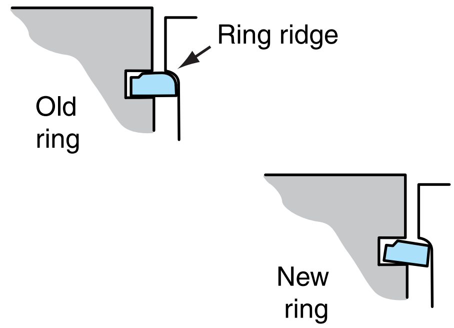


FIGURE 3.44 Failure to remove the ring ridge. A new square ring will strike the old rounded ridge.

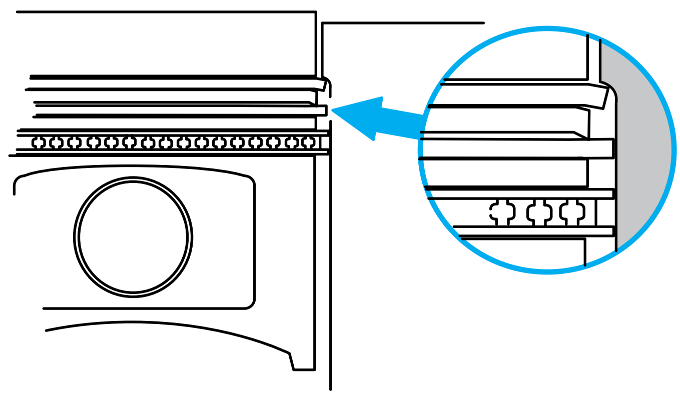


FIGURE 3.45 The ring land above the second ring can be forced down.

Valvetrain Noises

Valvetrain noises are the most common engine noises, making a loud "ticking" sound. Pushing with your finger placed on the valve spring retainer while the engine idles will produce a shock each time the loose valve hits its seat.

VINTAGE ENGINES

- *Noisy Fuel Pump.* A defective mechanical fuel pump makes a noise that resembles a bad hydraulic lifter. The noise will be loudest at idle speed when little fuel is being used by the engine.
- *Loud Rocker Arms.* Lack of lubrication to rocker arms can cause a loud, "squeaky" sound in some older engines. This problem is uncommon in modern engines, partly because of the better oils in use today.

NOTE

Valvetrain noise occurs at half the speed of engine rpm. This is because the camshaft only turns once for every two turns of the crankshaft.

Valvetrain noises can result from a variety of sources.

- *Excessive Valve Stem-to-Guide Clearance*. Noise from excessive valve stem-to-guide clearance can be pinpointed with the engine running. Squirt oil on the suspected guide to take up the clearance and stop the noise.

NOTE

Be careful not to adjust all of the clearance out of a hydraulic valve lifter—this can hold a valve off its seat.

- *Sticking Valve*. A sticking intake valve can result in a popping noise at the throttle plate as burning gases escape into the intake manifold past the valve.

SHOP TIP

To find a sticking valve in a pushrod engine, connect a timing light to one spark plug wire at a time and run the engine with the valve cover removed. The strobe action of the light will catch the offending valve in the open position.

- *Worn Cam Lobe*. When an engine has a smooth idle but runs rough under acceleration, "popping back" through the intake valve, this can often be traced to an exhaust lobe on the cam that has "gone flat." Pressure builds up on the power stroke and cannot escape during the exhaust stroke, so it goes back up the intake port. The lobe can go bad fairly quickly once it starts to wear, so the condition seems to occur overnight.

The popback can be more severe with port fuel injected engines, because each individual injector is near an intake valve port. The drop in suction from the offending cylinder does not cut the flow of fuel as it would in a carbureted engine or an engine with throttle body injection.

NOTE

If you hold your hand above the air intake throttle plate on an engine with a bad cam, it can get wet with fuel.

- *Timing Components*. Valvetrain noises coming from inside the timing cover can be caused by a bad timing chain or chain guide (**Figure 3.46a**) or a loose sprocket or gear. The noise usually is a rattle or knock that becomes louder when decelerating. For engines with a timing chain tensioner, a worn chain can become loose enough on the sprocket to rattle whenever the engine floats or cruises between load and coast conditions. In severe cases, a chain can actually wear a hole in the timing cover, resulting in an oil leak (**Figure 3.46b**). Severely worn cam bearings can also be the cause

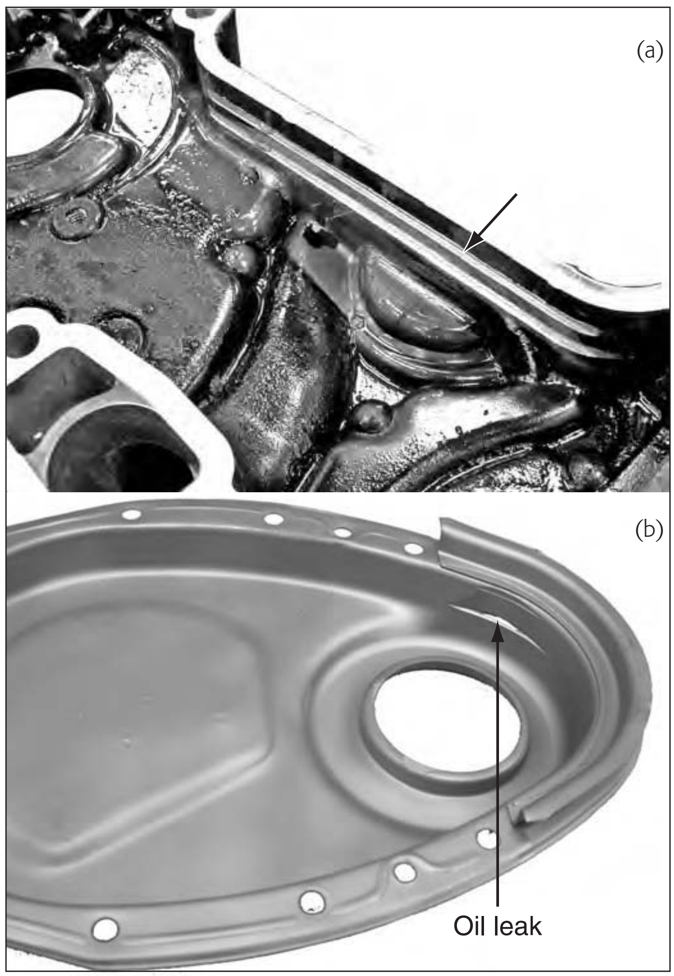


FIGURE 3.46 (a) The wear on the inside of this timing cover happened when the timing chain guide broke. The engine was very noisy. (b) A worn timing chain rubbed on this timing cover, causing noise and an oil leak. *(Courtesy of Tim Gilles)*

of excessive timing chain slack. Depending on the design of the lubrication system, this problem can also be accompanied by low oil pressure at idle.

- *Excessive Valve Lash*. When an engine has adjustable mechanical valve lash clearance, excessive valve lash can occur due to wear between valve-train parts. Periodic valve adjustment is part of the service requirements on these engines.

Lifter Noise. A common valve noise is caused by a noisy valve lifter. Sometimes this occurs when the engine is first started, because some lifters have lost their oil while the engine was off. Whenever an engine is shut off, some of the valves are held open, putting spring pressure on lifters to bleed them down after startup. When pressurized oil reaches the lifter, the noise goes away. This is considered normal, if the noise goes away in less than 15 seconds. Some other lifter noises and their causes are:

- *Intermittent noise at idle or low speed*. This can often be traced to dirt or wear in the lifter check valve (see Chapter 9).
- *Noise at idle that goes away at higher speeds*. This usually indicates excessive wear between the lifter body and its plunger. This noise could also be caused by low oil pressure or oil that is contaminated with fuel.
- *Quiet at idle but noisy at high speed*. The oil could be full of air. This occurs when the oil level is so high that the crank whips the oil, filling it with air. It could also happen because there is air leaking into the suction side of the oil pump (see Chapter 14).

Lifter noise at all engine speeds can be due to:

- Dirt or varnish buildup inside the lifter
- Worn parts such as worn rocker arms or a cam lobe that is going flat
- An insufficient oil supply
- Oil too thin
- Oil pressure too low

SHOP TIP

Lifters that stick because of varnish buildup can sometimes be loosened by squirting chemical spray cleaner through the hollow pushrod, where it contacts the bottom of the rocker arm.

Spark Knocks, Carbon Noise, and Abnormal Combustion

During normal combustion, a flame front travels at a speed of from 50 to 250 meters per second (depending on rpm and load) to *push* the piston down in the cylinder. This is very fast but it is *not an explosion*.

- During cranking, pressures in the cylinder are usually around 140–170 psi.
- Following ignition, cylinder pressures reach about 400 psi at TDC and peak at about 600 psi around 15° after TDC.
- Normal burning of the fuel takes about 1/300 of a second.
- By the time the piston has traveled halfway down its bore, the flame has consumed most of the fuel and oxygen.

During normal combustion (**Figure 3.47**), the air-fuel mixture burns in a controlled manner to steadily force the piston down in the cylinder. Abnormal combustion can cause noise, shock damage, and burning of parts. Sounds caused by spark knocks can be mistaken for worn parts and can cause engine damage if ignored.

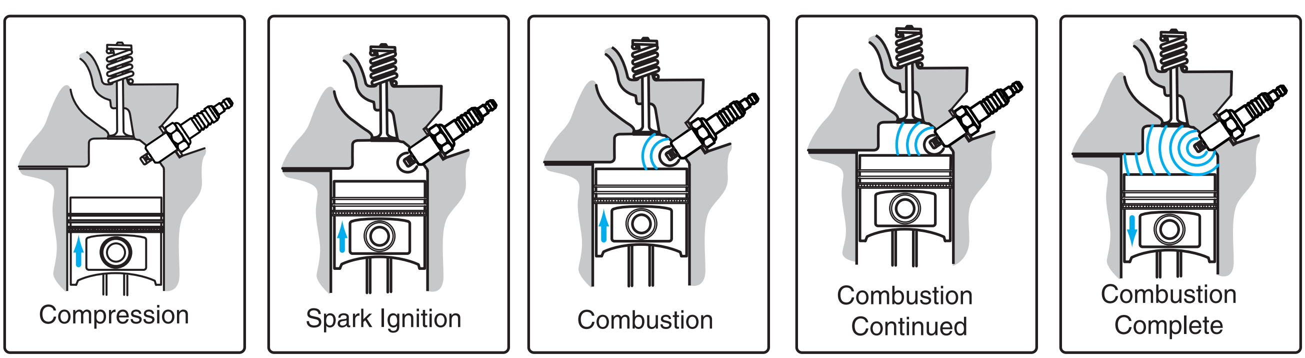


FIGURE 3.47 Normal combustion.

There are two common abnormal combustion conditions that can cause spark knock and engine damage: preignition and detonation.

Preignition

Preignition allows the high heat of combustion to remain for too long on engine parts. The rise in combustion chamber temperature can "burn" parts such as valves, pistons, and head gaskets.

Preignition occurs when the air-fuel mixture ignites before the regular spark occurs (**Figure 3.48**). Causes of preignition include:

- Spark plugs of too high a heat range
- Hot spots in the combustion chamber (from sharp edges on valves, head gaskets, or hot carbon particles)
- A loose spark plug

Notice the burning that results from preignition shown in **Figure 3.49.** Passenger car engines can usually survive detonation for a period of time, but preignition can damage an engine very quickly.

The air-fuel mixture is more easily ignited when the piston is at BDC as it begins its compression stroke before pressure begins to build. Lighting the mixture becomes more difficult as the piston moves up, so preignition is more likely to occur earlier in the compression stroke (provided fuel is present). When the air-fuel mixture is preignited by a hot spot while the piston is at BDC, the heat of combustion stays on the piston, cylinder walls, combustion chamber, and valves for a much longer time than normal, and engine temperature goes up. When the mixture is ignited at BDC, additional burning takes place for well over 100° of crankshaft rotation before the piston reaches the normal spark ignition point near the top of the cylinder. The rise in cylinder pressure, after preignition and before normal spark occurs, is not immediate. But the pressure becomes intense as the piston moves up in the cylinder while the burning flame front continues expanding against it. An engine can quickly suffer damage from the extra heat and pressure that occurs during preignition. Unlike detonation, preignition does not produce a knocking sound, so the impending damage is not apparent until it is too late.

A typical symptom of preignition is a hole burned in a piston or spark plug center and ground electrodes that have melted. The center of the piston burns because it is relatively thin and aluminum absorbs heat more rapidly than the cylinder

FIGURE 3.49 This piston burned due to preignition when a spark plug with too hot a heat range was mistakenly installed in the cylinder head. *(Courtesy of Tim Gilles)*

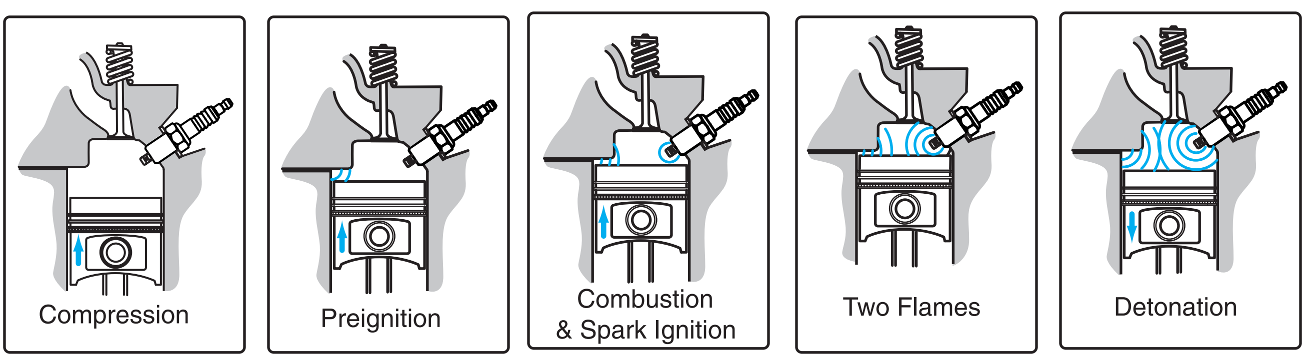


FIGURE 3.48 Preignition.

wall or cylinder head. Sometimes preignition can be caused by detonation. When a heavily loaded engine has been detonating for an extended period, the spark plug can overheat and become a source of preignition as well. This is known as detonation-induced preignition.

Detonation

Detonation, also called ping, spark knock, or engine knock, is when the air-fuel mixture self-ignites due to increased pressure in the cylinder (**Figure 3.50**). It occurs when the unburned part of the air-fuel mixture explodes violently *after* regular spark ignition has occurred. The normal burn is already in progress when detonation happens. After the air-fuel mixture is ignited, it expands, moving the piston down in the cylinder. Suddenly the mixture explodes, producing a brief, extreme spike in pressure as the rest of the combustible energy is expended. The explosion causes parts to break. The explosive result of detonation is shown in **Figure 3.51.** Detonation can also cause the piston to expand too much, resulting in cylinder wall scuffing at the four corners of the piston skirts. The aluminum melts and runs into the ring grooves, causing them to stick. This causes a compression loss and sometimes the flame front leaks past the rings, burning out an area on the ring lands. Damage of this type is often confused with preignition because of the burned ring lands, but the original cause was detonation.

NOTE

This type of detonation failure is especially common in the air-cooled engines found in snowmobiles, jet skis, quads, and motorcycles.

Under the extreme loads of drag racing, an engine might run fine at WOT without detonation due to the rich air-fuel mixture. But when it returns to part throttle, the mixture will be leaner and detonation might cause a piston to overheat and scuff the skirts.

Detonation is a race between the flame front and heat buildup during combustion. The faster the burn is completed, the more immune the engine is to detonation. If the air-fuel burn is completed before the temperature and pressure reach the point of detonation, abnormal combustion will *not* occur.

FIGURE 3.51 This ring land was broken by detonation. *(Courtesy of Tim Gilles)*

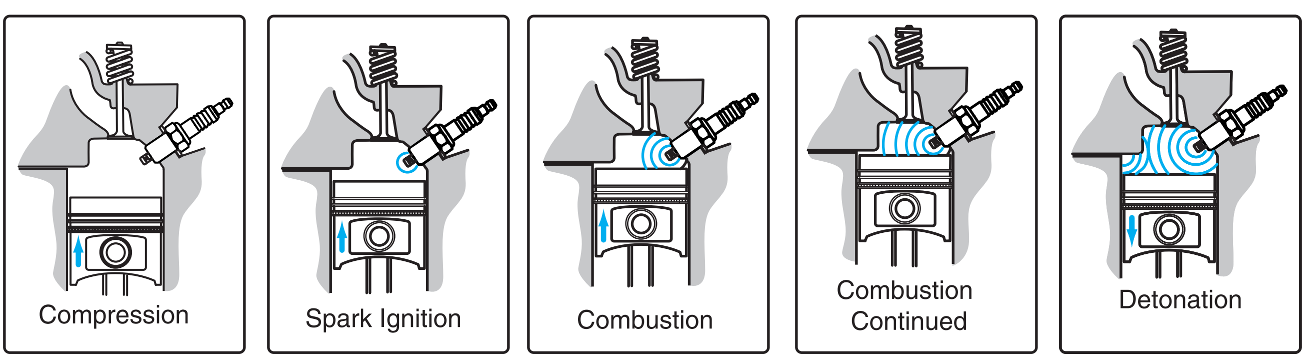


FIGURE 3.50 Detonation.

VINTAGE ENGINES

Before sophisticated computer-controlled spark timing, a common cause of detonation was over-advanced ignition timing.

Older engines required more spark advance to complete combustion by the targeted point of 11–14° after TDC. On modern engines, to help speed up normal combustion and prevent detonation, the spark plug location is often centrally located, or there are multiple spark plugs. This is more efficient mechanically because firing the spark closer to TDC means that the piston is not working against compression for as long a time. One of the advantages of a four-valve pent-roof combustion chamber is its faster burn time.

Sometimes the pistons and cylinder head absorb the sound of engine knock, making it inaudible. This condition is called cold knock or inaudible ping. Other times the rattling that results from detonation can be very loud. The noise is caused by vibration of the combustion chamber walls.

When the air-fuel mixture detonates, the explosion is instantaneous and the loss of power can result in serious engine damage, including broken pistons, piston rings, and head gasket failure.

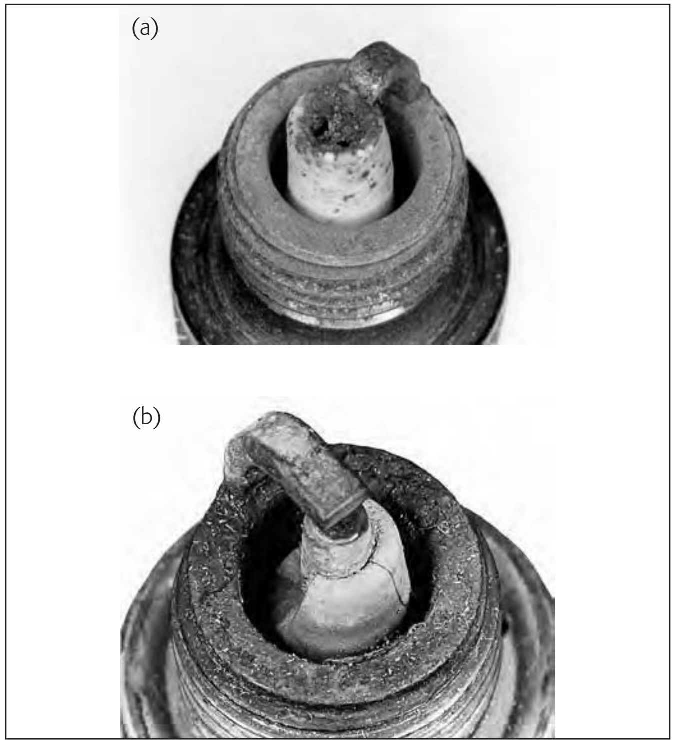


FIGURE 3.52 Damage due to (a) preignition and (b) detonation. *(Courtesy of Champion Spark Plugs)*

SHOP TIPS

- Spark plugs are a window to combustion chamber action. **Figure 3.52** shows spark plug conditions that resulted during preignition and detonation.
- Dynamometers (see Chapter 10) are used to test engines under load. Experienced dyno operators know that the temperature of exhaust gas in a detonating engine will drop.

Fuel Octane, Spark Advance, and Detonation

Octane rating is a measurement of a fuel's ability to resist explosion under pressure. Design engineers test an engine on a dynamometer, using fuels of different octanes. Different spark advances are tested at various speeds and loads to determine the engine's highest torque output. Ignition timing is best when it is advanced to the furthest point without causing detonation. Modern computer-controlled engines use a detonation sensor (**Figure 3.53**), sometimes called a knock sensor. When it senses the vibration caused by detonation, the computer retards the ignition timing until the spark knock goes away. The computer continually relearns the best timing for the fuel by advancing the timing until detonation occurs and then retarding the spark slightly until detonation stops. All modern automotive engines have this capability. Manufacturers recommend fuel of a particular octane rating for each of their vehicles. When fuel of a lower octane rating is used, the timing will be adjusted to a lower amount of advance. The price is a slight penalty in fuel economy and performance.

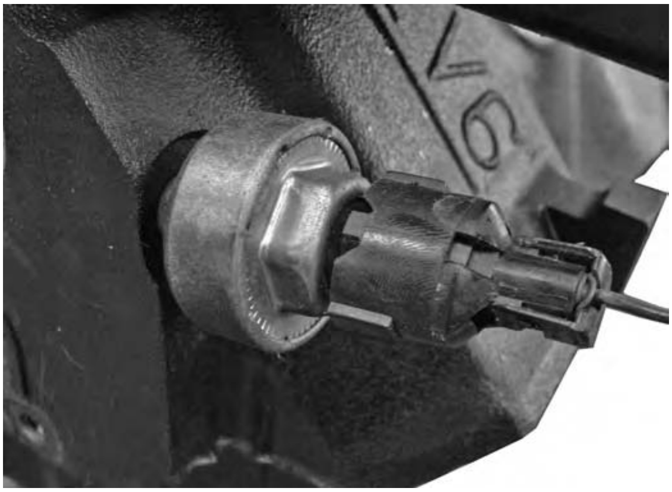


FIGURE 3.53 A detonation sensor (or knock sensor) signals the computer to change ignition timing as it responds to vibration caused by spark knock. *(Courtesy of Tim Gilles)*

When fuel with too low an octane rating is used in an engine with a high compression ratio, detonation often occurs at low or moderate speed. There is a fuel octane consequence to increasing an engine's compression ratio by one point. In an engine with a conventional combustion chamber that previously used regular octane fuel, premium fuel will now be needed. With a fast-burn combustion chamber, only midrange fuel will be needed.

Newer combustion chamber designs can lower the octane requirement. Engines with fast-burn combustion chambers can have less spark advance than ones with conventional combustion chambers. When the spark is more advanced, the pistons have to push against pressure for a longer amount of crankshaft rotation. With a fast-burn combustion chamber, less spark advance is required so the pistons do not work against pressure as long. The engine becomes more efficient and pumping losses are reduced.

NOTE

- Excessively advanced ignition timing can cause a burned piston but will **not** cause an increase in engine temperature.
- Excessively retarded ignition timing will cause an engine to overheat but will **not** burn a piston.

Abnormal combustion can be caused by cylinder temperatures that are too high, too lean an air-fuel mixture, lugging the engine (see glossary), cooling system overheating, or an increase in compression ratio resulting from carbon buildup. Detonation can also be caused by an inoperative EGR valve, which can be confirmed while running the engine at high idle (1800–2000 rpm) while the knock occurs. When possible, manually open the valve while the engine idles. If the noise disappears, the valve is at fault.

CAUTION

Be careful of hot exhaust components when working around the EGR valve.

Length of Combustion. The *burn time* of the air-fuel mixture is critical in an engine. Excessively lean air-fuel mixtures, like preignition, can result in burned parts. Lean mixtures burn more slowly than rich mixtures, so the metal parts are exposed to the flame for a longer period. This is why one lawnmower manufacturer recommends that only regular

VINTAGE ENGINES

Whether the engine is new or old, ignition timing is set according to engine speed and load. Prior to the introduction of advanced computer engine controls, ignition timing was controlled mechanically. Centrifugal weights in the ignition distributor moved the timing forward as engine speed increased. Timing was also advanced and retarded in response to changes in engine vacuum.

On carbureted engines, a temperature-controlled air cleaner stuck in the heat-on position or a malfunctioning early fuel evaporation system can cause detonation.

fuel be used in its mowers. Premium fuel has a longer burn time so engine valves could be burned.

The longer a part is exposed to the flame, the more heat it absorbs. When burned parts are discovered, check for a plugged fuel filter or an electric fuel pump that is failing. The lean mixture that results can raise temperatures excessively.

Excessive Carbon Buildup. In a car with relatively low mileage, carbon buildup in the combustion chambers can cause an increase in the compression ratio (**Figure 3.54**). Although this is no longer as common a problem because of improvements in gasoline, which leaves fewer deposits, some late-model engines develop carbon problems in less than 10,000 miles.

NOTE

"Carbon knock" results from increased compression in the cylinder caused by carbon buildup. This can be very noticeable when the engine is cold. Engine knock typically occurs under load, but carbon knock can occur even when not under load.

There are two kinds of deposits: *oil-based* and *carbonaceous*. Oil-based deposits are the traditional gummy, black ones that are caused when oil and heat come together.

Carbonaceous deposits result from fuel. They are called cauliflower deposits because of their resemblance to the vegetable. These deposits are not as thick as oil deposits and are hard, dry, and tougher to remove. They cause drivability problems because fuel vapors can be absorbed into them. This results in rough idling when cold, as well as loss of power, surging, and high emissions.

One method of removing carbon deposits is with a carbon blaster, which uses crushed walnut shells blasted by compressed air. If any pieces of the shells remain in the engine after cleaning, they will be burned up during combustion.

Sometimes carbon that has accumulated on a valve or in the combustion chamber can drop off and be crushed against the cylinder head. If this occurs during cranking, the piston can stop on its upstroke. When this happens at low rpm with the engine running, the noise resembles the sound of a bad rod bearing.

Carbon can be removed using an additive but carbon removers can damage the catalytic converter. Follow the manufacturer's instructions.

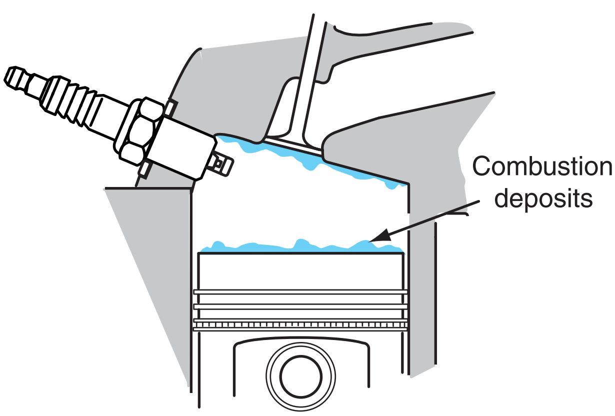


FIGURE 3.54 Carbon in the combustion chamber can raise the engine's compression ratio.

Broken Engine Mount

The engine is attached to the frame with a rubber and metal engine mount, often called a *motor* mount. Some of the results of a broken engine mount (**Figure 3.55**) include vibrations, a sticking throttle and/or shift linkages, a torn radiator hose, interference between the fan and radiator, and broken electrical cables or ground straps from the engine to the firewall or frame.

A typical symptom of a bad engine mount is a vibration that occurs in Drive, but not in Reverse. Late-model engine mounts are designed with safety provisions so that even when they fail, the engine will still be restrained.

To check for a broken engine mount, have another person put the transmission in both forward and reverse while keeping the vehicle braked. This will cause the engine to lift on one side and then on the other.

FIGURE 3.55 A broken engine mount. *(Courtesy of Tim Gilles)*

Broken Electrical Ground Connection

A broken ground wire or strap can cause several problems as electricity hunts for its easiest path to ground. These include an etched transmission bushing and drive shaft yoke, burned emergency brake cables, an electrically etched thrust bearing, flickering headlights, failure of the engine to start, burned front wheel bearings or CV joints, and other mysterious conditions.

Corrosion of the core plugs in the block can also result from a bad ground strap. The engine block is part of the ground circuit for the ignition and starting systems. Current flowing through the engine block speeds up the corrosion process. Additives in the coolant prevent this, but they deteriorate with age. For a good electrical connection, be sure the ground strap is connected to the head or block, not to the valve covers.

SHOP TIP

When the engine runs and all lights and accessories are on, check to see if a voltage can be measured between the transmission housing and the frame. If so, attach a ground strap from it to the frame.

OIL PRESSURE PROBLEMS

Although oil pressure can be too low or too high, low oil pressure is far more common. Engines with advancing mileage begin to use oil between oil changes. When people neglect to check the engine's oil level at each fill-up, the oil level can drop too low, causing major engine damage. Usually the first thing to happen is lower main bearing wear (**Figure 3.56**). After this happens, oil pressure will remain permanently low at idle speed but may be acceptable at higher rpm.

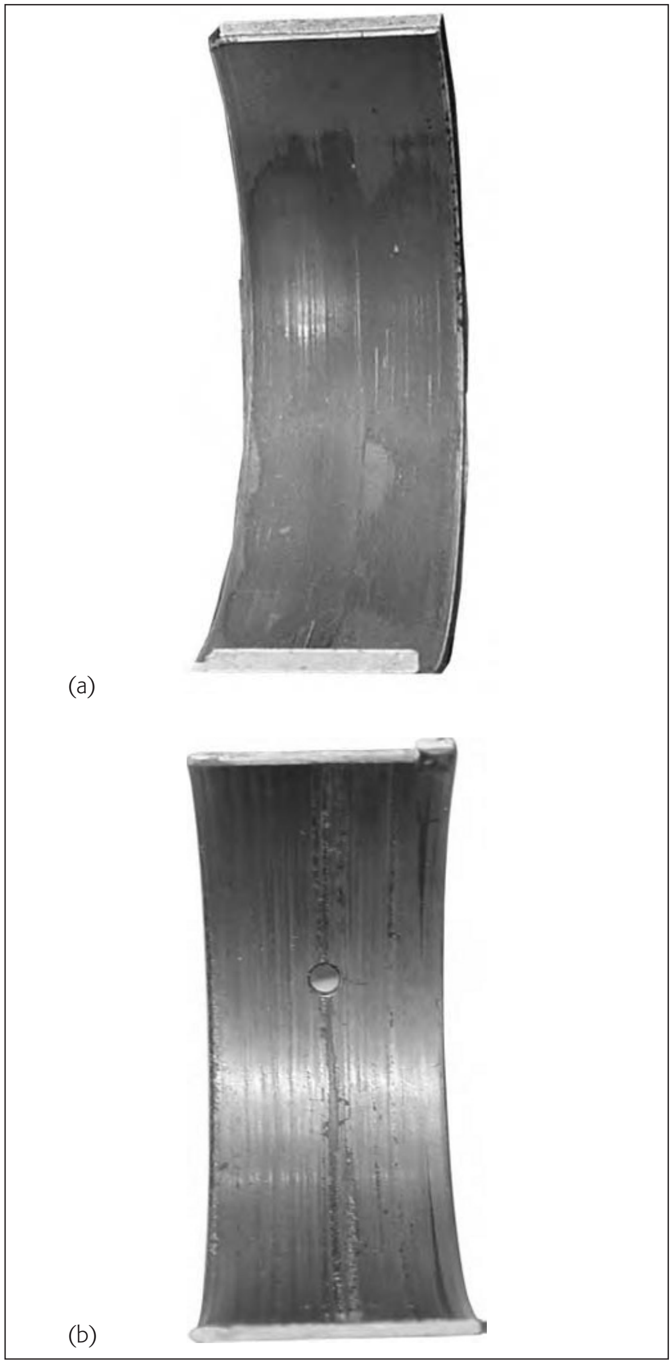


FIGURE 3.56 (a) Lower main bearing wear. (b) More serious bearing wear. *(Courtesy of Tim Gilles)*

Low Oil Pressure

Low oil pressure can ruin an otherwise good engine in a short time. A faulty oil pressure sending unit is sometimes the cause of a low oil pressure reading on an electric dash gauge or light.

- Test the gauge by grounding the wire that leads to the sending unit on the block. When the wire is grounded with the key switch on, the gauge should show full oil pressure, or the light should go on. If either happens, the gauge is good and the sending unit is at fault.
- Pressure can be tested by temporarily installing a gauge in place of the sending unit (**Figure 3.57a**).

Use an oil sending unit socket to remove the sender (**Figure 3.57b**) because pliers can damage it.

The oil pump can also cause low oil pressure. It might be worn excessively, or have a sticking relief valve. The intake screen can be loose or partially plugged, or the pump body could be loose on the block.

High Oil Pressure

A rare condition is when an engine has oil pressure that is too high. This can lead to oil consumption, bearing material being washed from the bearings, or a bursting oil filter. The problem can be caused by a stuck pressure relief valve in the oil pump or by a severe blockage in an oil gallery near the cam or crank (close to the oil pump). In either case, the oil pump relief valve would be unable to bypass enough oil at high speeds.

Oil problems and the process for checking oil pressure are covered in detail in Chapter 14.

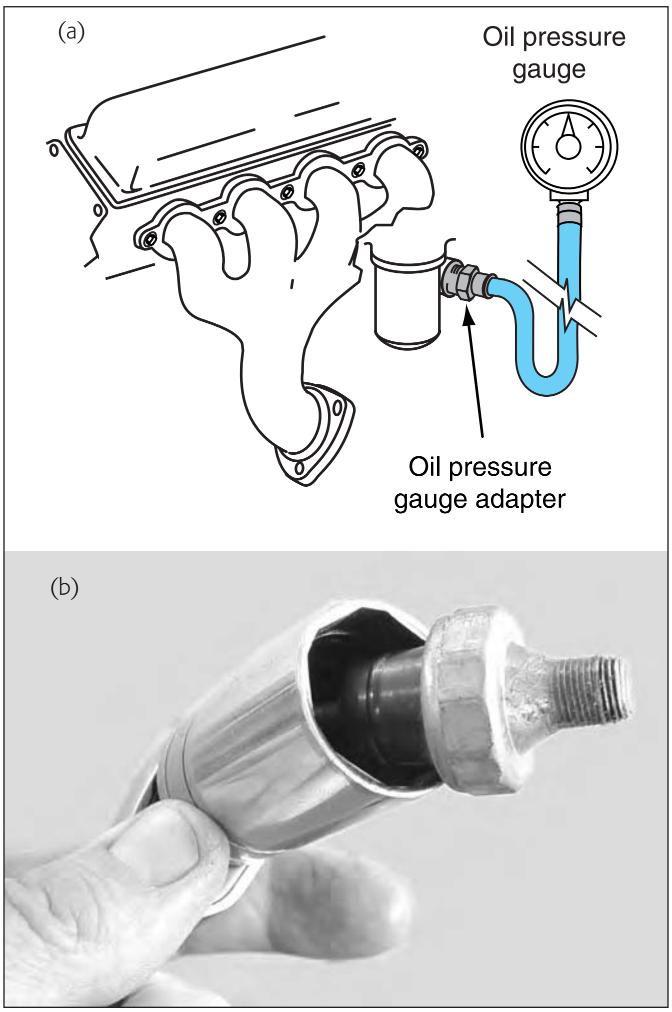


FIGURE 3.57 Testing oil pressure. (a) An oil pressure gauge is installed in the oil sending unit hole in the block. (b) An oil pressure sending unit is removed with a special socket. *([b] Courtesy of Tim Gilles)*

COOLING SYSTEM PROBLEMS

Cooling systems are sometimes neglected. When a customer spends a great deal of money on an engine rebuild, he or she will not be getting a complete repair if the cooling system is not put in like-new condition, too. Radiators are sometimes restricted or rotten. If a radiator cannot conduct enough heat to the surrounding air, the engine will overheat at freeway speeds.

Water jackets sometimes have mineral and scale buildup. If the engine is removed from the car for a rebuild, the block will probably be hot-tanked or cleaned in a bake oven. Acid cleaning by a specialty shop is required for scale removal. Chapter 5 covers engine cleaning in detail.

Internal and External Cooling System Leakage

Steam from the exhaust is a normal condition in the morning. Excessive coolant from the exhaust can be caused by a crack in the combustion chamber or a head gasket leak.

Internal leaks can happen in the following locations:

- In the coolant-crossover passage of the intake manifold on most V-type engines
- In threaded plugs in cylinder heads
- In combustion areas like the head gasket (**Figure 3.58**)
- In a cracked head or block

When coolant has been leaking into a combustion chamber, this can be spotted easily during engine disassembly. A small amount of carbon is normal in a combustion chamber. The cylinder with the leak will not have any carbon in it (**Figure 3.59**). Internal leaks are diagnosed using the block tester, pressure tester, or infrared analyzer.

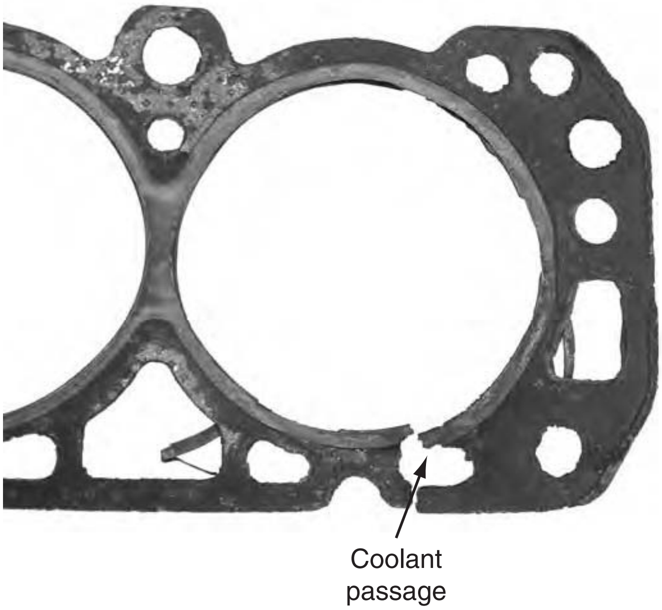


FIGURE 3.58 This blown head gasket resulted in coolant leaking into the cylinder and combustion gases leaking into the coolant. *(Courtesy of Tim Gilles)*

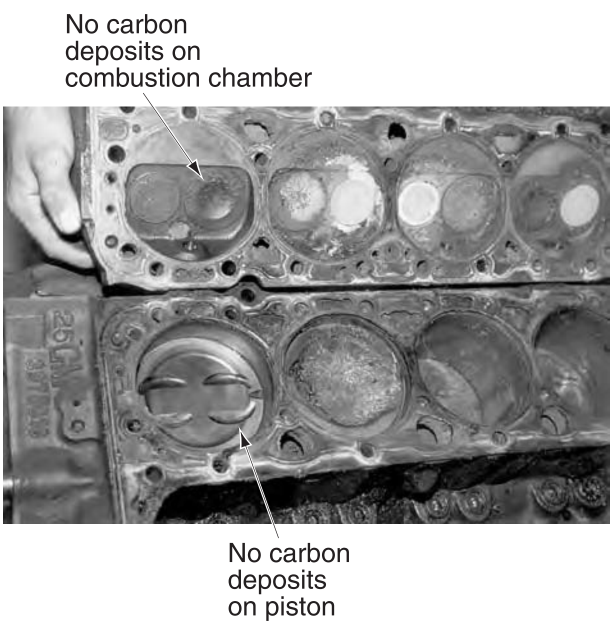


FIGURE 3.59 A cracked combustion chamber or leaking head gasket that resulted in a coolant leak will remove all carbon from one piston and combustion chamber. *(Courtesy of Tim Gilles)*

SHOP TIP

To pinpoint suspected internal cooling system leaks, before disassembling the engine, drain the radiator and then refill it with water and a large bottle of yellow food coloring. When the cooling system is pressurized, the food coloring will outline any cracks, making them easy to find after disassembly. Fluorescent dye can also reveal cooling system leaks in the same manner as discussed earlier in the section on oil leaks.

Checking for cracks after disassembly is covered in Chapter 7.

Coolant leaking into the crankcase will contaminate the oil. This is called **cross fluid contamination.** The condition will be very evident when a valve cover is removed (**Figure 3.60**).

An internal coolant leak can occur when a loose timing chain wears a hole in the inside of a timing cover that has the coolant pump mounted to it. Another problem resulting from an internal leak is when an oxygen sensor fails due to silicate contamination coating the sensor. Silicates are part of the additive package of some coolants. A similar problem can result when the wrong type of silicone RTV sealant is used (see Chapter 16).

When there is a crack or a head gasket leak, sometimes pressurized coolant can leak when the engine is shut off, filling a cylinder, resulting in *hydrolock*. If both of that cylinder's valves are closed, the engine will not be able to turn completely over when cranked. If the spark plugs are removed, the engine will be able to turn over with coolant pouring out of the offending plug hole.

CASE HISTORY

A machinist bought an old pickup with the intention of rebuilding the engine. The previous owner said that the engine was seized up (would not turn over). After towing the vehicle to his garage, he began to diagnose the engine before disassembling it. He discovered that the engine was not really seized, but was hydrolocked. He knew that head gaskets on long in-line six cylinders are more likely to fail in the middle, so he took out the center two spark plugs and cranked the engine. After coolant came out the spark plug holes, he was able to replace the spark plugs and run the engine. Surfacing the cylinder head, replacing the head gasket, and changing the oil were the only things required to put the truck in good working order.

FIGURE 3.60 A blown head gasket caused the oil to take on this appearance *(Courtesy of Tim Gilles)*

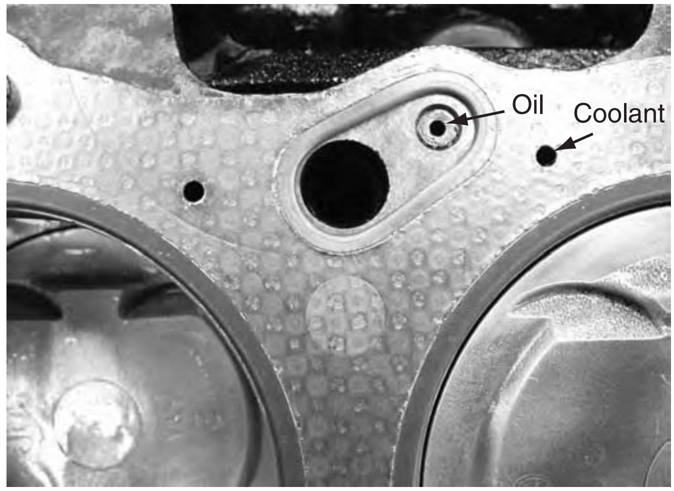


FIGURE 3.61 When a head gasket failure occurs between an oil gallery and a coolant passage, cross-contamination of oil and coolant will occur. *(Courtesy of Tim Gilles)*

SAFETY NOTE

If the vehicle has an electric fuel pump, be sure that the liquid in the cylinder is not gasoline before cranking the engine. A fire could result.

When a leak occurs between oil and coolant passageways, pressurized oil (approximately 30 psi) will force its way into the cooling system (approximately 15 psi) **(Figure 3.61)**. The engine will overheat and pour a messy oil and water mixture from the radiator overflow.

Beneath an OHC camshaft, there is a trough that provides clearance for the camshaft. Because oil collects in this trough, should this area become cracked, the oil will be sucked into the cooling system as the engine cools.

Cross fluid contamination can also occur when there is a leaking automatic transmission cooler (see Chapter 15). The transmission will fill with coolant when the engine is turned off and ATF will leak into the coolant when the engine is running. A cooling system pressure test can be used to pinpoint a leak in an automatic transmission heat exchanger.

FIGURE 3.62 A cooling system pressure tester installed on a radiator filler neck. *(Courtesy of Tim Gilles)*

Cooling System Pressure Test

Internal leakage can be diagnosed with a pressure tester installed on the engine's cooling system opening **(Figure 3.62)**.

- The system is pressurized with the engine off.
- The pressure should remain stable.
- When a leak is not readily apparent, the system can be left pressurized overnight.

SAFETY NOTE

Do *not* run the engine with the tester in place. The tester does not have an automatic pressure release like that found in a radiator cap. Too much pressure can damage the cooling system, but it can also present a dangerous situation if the coolant temperature is high and the tester is suddenly removed. Pressure can be released from most testers by pushing sideways on the tester hose where it connects to the radiator opening. Be sure to protect yourself from possibility of steam leakage.

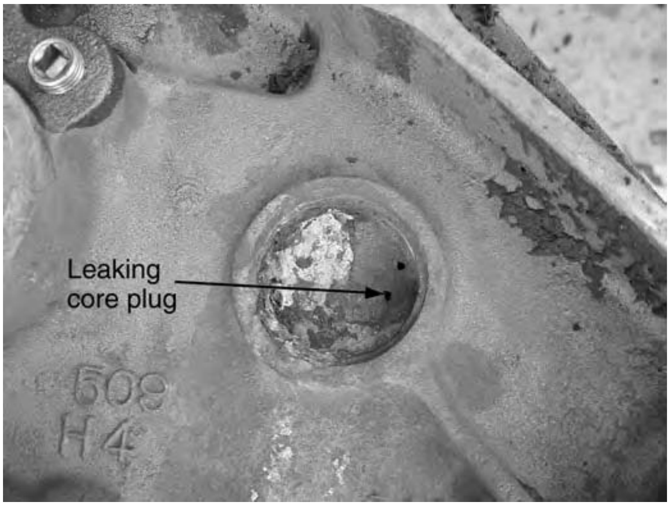


FIGURE 3.63 This core plug behind the flywheel was leaking. *(Courtesy of Tim Gilles)*

SHOP TIP

A very effective way of determining whether coolant is leaking into a cylinder is as follows:

- Pressurize the cooling system with the cooling system pressure tester.
- Allow the vehicle to sit overnight with the cooling system pressurized.
- Remove all of the spark plugs.
- Hold paper in front of the spark plug holes while cranking the engine. If coolant is leaking into a cylinder, the paper in front of that spark plug hole will become wet.

A pressure tester can also pinpoint the location of a leaking core plug. Use a flashlight and an inspection mirror to pinpoint the leak. Experienced technicians will not begin a repair until they are positive of the locations of leaks.

There are core plugs behind the flywheel on some (but not all) engines **(Figure 3.63)**.

CASE HISTORY

A student wanted to replace leaking core plugs on the back of the block between the engine and the transmission. He removed the automatic transmission from the car and removed the flexplate from the back of the crankshaft. Unfortunately, the block he was working on did not have core plugs on the back. When he pressurized the cooling system, he found that a core plug behind one of the side motor mounts was leaking. Coolant was running down the edge of the oil pan to the rear of the block and appeared to be coming from behind the flywheel. Using a pressure tester and flashlight to locate the leak before attempting to repair it would have saved a good deal of needless work.

Exhaust Gas in the Coolant. A leaking head gasket will not always be evident using a cooling system pressure tester. Another means of testing for leakage of exhaust gas into the cooling system is the *combustion leak tester*, also called **block check tester,** shown in **Figure 3.64.** The tester samples air in the filler neck of the radiator.

- Unlike the pressure tester, the combustion leak tester is used with the engine running.
- Carbon monoxide (CO) exhaust gas in the radiator will change the color of the liquid in the tester.
- CO is a by-product of combustion, so the tester will not work if the leaking cylinder's spark plug is not firing.
- If compression is too low or if coolant entering the cylinder causes the plug not to fire, the tester will not give a reading.
- The block check tester can sometimes give a false reading with coolant. It works best on pure water.

FIGURE 3.64 Using a combustion leak tester to check for combustion leakage into the cooling system.

To perform this test, lower the coolant level until it is at least 2 inches below the radiator filler neck.

SHOP TIP

A handy method of siphoning some coolant from a radiator is to cut a hole in a piece of rubber fuel line near the end. Put the other end in the coolant. Insert a rubber-tipped blowgun into the hole and blow toward the end of the hose. This will siphon coolant from the radiator.

The bulb of the tester is squeezed repeatedly for about 1 minute to force gases in the radiator through the fluid in the tester.

If the color of the blue-green fluid changes to yellow, a combustion leak is indicated. If the fluid remains blue-green, a leak is not present at that moment.

When test results are positive on a V-type engine, disable all spark plugs to one bank of cylinders.

> **REMEMBER:**
> **CO is a by-product of combustion. Without ignition, no CO is produced.**

Allow the engine to idle for 5 minutes to purge all gases that might remain in the cooling system from the first test and then retest. If the test is negative, the leak is from the disabled bank of cylinders and that head can be removed for repair. If the test is positive, be sure to repeat the test on the other bank of cylinders before removing the head. Both heads are independent of each other and could have leaks.

An infrared exhaust analyzer can also be used to check for exhaust gas in the coolant **(Figure 3.65)**.

- This method works whether the mixture is fired or not.
- Load the engine by accelerating it in gear with the brakes on for 3 seconds or less.
- Hold the probe over the radiator filler neck to check for HCs in the coolant. Be sure not to suck coolant into the tester probe.
- If there is CO in the cooling system, exhaust gas is leaking in during combustion.

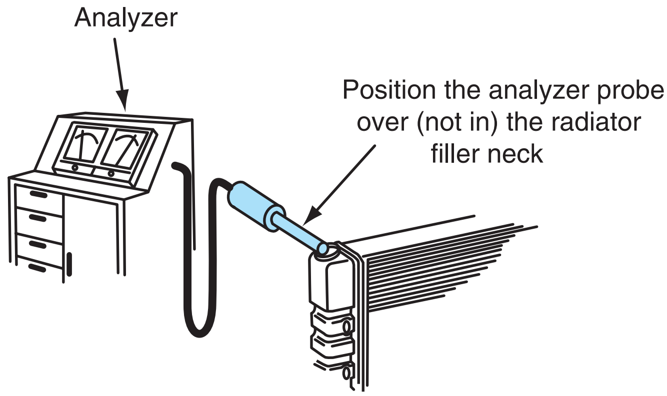


FIGURE 3.65 An infrared analyzer can be used to check for a combustion leak.

Checking for Bubbles in the Coolant. To determine which head has a crack or a leaking gasket on a V-type engine:

- Remove the thermostat and water pump drive belt.
- Plug the top end of the radiator.
- Run the engine.
- Bubbles in the thermostat opening will be visible coming from the side of the engine with the leak.

On a leaking V-type engine, spark plugs on the side with the leak will often appear wet after a short time of cold running.

To be especially certain an internal cooling system leak exists try the following method:

- Remove the top radiator hose from the radiator.
- Remove the thermostat.
- Leave the hose attached to the thermostat housing and fill it with water like a funnel.
- Put a thermometer in the hose.
- Run the engine.
- If any bubbles appear before the boiling point is reached, there is a combustion leak into the cooling system.

SHOP TIP

Here is an effective way to test for a head gasket leak. With the engine cold, pressurize the cooling system with a radiator pressure tester. Remove all of the spark plugs. Disable the fuel injectors and crank the engine with the starter. While cranking, hold a piece of paper in front of the spark plugs holes. If there is a leak in one or more of the cylinders, the paper will become wet.

Other Causes of Overheating

Overheating can also be caused by a water pump with a loose or corroded impeller. Check the pump flow by holding the top radiator hose with the engine running and the thermostat open at normal operating temperature. The surge of the coolant can be felt when the engine is accelerated.

Besides obvious cooling system problems, overheating can be caused by retarded ignition timing, a partially blocked catalytic converter or exhaust system, or even by detonation due to an inoperative EGR valve.

Testing the cooling system and cooling system problems are covered in Chapter 15.

Seized Engine

When a starter motor will not crank the engine over and the crankshaft cannot be turned with a socket and breaker bar, loosen all accessory drive belts. A frozen smog pump, power steering pump, water pump, or other belt-driven accessory can actually keep an engine from turning over. The overheated drive belt can melt and stick to the pulley when the engine is shut off.

CASE HISTORY

A technician in a dealership was preparing to replace a seized engine in a car. He had confirmed the diagnosis of a seized engine by attempting to turn the crankshaft with a socket and breaker bar on the damper bolt on the front of the crankshaft. The engine would not turn. All of the paperwork was in order and the order for the replacement engine had been phoned in. Beginning the disassembly, he removed the battery cables and the starter motor. When he started removing the accessory drive belts he noticed that the one that drives the smog pump was slightly melted. Further inspection showed that the smog pump was frozen. Next, he tried to turn the crankshaft again. This time it did turn. The engine was reassembled, fitted with a new smog pump and returned to the very happy customer.

If the engine will not turn in either direction with the belts loose, the cause could be coolant *thermoplastic seizure* (discussed in Chapter 15) or other serious engine damage, such as piston seizure, seized bearings, a broken crank, or a seized rod or valve. The problem could also be a broken starter motor or housing.

CASE HISTORY

A technician purchased a car that was in good condition, except for a bad engine. The previous owner sold it after being told by a repair shop that it had "thrown a rod" and would require a replacement engine. The crankshaft could be turned in one direction and then would stop. Turning the crank backwards produced the same result. As he began the process of removing the engine from the car, he removed the starter and discovered a broken starter drive (see Figure 3.1). He replaced the starter, and the engine checked out in excellent condition.

ELECTRONIC FAILURES/ENGINE DAMAGE

Engine damage such as burned valves, scuffed pistons, worn bearings, and damaged cylinder heads can sometimes be traced to electronic failures. Today's fuel and emission control systems are computer controlled. Computers receive input from various engine sensors. An EGR valve controlled by a computer can become inoperative if two of its input sensor signals are interrupted. This results in detonation. Some engines can have an electric cooling fan failure due to an inoperative sensor. An overly rich air-fuel mixture due to an electronic failure can cause oil dilution, resulting in piston damage or crankshaft bearing wear. A tip-off here is that the catalytic converter could overheat and melt, causing exhaust system backpressure.

Oil Analysis

Large fleets use oil analysis to determine when to change oil. They put hundreds of thousands of miles on their engines and the engines have very large crankcase capacities. In addition to telling when the oil's additives are depleting, oil analysis performed by testing laboratories can also tell if there is potential mechanical trouble on the horizon.

A sample of about 4 ounces is sent to the laboratory. The oil is collected when the engine is at operating temperature. The lab is given information on the original viscosity of the oil, how long it has been since the last oil change, and how many miles are on the engine.

Fleets often sample oil using a suction tube inserted into the dipstick tube. Be sure that the sample is not taken from the bottom of the oil pan. This will not yield an accurate result. If the oil sample is taken through the oil pan drain opening, remove at least 1 quart of oil so that dirt deposits are washed away from the drain opening.

The results of the test include information about the viscosity (thickness) of the oil. (Oil is covered in detail in Chapter 14.) Thicker oil is due to oxidation, usually from heat. Thickening must be less than 30% of the original viscosity. Thinner oil is usually due to fuel dilution, either from an accumulation of short trips or from a defect in the engine's fuel system.

Other results of an oil analysis include the oil's moisture content (which should be less than 2%) or the presence of antifreeze/coolant, either of which could indicate internal coolant leaks. The test also gives results in parts per million of the presence of metals such as iron, chromium, copper, aluminum, and tin from worn or failing engine parts. Also included is silicon, which is sand or dirt. High amounts of iron indicate excessive wear to cylinder walls. Aluminum can indicate piston wear and chromium can indicate wear to chrome piston rings. Excessive copper in an oil sample can be due to a new oil cooler on the engine. After a first oil change, this should no longer be a problem because the inside of the oil cooler will oxidize during normal use. When lead and copper are found in the sample, this can be due to engine bearing wear or failure.

Key Terms

ATF	cranking vacuum test	intake manifold vacuum
black light testing	cross fluid contamination	PCV
block check tester	EGR	seized engine

Study Questions

1. When an engine runs for a long period with an excessively lean air-fuel mixture, what kind of engine damage can result?
2. Carbon has built up in the neck area of a valve. What is the most probable cause?
3. If a spark plug is oil-fouled with carbon on only one side, what could be the cause?
4. At the end of a spark plug deposit test, what must be done before the engine is accelerated off idle?
5. A roar will be heard through the engine's air intake when the _____ system is restricted.
6. What happens to the outside of an exhaust pipe at the point of an internal restriction?
7. During a compression test, remove all of the _____ _____ so the starter can crank the engine easily.
8. How many compression strokes (minimum) should the engine crank during a compression test?

9. When engine idle rises during a cylinder power balance test, what could be the cause?
10. Vacuum readings will drop approximately 1 inch for each _____ feet above sea level.
11. An engine should produce a minimum of _____ inches of vacuum while cranking, but most engines will produce far more.
12. A noise goes away when the spark plug wire for one cylinder is disabled. What could this noise be?
13. What other engine part failure sometimes results in a cracked piston?
14. When a spark plug is disabled and the noise becomes *louder*, what could this be?
15. What possible problem can be pinpointed by looking at the top of this piston **(Figure 3.66)**?

FIGURE 3.66 Carbon formation on a piston top. *(Courtesy of Tim Gilles)*

ASE-Style Review Questions

1. An engine has late valve timing. Technician A says that this will cause poor, low-rpm performance. Technician B says that at higher rpm, engine performance might be acceptable. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that with a vacuum leak, an engine with an oxygen sensor feedback fuel system can run fine when cold but rough when hot. Technician B says that advanced ignition timing will often cause an engine to run hot. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that vacuum readings for an engine with a performance camshaft might be lower at idle. Technician B says that an engine that has worn lower main bearings will have lower oil pressure at freeway speeds. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that a compression test can be used to check the condition of the oil control rings. Technician B says that when several cylinders have low compression test readings, this can be due to burned or tight valves. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Two technicians are discussing compression test results. Technician A says that abnormally low compression in adjacent (neighboring) cylinders most likely indicates a bad head gasket. Technician B says that if the reading on the compression tester goes up after adding oil to the cylinder, the compression rings are probably worn. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B

d. Neither A nor B

6. Technician A says that a cylinder leakage test is better than a compression test for testing the condition of an engine *before* installing it in a car. Technician B says that a compression tester is better than a cylinder leakage tester for testing the condition of an engine with a performance camshaft. Who is right?

   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that an engine that idles rough due to burned valves might run fine at speeds above idle. Technician B says that carbon buildup in a combustion chamber can cause an engine to have higher compression. Who is right?

   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. A noise occurs at ½ crankshaft rpm. Technician A says that this could be a bad lifter. Technician B says that this could be a valve that needs to be adjusted. Who is right?

   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. An engine has a crack between a water jacket and an oil gallery. Technician A says that oil will go into the cooling system when the engine is running. Technician B says that coolant will go into the oil when the engine is off. Who is right?

   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. A car has oil smoke from its exhaust during deceleration. Technician A says that bad valve guide seals could be the cause. Technician B says that worn piston rings could be the cause. Who is right?

   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

CHAPTER 4

Engine Removal, Disassembly, Inspection, and In-Chassis Repairs

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Locate repair information in shop manuals.
- Safely and properly remove an engine from a vehicle.
- Disassemble an engine in an orderly manner.
- Select the most appropriate method of engine repair.

Introduction

There are many procedures to be learned in order to successfully remove, disassemble, and inspect an engine before ordering parts for it. This chapter deals with the correct methods of engine removal and disassembly, repairs that can be accomplished while the engine is still in the vehicle, and the ordering of parts. Most of the practices covered in this chapter are generic, applying to all piston engines.

SERVICE INFORMATION

In 1965 the amount of material a mechanic needed to be able to read in order to be very knowledgeable about automobiles was about 5000 pages. The amount of published information for automobile repair in 1974 was less than a quarter of a million pages. In 1993 that amount was 1,251,016, almost five times as many pages. Information is doubling two times a year. Today a technician needs to have access to much, much more service information. In the year 2000 the amount of information a technician had access to reached approximately 1,601,300,400 (1.6 billion) pages and continues to grow.

Repair manuals in 1965 were relatively small, but service information for only one of today's makes of vehicles usually consists of more than one manual or information stored on compact disks (CDs), DVDs, a large computer hard drive or LAN, or on the Internet.

There are many procedures to be learned in order to successfully service and repair automobiles. The first part of this chapter deals with how to locate service information. Several types of service information are available, including traditional service manuals, computer libraries, and microfiche.

SERVICE LITERATURE

Service literature, whether in book form or digital, gives written instructions for repairs. Illustrations provide helpful hints.

Before working on any make of vehicle for the first time, it is a good idea to consult the service literature to find any helpful hints or precautions that can make your task more successful. Information is written for experienced technicians and makes the assumption that certain procedures are understood and will be followed.

Keep in mind that it is important to keep parts organized when you are disassembling a component or system. Be sure to label parts for reassembly. As you progress in your automobile service literature, you will see why it is important to be methodical. When in doubt, always check the repair manual. Even with the help of good information, it is very difficult to put back together something that you did not take apart yourself.

It is especially helpful to note the location of accessory brackets, such as those for the alternator, smog pump, power steering pump, or air-conditioning compressor. After removing brackets from an engine, reassemble them to the unit they hold, so you do not forget where they belong. Factory service manuals do not always include this information.

SHOP TIP

It can be helpful to take a digital photograph or a videotape of the engine compartment or of an assembled component before disassembly of something unfamiliar. Other helpful items to organize your project besides a camera or video camera include a permanent marking pen, masking tape, and plastic baggies (**Figure 4.1**).

Identifying the Vehicle

Even though you may know the year and model of the vehicle, sometimes you may need to know more about the specific vehicle. Each vehicle comes with a *vehicle identification number (VIN)*. Passenger vehicles manufactured for sale in the United States (domestic cars) have the VIN located on a plate on top of the dashboard, just under the windshield, on the driver's side of the vehicle (**Figure 4.2**). Since 1980, each VIN has been made up of 17 numbers and letters. Each letter or digit stands for something. For instance, on domestic cars the engine code is the eighth character and the year of the vehicle is the tenth character (**Figure 4.3**). Check the manufacturer's service manual for the meaning of each character for that make of car.

FIGURE 4.1 Some helpful items for a first-time engine rebuild include a camera, masking tape, marking pen, and baggies. *(Courtesy of Tim Gilles)*

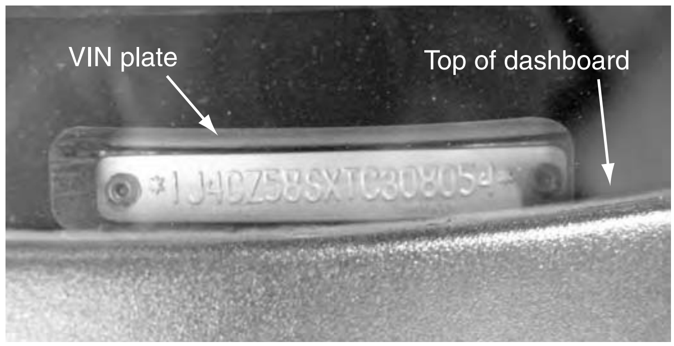


FIGURE 4.2 The vehicle identification number (VIN).

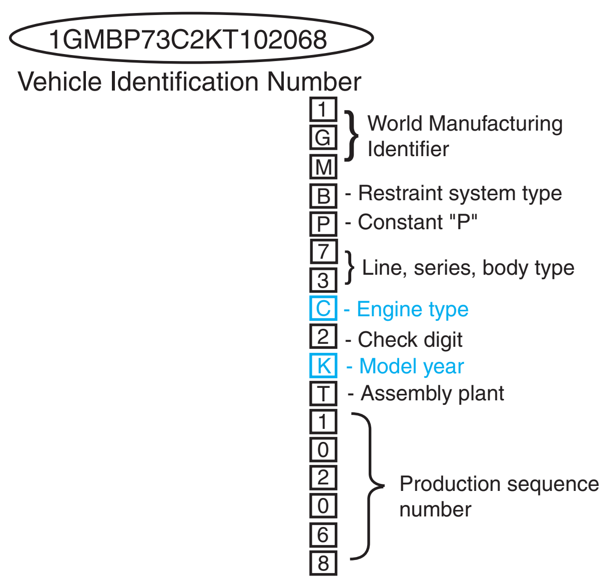


FIGURE 4.3 Each digit of the VIN stands for something.

VINTAGE ENGINES

Manufacturer Service Manuals and Microfiche

Until computers eventually made them obsolete, manufacturer service manuals were published each year for each make of vehicle. These were designed for use by the technicians in a dealership and covered only one year and model of vehicle. Every service operation was listed in detail. In the days of simple cars and trucks, when do-it-yourself was a popular service option, many new vehicle owners would purchase a dealer service manual to go with their vehicle. These are still available from some aftermarket publishers.

Another casualty of the computer revolution is microfiche. Although it is still available from some service literature providers, it has largely been replaced by computers and has become uncommon. Microfiche is a small plastic film card that is magnified by a microfiche reader. Many of these machines had copying capability so a hard copy of the information could be carried to the service bay.

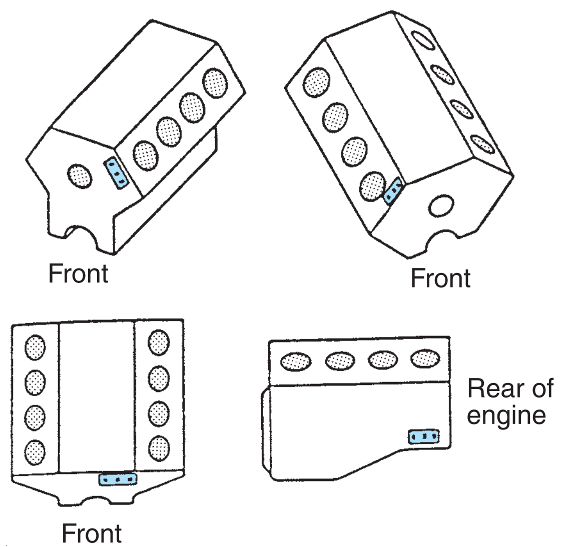


FIGURE 4.4 Engine serial number locations.

Vehicle Emission Control Information - XXXXXXX
Engine Family XXXXXXXXX
Evaporative Family XXXX
Displacement XXXXcm^3
CATALYST
Tune-up specifications
Tune-up conditions
Engine at normal operating temperature, all accessories turned off, cooling fan off, transmission in neutral
Adjustments to be made in accordance with indications given in shop manual

Idle speed	5 speed transmission	800 ± 50 rpm
	Automatic transmission	800 ± 50 rpm
Ignition timing at idle		15 ± 2° BTDC
Valve lash	Setting points between camshaft and rocker arm	In. 0.17 ± 0.02 mm cold
		Ex. 0.19 ± 0.02 mm cold
No other adjustments needed		

FIGURE 4.5 An under-hood emission label.

Engine Identification. If the engine is out of the vehicle, the VIN code might not be available. Some manufacturers use tags or stickers attached at various places such as the valve cover or oil pan. Do not lose the tag.

Blocks often have a serial number stamped into them. **Figure 4.4** shows several examples of serial number locations. The service manual gives the location of the code for a particular engine.

Under-Hood Label. Vehicles produced since 1972 are equipped with an *under-hood emission control label* (**Figure 4.5**). This label gives useful information to the technician as well as to an emission control specialist. It contains such information as ignition timing specifications, emission control devices, engine size, vacuum hose routing, and valve adjustment specifications.

Generic Service Manuals

Generic manuals, which deal with all makes of either foreign or domestic cars, are produced by several companies. There are usually two types of

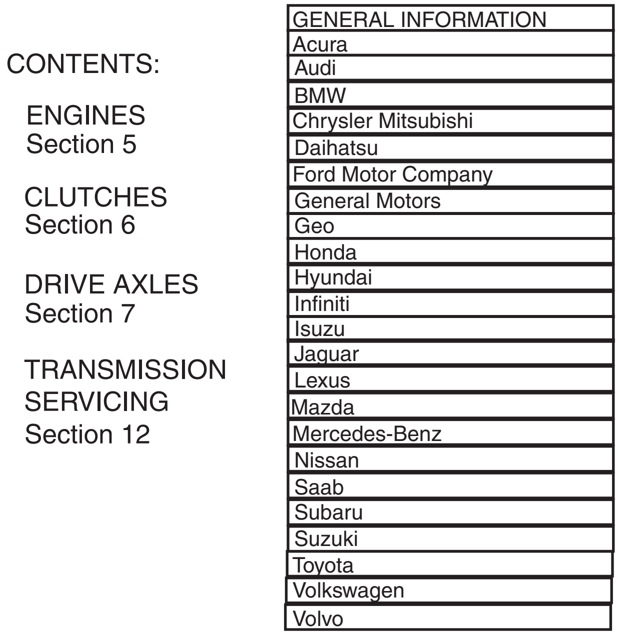


FIGURE 4.6 In the front of the service manual is an index of cars by maker.

generic manuals: those that deal with mechanical repairs such as engines and transmissions, and those devoted to the areas of fuel, emission, ignition, and air conditioning. Separate manuals are available for vans and light trucks.

Using the Manuals. Comprehensive generic repair manuals include sections for each make of car arranged in alphabetical order by manufacturer. An index of cars is located at the front of the manual (**Figure 4.6**). On the first page of each section is an index of service operations that can be used to locate a particular service procedure. Many manuals have separate sections for component repair, such as starters, alternators, transmissions, or differentials. A few pages of each section are devoted to specifications for things such as tune-up, electrical, wheel alignment, cylinder head and valves, and engine torque specifications (**Figure 4.7**).

Electronic Service Information

Computers have become the predominant storage system for service information. Subscription services are available from companies like AllData and Mitchell On-Demand. AllData covers vehicles from the 1982 model year to the present. Mitchell On-Demand goes back to 1984. They also sell a vintage system that dates back to 1960.

On single-user systems, information can be stored on CDs or DVDs that are updated quarterly. Many of today's repair shops have a computer in each service bay. All of the computers in the shop can be served by the shop's local area network. Some of the subscription service providers have information available directly from the Internet, where information is updated instantly and continuously.

- Some scan tools include access to subscription service information as well.
- Parts and labor estimating guides are also included in electronic systems.

The systems are easy to use and information is easy to access. The technician uses the computer's keyboard or mouse to make selections from a menu on the screen. When the technician locates the information in the computer, it can be read off the screen or sent to a printer so it can be taken to the service bay or workbench. Laptop computers and wireless Internet access also allow the technician to view the screen at the vehicle, saving paper.

The Automotive Engine Rebuilders Association (AERA) has a CD system called Pro-sis, covering over 3600 engines, 30,000 casting numbers, and over 2500 technical bulletins. CD systems also provide labor time estimates.

Technical Service Bulletins

Manufacturers and industry professional associations such as the AERA publish monthly *technical service bulletins* (TSBs) to subscribers and members. The AERA Technical Committee writes technical bulletins, often from material contributed by the membership. In some of these bulletins, association members report experiences discovered through trial and error. Other times, information in AERA bulletins comes from manufacturers. An example of one of its technical service bulletins is shown in **Figure 4.8**.

Manufacturers make extensive use of TSBs as well, issuing thousands of them each year to automotive technicians. TSBs are helpful in providing fixes for problems experienced by owners of new vehicles. They often provide detailed instructions, along with part numbers.

GENERAL MOTORS ENGINES

3.0L, 3.8L and 3.8L "3800" V6

Engine Specifications

Crankshaft Main and Connecting Rod Bearings

Engine	Main Bearings				Connecting Rod Bearings		
	Journal Diam. In. (mm)	Clearance In. (mm)	Thrust Bearing	Crankshaft End Play In. (mm)	Journal Diam. In. (mm)	Clearance In. (mm)	Side Play In. (mm)
All Models	[1]2.4988-2.4998 (63.469-63.494)	.0003-.0018 (.008-.005)	2	.003-.009 (.08-.23)	[1]2.2457-2.2499 (57.117-57.147)	.0003-.0028 (.008-.071)	.003-.015 (.076-.38)

[1] Maximum taper is .0003" (.008mm).

Pistons, Pins, and Rings

Engine	Pistons	Pins		Rings		
	Clearance In. (mm)	Piston Fit In. (mm)	Rod Fit In. (mm)	Ring No.	End Gap In. (mm)	Side Clearance In. (mm)
All Models	[1].0013-.0035 (.033-.089)	.0004-.0007 (.010-.018)	.00075-.00125 (.019-.032)	1	.010-.020 (.254-.508)	.003-.005 (.08-.13)
				2	.010-.020 (.254-.508)	.003-.005 (.08-.13)
				3	.015-.035 (.381-.889)	.0035 (.09)

[1] Measured at bottom of piston skirt. Clearance for 3.8L turbo is .001-.003" (.03-.08 mm).

Valve Springs

Engine	Free Length In. (mm)	Pressure Lbs. @ In. (Kg @ mm)	
		Valve Closed	Valve Open
3.8L (VIN C)	2.03 51.6	100-110@1.73 (45-49@44)	214-136@1.30 (97-61@33)
3.0L & 3.8L (VIN 3)	2.03 51.6	85-95@1.73 (39-42@44)	175-195@1.34 (79.1-88.2@34.04)
3.8L (VIN 7)	2.03 (51.6)	74-82@173 (33-37@44)	175-195@1.34 (79.1-88.2@34.04)

Camshaft

Engine	Journal Diam. In. (mm)	Clearance In. (mm)	Lobe Lift In. (mm)
3.0L	1.785-1.786 (45.34-45.36)	.0005-.0025 (.013-.064)	Int. .210 (5.334) Exh. .240 (6.096)
3.8L (VIN C)	1.785-1.786 (45.34-45.36)	.0005-.0025 (.013-.064)	[1].272 (6.909)
3.8L (VIN 3)	1.785-1.786 (45.34-45.36)	.0005-.0025 (.013-.064)	[1].245 (6.223)
3.8L (VIN 7)	1.785-1.786 (45.34-45.36)	.0005-.0025 (.013-.064)	....

[1] Specification applies to both intake and exhaust

Caution: Following specifications apply only to 3.0L (VIN L) 3.8L (VIN 3), 3.8L (VIN 7) and 3.8 "3800" (VIN C) engines.

TIGHTENING SPECIFICATIONS

Application	*Ft. Lbs. (N.m)*
Camshaft Sprocket Bolts	20 (27)
Balance Shaft Retainer Bolts	27 (37)
Balance Shaft Gear Bolt	45 (61)
Connecting Rod Bolts	45 (61)
Cylinder Head Bolts	[1]60 (81)
Exhaust Manifold Bolts	37 (50)
Flywheel-to-Crankshaft Bolts	60 (81)
Front Engine Cover Bolts	22 (30)
Harmonic Balancer Bolt	219 (298)
Intake Manifold Bolts	[2]
Main Bearing Cap Bolts	100 (136)
Oil Pan Bolts	14 (19)
Outlet Exhaust Elbow-to-Turbo Housing	13 (17)
Pulley-to-Harmonic Balancer Bolts	20 (27)
Outlet Exhaust Right Side Exhaust Manifold-to-Turbo Housing	20 (27)
Rocker Arm Pedestal Bolts	37 (51)
Timing Chain Damper Bolt	14 (19)
Water Pump Bolts	13 (18)

[1] Maximum torque is given. Follow specified procedure and sequence.
[2] Tighten bolts to 80 INCH lbs. (9 N.m.)

FIGURE 4.7 Engine specifications.

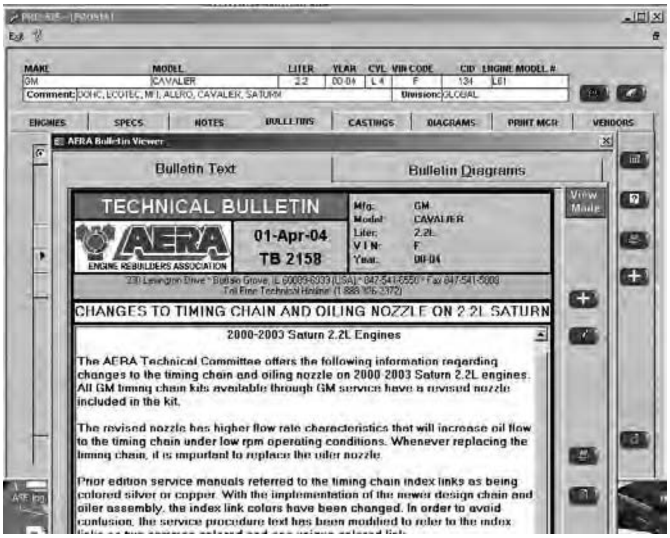


FIGURE 4.8 A typical technical bulletin. *(Courtesy of AERA)*

Hotline Services

Hotline services are those that provide answers to service questions by telephone, fax, or e-mail. Manufacturers provide help by telephone or electronically for the technicians in their dealerships. There are subscription services for independent shops to be able to get repair information by phone.

Some manufacturers also have phone modem systems that can transmit computer information from the car to another location. The car's diagnostic link is connected to the modem. The technician in the service bay runs a test sequence on the automobile. The system downloads the latest updated repair information on that particular model of car. If that does not diagnose the problem, a technical specialist at the manufacturer's location will review the data and propose a repair.

Internet

Technicians make extensive use of the Internet. The International Automotive Technicians Network (IATN) is a group with over 48,000 technician members representing 133 different countries. Members help each other solve tough problems and share technical theory ideas and diagnostic tips. The Web address is http://www.iatn.net.

AERA has a members-only Web page. It includes a current index of all AERA's shop bulletins, convention proceedings, and a casting number database that lists casting numbers for heads, blocks, and crankshafts. There are also discussion groups on the page http://www.aera.org.

Magazines

There are many professional magazines that technicians subscribe to; for example, *Motor, Automotive Rebuilder, Motor Service, Motor Age, Import Service,* and *Precision Machine Shop.* These magazines usually include information from the latest TSBs. They also include a mail-in reader service postcard. Readers can circle numbers on this card that relate to items about which they would like to receive more information.

Parts and Labor Estimating

When parts fail, they are replaced with either new or rebuilt ones. When the technician replaces the part, there is a time estimate available for this procedure. The time it should take a professional technician to perform a particular job is commonly called the *flat rate*. This information is available as part of the electronic subscription services or in a parts and time guide. Also included is an estimate cost of parts, so the business owner or service writer can provide the customer with a fairly accurate estimate.

SERVICE RECORDS

A service record is written for every car that enters a repair facility. A multiple copy, numbered service record, repair order (R.O.), or work order (W.O.) is used for legal, tax, and general recordkeeping purposes. One of the copies of the R.O. is given to the technician. It lists the repairs needed and it is used for making notations of repairs completed and items needing attention. One of the copies of the R.O. includes the cost estimate, which is for the customer; the remaining copy is for the shop's files.

The R.O (**Figure 4.9**) is important for several reasons. It is a legal document that:

1. Fully identifies the customer and the vehicle
2. Gives the technician an idea of the reason the car is in the shop for repairs
3. Tells the shop's hourly labor rate
4. Gives the customer an estimate of the cost of the repair
5. Gives the time the vehicle will be ready for the customer

The signature of the customer gives approval for the repair and indicates that he or she agrees to pay for the shop's services when the job is completed.

TERMS: Cash ☐ Credit Card ☐ Prior Approval ☐	VEHICLE IDENTIFICATION NUMBER (VIN):	YEAR:	MAKE: MODEL:	LICENSE NO:	REPAIR ORDER NO:
	CUSTOMER NAME/ADDRESS:		COLOR:	MILEAGE:	R.O. DATE:
CALL WHEN READY ☐ YES ☐ NO	RESIDENCE PHONE:	BUSINESS PHONE:	PRELIMINARY ESTIMATE:	**CUSTOMER SIGNATURE**	ADVISOR: HAT NO:
SAVE REMOVED PARTS FOR CUSTOMER ☐ YES ☐ NO	TIME RECEIVED:	DATE/TIME PROMISED:	REVISED ESTIMATE:	REASON:	ADDITIONAL COST:
CUSTOMER PAY ☐ WARRANTY ☐			AUTHORIZED BY: ☐ IN PERSON ☐ PHONE #	DATE:	TIME:
WE USE NEW PARTS UNLESS OTHERWISE SPECIFIED.	TEARDOWN ESTIMATE. IF THE CUSTOMER CHOOSES NOT TO AUTHORIZE THE SERVICES RECOMMENDED THE VEHICLE WILL BE REASSEMBLED WITHIN ____ DAYS OF THE DATE OF THIS REPAIR ORDER.			ADDITIONAL COST (TEARDOWN ESTIMATE):	
LABOR INSTRUCTIONS					
CUSTOMER STATES:					Concern
CHECK AND ADVISE:					Cause
REPAIR(S) PERFORMED:					Correction
WE DO NOT ASSUME RESPONSIBILITY FOR LOSS OR DAMAGE OF ARTICLES LEFT IN YOUR VEHICLE. PLEASE REMOVE ALL PERSONAL PROPERTY ______ CUSTOMER RENTAL ______ COURTESY VEHICLE ______ SHUTTLE					

FIGURE 4.9 A repair order includes the concern, the cause, and the correction. (*Courtesy of Tim Gilles*)

R.O.s are numbered for future reference. Also entered on them are the odometer mileage, vehicle make and model, vehicle model year, and license number. Information that will identify the customer includes his or her name, address, and telephone numbers for home, cell, and business. A space for labor instructions is located below the customer information area. This area will be filled in with the customer's complaint, possible cause(s), and repairs to be performed.

NOTE

The three items on the R.O. are called the "3 Cs": concern, cause, and correction.

Computer Records

Service and repair facilities use personal computers for keeping records, maintaining a running inventory and ordering parts, and tracking employee productivity. Notes saved in memory can include personal notes regarding a particular customer and what occurred during his or her most recent visit to the shop. The computer locates a customer's records using the vehicle's license number, the owner's name, or the owner's address. The license number is the most popular means of access.

Although a shop may keep computer records, a *hard copy* is still used by many shops for the technician, although some shops have a computer terminal in the service bay. It is important that a shop keep written records of all repairs and recommendations. Litigation (court cases) often results in a lost case due to a lack of adequate records. A completed R.O. includes a written estimate of the cost of the repair and a record of phone conversations with an owner when an earlier approved estimate requires updating.

ENGINE REMOVAL

This section of the chapter describes how to remove an engine from both front- and rear-wheel drive vehicles. Rear-wheel drive, which was the predominant driveline arrangement in North American vehicles until the 1980s, is still used in many SUVs, pickup trucks, and luxury automobiles. In this chapter, engine removal specifics common to both front- and rear-wheel drive vehicles are covered first. Rear-wheel drive engine removal is covered next, followed by front-wheel drive.

NOTE

Computer information systems like AllData and Mitchell On-Demand, AERA's Pro-sis, and manufacturer specific Web sites have technical bulletins. Always refer to these before attempting a large repair.

Install fender covers on both fenders and over the grille to protect the vehicle's paint. Some shops like to protect the windshield with a piece of corrugated cardboard.

NOTE

Work carefully. When flat rate work fails, the job is done again by the technician at no charge to the customer. A problem deep inside a recently rebuilt engine could require removal of the engine, which is a disaster for the technician who first performed the job.

Disconnect the battery cables. The ground cable (usually the negative) should be disconnected first. This is a good habit to get into. Disconnecting the ground cable first eliminates the danger of a spark when disconnecting the positive cable.

There is usually a thin film of battery acid all over the outside of the battery. After handling the battery, be sure to clean your hands. Hands soiled

VINTAGE ENGINES

Before fuel injection became common starting in the late 1960s, older engines used carburetors. Emission controls became more prevalent, with most of them being controlled by vacuum. A carburetor could have as many as 14 hoses connected to it.

by battery acid can ruin any clothing they come into contact with.

SHOP TIP

If the car has been raised in the air on a lift with the battery still connected, the ground cable can usually be unbolted from the block. Slip a piece of hose over the end of the cable, or tape it, so that it cannot accidentally contact the ground at the frame or the block.

NOTE

Sometimes there is a small ground wire that is connected from the battery terminal to the fenderwell. Be sure to remove the battery terminal connection from cars that have this or a complete circuit could still be present through the ground strap from the block to the bulkhead or fire wall that separates the engine compartment from the passenger compartment.

Perform the following steps to remove the engine.

1. **Remove the air cleaner and label all wires and vacuum lines.** The air cleaner on a typical port fuel injected engine is located off to the side and is connected to the fuel system by a molded hose (**Figure 4.10**). These hoses can become fragile with age and can be expensive to replace. A broken hose can cause drivability complaints on some types of fuel injection and can allow dirty air to enter the engine on all systems.

   If possible, leave the wires connected to the alternator; simply unbolt it and use wire to fasten it to something out of the way. Use masking tape to label any electrical wiring that must be disconnected. Taking the time to do this will save the time that would be wasted in trying to determine the proper locations for the wires during reassembly.

   Later model vehicles usually have some of the hoses grouped together with male and female connectors on the ends to make proper hose connection easier. Sometimes the hoses are numbered, color coded, or different sizes.

   There are several methods used to keep hoses identified so they can be reattached in the correct position. Rolls of numbered tape are available from automotive tool and parts suppliers (**Figure 4.11**). Affix two pieces of tape with the same number, one on the hose and the other on the connection where the hose was removed (**Figure 4.12**). Some technicians keep several narrow rolls of different color tape for labeling unmarked hoses in this same manner.

   Late-model vehicles have a vacuum diagram under-hood label (**Figure 4.13**). When there is none, draw a map of the vacuum hoses. Assign a number to each hose on the map.

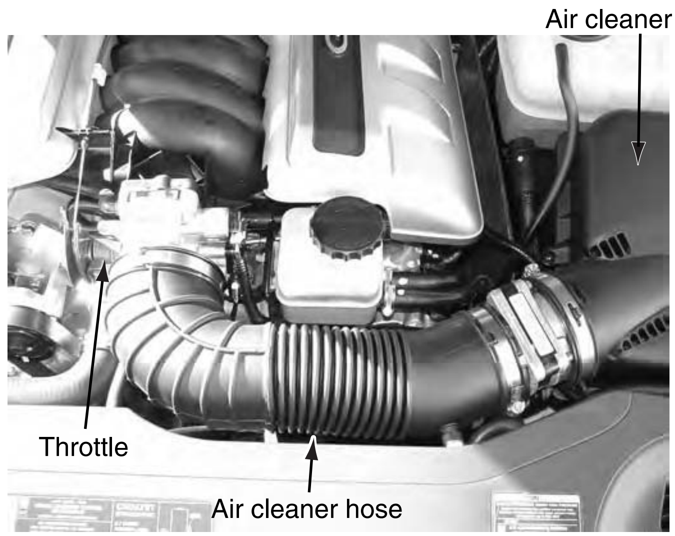


FIGURE 4.10 Remove the air cleaner and hose. Be careful not to crack the hose. *(Courtesy of Tim Gilles)*

FIGURE 4.11 A numbered tape dispenser. *(Courtesy of Tim Gilles)*

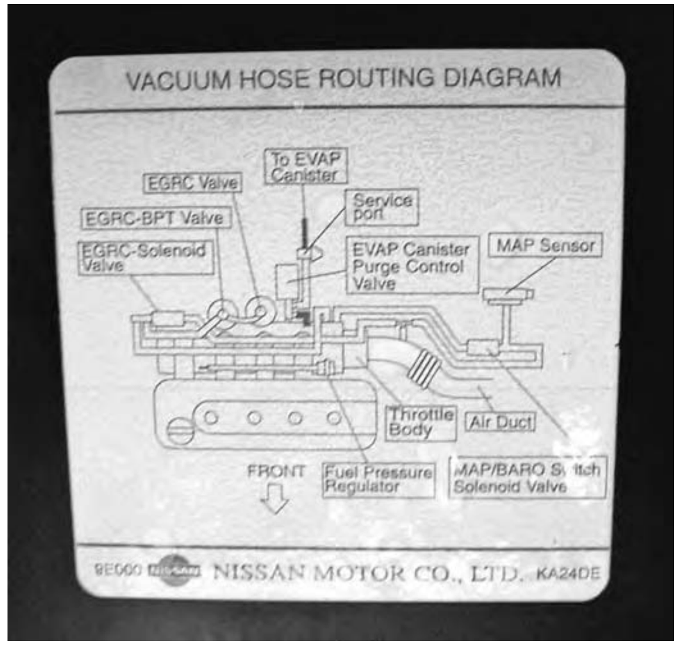


FIGURE 4.13 An under-hood label showing the location of vacuum hoses. *(Courtesy of Tim Gilles)*

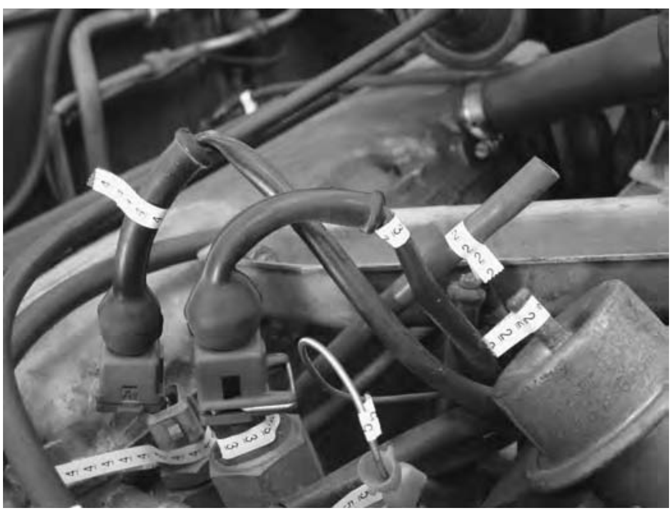


FIGURE 4.12 Tape is numbered to label matching vacuum and electrical lines. (*Courtesy of Tim Gilles*)

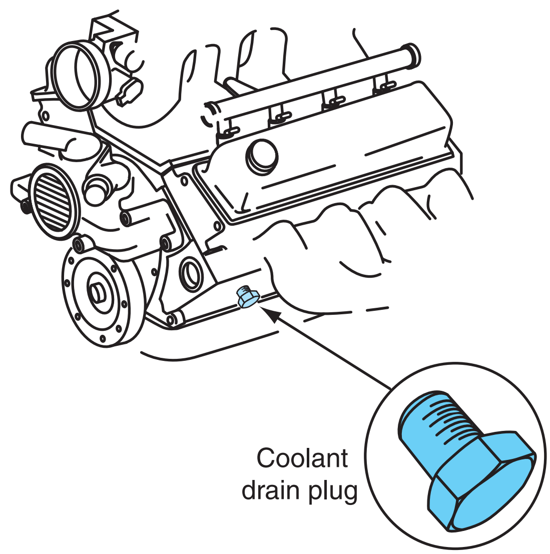


FIGURE 4.14 A coolant drain plug in a cylinder block.

Then use masking tape and a pen to number each line as it is removed.

2. **Drain coolant and oil.** Drain all coolant from the radiator and block. If the coolant is not to be reused, be sure to comply with local regulations for its disposal. If the block is equipped with a coolant drain plug (**Figure 4.14**), the engine block should also be drained. Drain engine oil and remove the oil filter. The oil filter is made of thin sheet metal that is easily crushed or torn if the filter wrench is not held as close to the filter base as possible (see Chapter 14).

3. **Remove the hood.** The hood should be removed before removing the engine. Mark the location of the hood to the hood hinges so that it can be properly reinstalled.

SHOP TIP

Always remove the highest hood bolts first so the lower bolts can continue holding the hood while you remove them. This prevents the hood hinge from accidentally bending.

The hood can be temporarily stored upside down on the roof of the car (**Figure 4.15**). Be careful not to damage the paint. Do not stand the hood on end. This can damage paint on the corners or edges of the hood. Set the hood on a fender cover or cardboard. Hood hinges may be pried down to get them out of the way if the hood is not to be reinstalled right away.

CASE HISTORY

A student removed the engine from a van. To make sufficient space for the engine to be removed from the front, he removed the radiator and crossbar support above it (Figure 4.16a). The crossbar support also held the hood latch. Unfortunately, the wind came up and lifted the hood, tossing it against the windshield, which was shattered by the impact (Figure 4.16b). The student was upset that someone had vandalized his windshield, until he figured out that the unrestrained hood had been the culprit.

4. **Remove the radiator.** Disconnect the radiator hoses from the engine. They can be left attached to the radiator, so they do not need to be marked for reassembly. Remove the radiator from the car. It can be stored with its hoses installed and the radiator cap installed.

FIGURE 4.15 When the hood is temporarily stored upside down on the roof of the car, be certain that there is a fender cover protecting the paint and that the car is indoors, away from potential wind. *(Courtesy of Tim Gilles)*

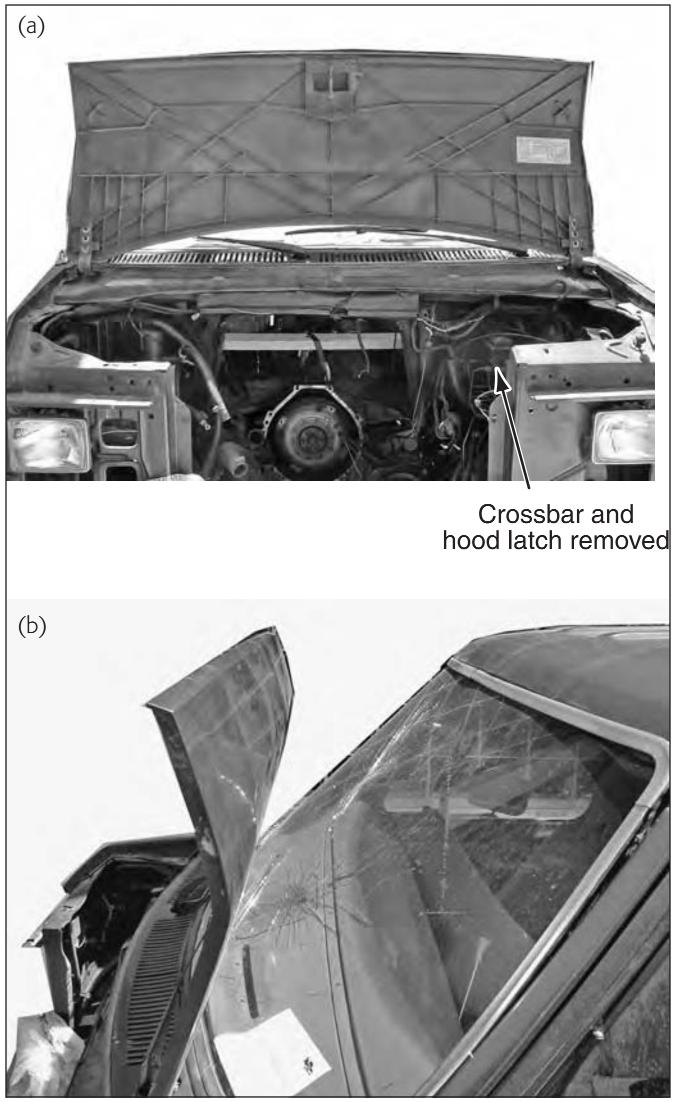


FIGURE 4.16 (a) The crossbar was removed to allow room for engine removal. (b) The van was stored in an outdoor parking area. Wind during the night tossed the hood against the windshield. *(Courtesy of Tim Gilles)*

SHOP TIP

If the engine or radiator sits for a long time, be sure to leave it filled with water or 50/50 coolant to keep air away. A used radiator will be ruined in a short time if left exposed to air.

If the car has an automatic transmission, it is probably equipped with a heat exchanger (cooler) in the bottom or side tank of the radiator (see Chapter 15). The two lines leading to the radiator from the transmission must be removed and plugged. Use a flare-nut (tubing) wrench (see Figure 4.24).

SHOP TIP

A ruined transmission oil line can be repaired using a union (see Chapter 16). A piece of hose is another alternative, but two considerations must be made:

- Transmission oil cooler (TOC) hose must be used. Fuel hose will be damaged by automatic transmission fluid. A leak and/or a fire could result.
- Both ends of the tubing must be flared to prevent the hose from slipping off. Transmission fluid in this circuit ranges from 35 to 55 psi. A bubble flare works best for this because it will not cut the inside of the hose.

5. **Remove the distributor and spark plug cables.** Some engines have distributors. It is a good idea to remove the distributor and spark plug wiring before removing the engine to prevent damage caused by interference with the lifting sling. Do not remove the spark plug cables from the distributor cap. They are already in the correct firing order and need not be disturbed. Mark the location of the number 1 spark plug cable on the distributor cap before removing any of the other cables. If the cables are to be replaced, replace them one at a time so they can be measured easily and kept in order.

6. **Remove the alternator and accessory wiring.** First, remove the alternator. If possible, leave the wires connected to the alternator; simply unbolt it and use wire to fasten it to something out of the way. Use masking tape to label any electrical wiring that must be disconnected. Taking the time to do this will save the time that would be wasted in trying to determine the correct location of wires during reassembly.

   Many of today's engines do not have belt-driven cooling fans or air pumps for the emission control system. To prevent damage to these items if an engine is so equipped, they should be removed, along with the alternator, before attempting to remove the engine (**Figure 4.17**) .

CAUTION

If an engine is equipped with a belt-driven fan clutch, store it facing up or sideways, not upside down.

If the engine is to be cleaned before removal, protect the alternator so cleaner soap does not damage alternator bearings. After the engine is cleaned, be sure to clearly label the electrical connections to the starter and the oil pressure and coolant temperature sending units (**Figure 4.18**).

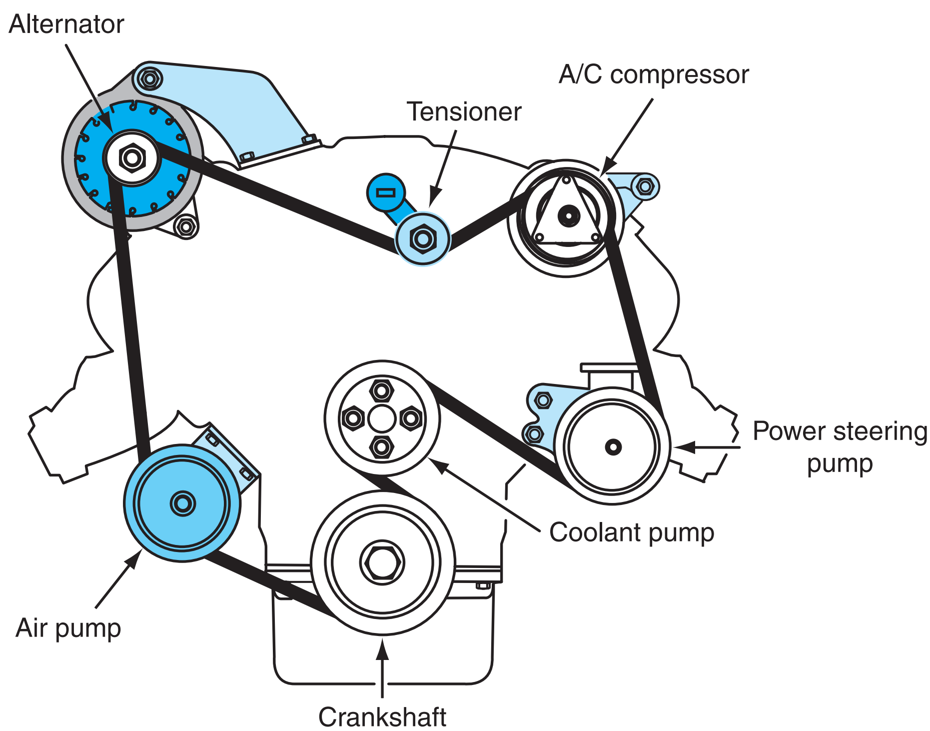


FIGURE 4.17 Remove any belt-driven accessories before removing the engine.

7. **Remove the heater hoses and ground strap.** The heater has a control valve in one of the heater hoses. Label the hose that comes from the coolant pump so it can be reattached there later. There are usually one or more ground straps from the engine to the fire wall (**Figure 4.19**). Be sure to disconnect it before the engine is removed.

SHOP TIP

A missing or broken ground strap can cause failure of a transmission bushing, wheel bearing, or emergency brake cable. This is because electricity follows the shortest path to ground, causing etching.

8. **Remove switches and sensors.** Newer engines have coolant temperature sensors that supply the PCM with information on engine coolant temperature. In response to this input, the PCM commands electrical devices, called actuators, to switch emission control devices on as engine temperature rises.

   Engines with distributorless ignitions have crankshaft position sensors. Sometimes they have camshaft sensors, too. Carefully remove them and store them where they will not be damaged. **Figure 4.21** shows one of these sensors.

   Late-model engines also have detonation sensors, also called knock sensors (see Figure 3.50).

FIGURE 4.18 Label the wires to the sending units.

FIGURE 4.19 Remove any ground straps or wires connecting the engine to the chassis. *(Courtesy of Tim Gilles)*

FIGURE 4.20 A thermal vacuum switch socket. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Older engines often had a coolant temperature-operated device to control vacuum to emission control devices. These switches, often called thermal vacuum switches, are very easily damaged and can be expensive to replace. Use a special socket (**Figure 4.20**) to remove one of these devices prior to removing the intake manifold. Many of them are plastic, which can get more brittle with age.

FIGURE 4.21 A crankshaft position sensor. *(Courtesy of Tim Gilles)*

Remove this if it is easily accessible to prevent breaking it during engine removal.

9. **Bleed fuel system pressure.** Fuel injection systems are designed to remain pressurized after the engine is shut off so that the engine can start quickly. Also, when fuel in the lines is kept under pressure, it is less likely to boil as it soaks up heat when the engine is shut off. If one of the clamps on the system is loosened, pressurized fuel can escape.

   Bleed pressure from the system before working on it. After fuel system pressure has been bled, the fuel injectors can be removed.

SAFETY NOTE

- Wear safety glasses and do not use a drop light. Liquid falling on the hot glass can cause the bulb to explode. If it is accidentally dropped or has a bad switch or loose connections, it can cause a fire.
- Work in a well-ventilated area with no possible source of ignition such as running vehicles or electrical equipment.

There are several methods that can be used to relieve pressure from the fuel system. Check the manufacturer's manual for the recommended procedure.

A very simple procedure for bleeding pressure from the fuel system is as follows:

- Disconnect the electrical connector to the fuel pump or remove the fuel pump relay or fuse.
- Crank the engine briefly to drop the fuel pressure or run the engine until it stalls.

Another pressure bleeding procedure is to:

- Disconnect the battery ground cable.
- Remove the filler cap from the fuel tank.
- Some systems have a *Schrader* valve that can be used to bleed off pressure from the system before disassembly. (A Schrader valve is the kind that is found on tire valve stems.) Remove the threaded cap from the fuel pressure test port on the fuel rail to find the Schrader valve.
- Use a special hose that has a pressure relieving tool on the fuel rail end to drain fuel to a gas can (**Figure 4.22**).

10. **Remove and plug the fuel line.** The fuel line from the tank must be disconnected. After fuel system pressure has been bled, the fuel injectors can be removed.

SHOP TIP

To prevent fuel leakage from the line, plug it with a bolt and hose clamp (**Figure 4.23a**) or pinch pliers (**Figure 4.23b**). When using pinch pliers on hose or tubing, care must be taken not to damage the inner lining of a hose. Also, some fuel injection tubing is designed for high-pressure use. This tubing is rigid and must not be clamped.

VINTAGE ENGINES

Cars with carburetors almost always have a mechanical fuel pump that is sometimes best removed before removing the engine from the car. The fuel pump is operated by an eccentric on the camshaft. Loosen the bolts that hold the fuel pump to the block. Then turn the engine until all spring tension is removed from the pump rocker arm. The cam eccentric will then be in its low position so the fuel pump can be easily removed.

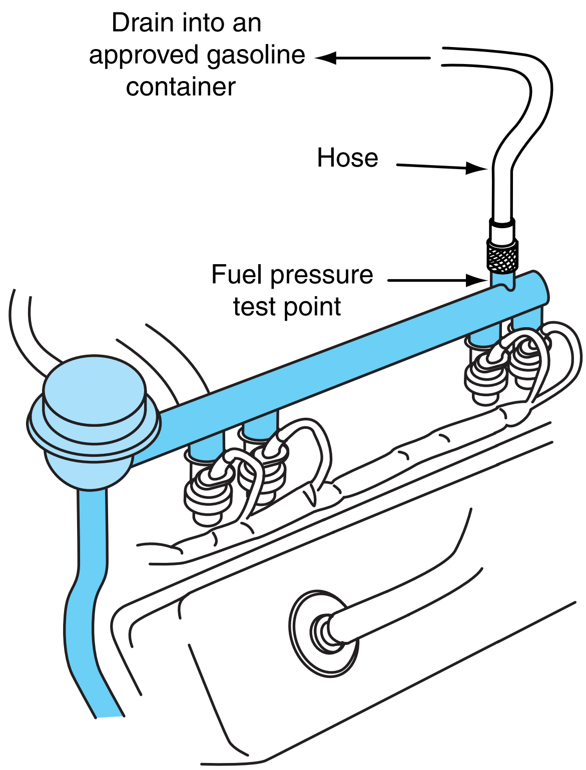


FIGURE 4.22 Bleed pressure from the fuel system before disconnecting fuel lines.

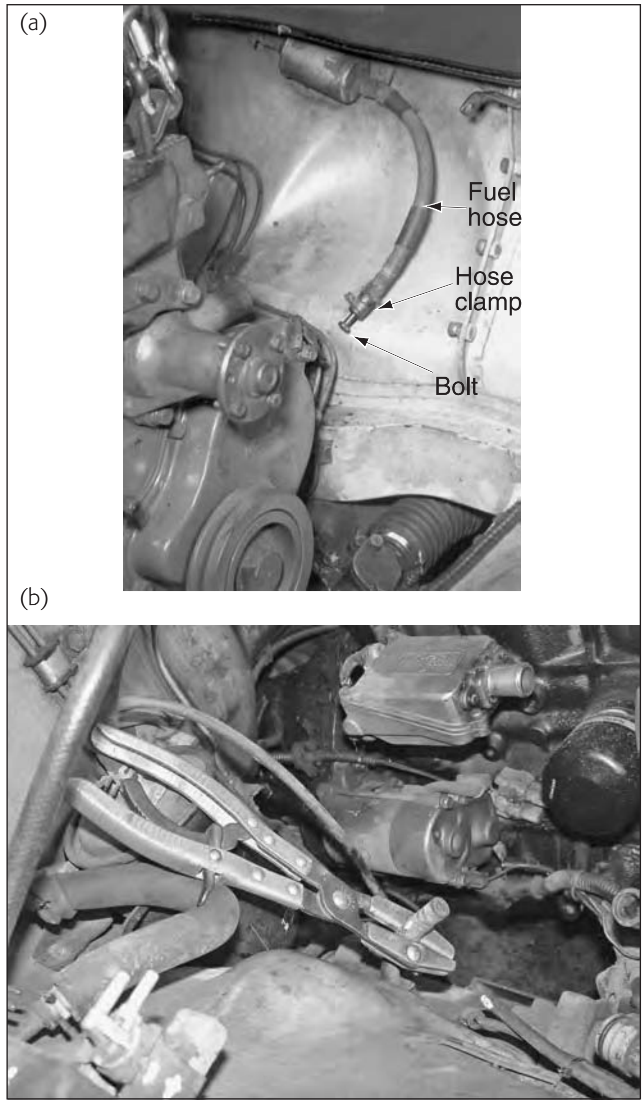


FIGURE 4.23 Disconnect and plug the fuel line. (a) A fuel hose plugged with a bolt and hose clamp. (b) A fuel line closed off with pinch pliers. *(Courtesy of Tim Gilles)*

SAFETY NOTE

Even though fuel may not pour out of a fuel line when it is first disconnected, a hot day can cause expansion of the fuel in the tank. This can result in the fuel in the tank siphoning out all over the ground. Be sure to plug all fuel lines, including those to the smog control vapor canister.

VINTAGE ENGINES

Older engines had carburetors. Some of them became very complicated and expensive in response to the needs of evolving emission control systems. If you are removing a carburetor, be sure to use a flare-nut wrench and an open-end wrench when removing its fuel line (**Figure 4.24**).

- Failure to use both wrenches can result in a ruined fuel line (see Chapter 13). An expensive carburetor could also be ruined.
- A flare-nut wrench, also called a tubing wrench, has five sides that contact the flats of the hollow six-sided fuel fitting. An open-end wrench will contact the fitting on only two flats, almost always resulting in a rounded-off fitting that will be difficult to remove.

FIGURE 4.24 Use both a flare-nut (tubing) wrench and an open-end wrench on fuel or transmission lines. *(Courtesy of Tim Gilles)*

11. **Remove the intake manifold and valve covers.** When engine work (such as a valve job) is performed on an engine while it is in the car, the flat rate technician will try to remove as few parts as possible in order to save time. During a complete overhaul, the engine will be completely disassembled for cleaning.

    Remove the throttle linkage or cable. Then remove the valve covers and motor mount bolts. Injectors, sensor wires, and harnesses must be disconnected. Before the engine is removed from the car, the intake manifold can also be removed.
12. **Mark accessory brackets and remove accessories.** Any accessory brackets (such as for air conditioning) that are attached to the head or block may be removed. If the vehicle has many accessories, label the brackets to show their locations on the head or block.

NOTE

Some accessories have multiple-piece brackets. Repair manuals do not usually show bracket locations. Sometimes the brackets can be left bolted to the accessories for easier reassembly.

Because of the unusual lengths of many accessory bracket bolts, it is a good idea to put them in labeled bags for easier reassembly. An air-conditioning compressor bolt that is too long can damage an expensive compressor housing. When there are bolts of different lengths, it saves time to assemble each one back into its accessory bracket as it is removed.

SAFETY NOTE

Do not disconnect air-conditioning hoses. They contain pressurized refrigerant. If a refrigerant line must be disconnected to recycle/reclaim refrigerant, *use extreme caution and wear eye protection*. Refrigerant vaporizes so fast that it freezes anything it touches. It can cause blindness and turns to deadly phosgene gas (nerve gas) if allowed to contact an open flame or an extremely hot metal surface.

NOTE

R12 (Freon) refrigerant, used in most vehicles until 1994, has been implicated in the depletion of the earth's ozone layer. In the Montreal Protocol of 1987, 23 countries (including the United States and Canada) signed an agreement setting limits on the production of ozone depleting chemicals. Since 1992, refrigerant recycling machines have been required by law. Persons using the equipment must be certified. Certification is available from several industry associations.

The *air-conditioning compressor* can usually be wired up out of the way with the lines still attached (**Figure 4.25**). When air-conditioning lines must be disconnected, be sure to plug all openings immediately. Moisture must not be allowed to enter the system. It is illegal to allow refrigerant to escape into the atmosphere. If refrigerant must be removed, a recycling machine is required (**Figure 4.26**).

VINTAGE ENGINES

In rare instances, older V-type engines might have the manifold stuck to the heads. These can sometimes be loosened up by loosening the cylinder head bolts first.

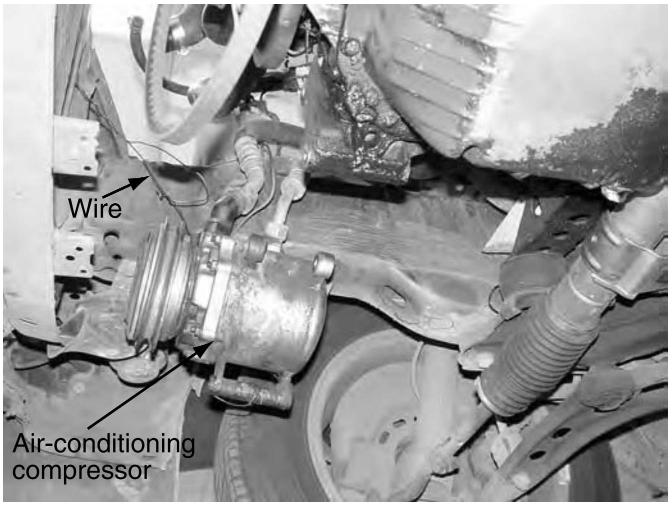


FIGURE 4.25 Wire the air-conditioning compressor out of the way with both refrigerant lines still attached. *(Courtesy of Tim Gilles)*

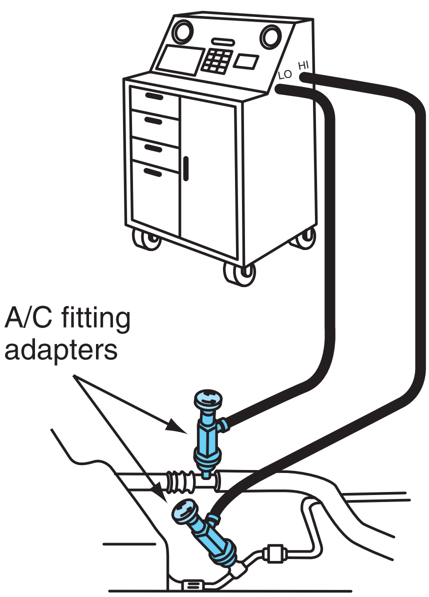


FIGURE 4.26 An air-conditioning charging and recycling machine.

SHOP TIP

Remove the power steering pump without disconnecting the lines and wire it in a position so that fluid cannot leak out.

13. **Remove exhaust components.** Because of rust, exhaust manifold and exhaust pipe bolts will be difficult to remove and have a tendency to break. Spray penetrating oil on them. See Chapter 16 for information on how to remove broken fasteners.

SHOP TIPS

- A rusted fastener can sometimes be tightened slightly to help penetrating oil get into the threads.
- Rusted manifold bolts are easier to remove with an impact wrench (**Figure 4.27**). Use this method to remove rusted bolts whenever possible.
- Use a six-point socket to remove most engine items, especially exhaust bolts and nuts. A 12-point socket will be more likely to slip, rounding off the corners of a nut.

Since the 1980s, most cars have computer-controlled fuel systems that use an oxygen sensor to determine the proper air-fuel mixture (**Figure 4.28**). Disconnect the wire to the sensor; the sensor can be left in the exhaust manifold. Oxygen sensors can be expensive. Use an oxygen sensor socket if it is to be removed from

FIGURE 4.27 Use an impact wrench to remove exhaust manifold-to-pipe bolts.

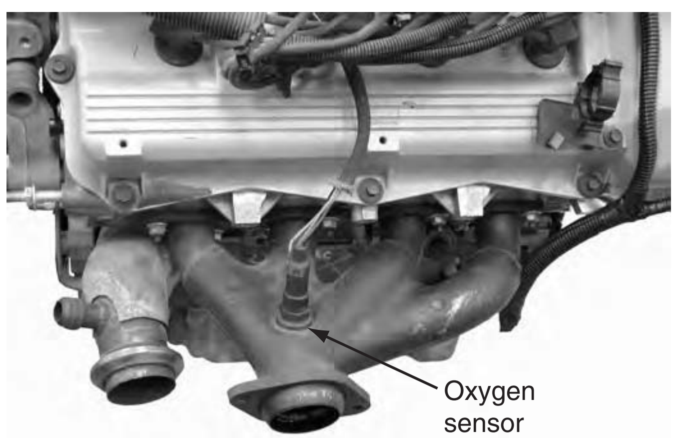


FIGURE 4.28 An oxygen sensor in an exhaust manifold. *(Courtesy of Tim Gilles)*

the exhaust manifold (**Figure 4.29**). Otherwise leave it in the manifold and be very careful not to damage it.

14. **Determine whether to remove the transmission.** Before engine removal, locate the recommended procedure in the service literature. On a rear-wheel drive vehicle, it is generally easier to leave an automatic transmission in the chassis when removing the engine (**Figure 4.30**). Some front-wheel drive engines are easiest removed without removing the transmission as well.

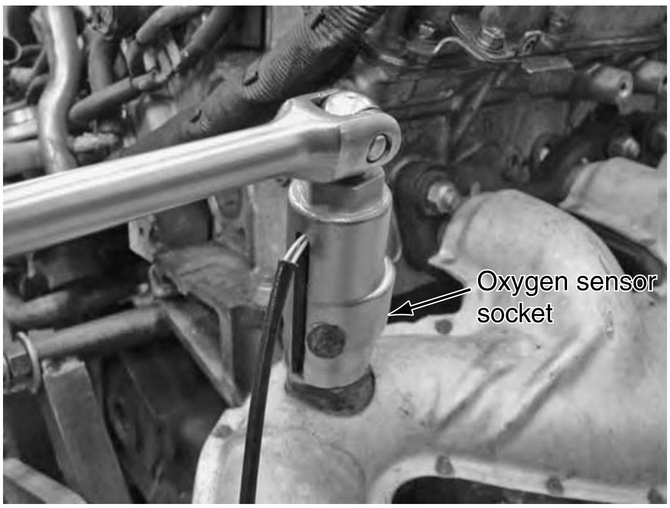


FIGURE 4.29 Oxygen sensors can be expensive. Use an oxygen sensor socket to remove one. It has a slot for the wires to the sensor. *(Courtesy of Tim Gilles)*

FIGURE 4.30 When an engine is removed from a rear-wheel drive vehicle, it is usually easier to leave the transmission in the vehicle. *(Courtesy of Tim Gilles)*

Separating the Engine and Transmission/Transaxle

Although the first set of instructions here apply to rear-wheel drive vehicles specifically, the following hints apply to separating the engine from an automatic transmission or transaxle on both front- and rear-wheel drive vehicles. Make center punch marks on the converter and the flexplate so they may be correctly aligned on reassembly (**Figure 4.31**).

Remove the torque converter attaching bolts from the flywheel flexplate (**Figure 4.32a**).

SHOP TIP

If an impact wrench is used, the crankshaft will not have to be held to keep it from turning.

To gain access to each bolt, rotate the engine by turning the crankshaft with a large socket and breaker bar on the damper bolt at the front of the engine (**Figure 4.32b**).

SHOP TIP

An easy way to rotate the engine on cars equipped with a standard transmission is to jack up one wheel, with the vehicle in gear, and turn the tire. Be sure to always turn the engine in its direction of normal rotation. Some OHC engines will skip cam timing if they are turned backwards.

FIGURE 4.31 Mark the flexplate and torque converter prior to disassembly. *(Courtesy of Tim Gilles)*

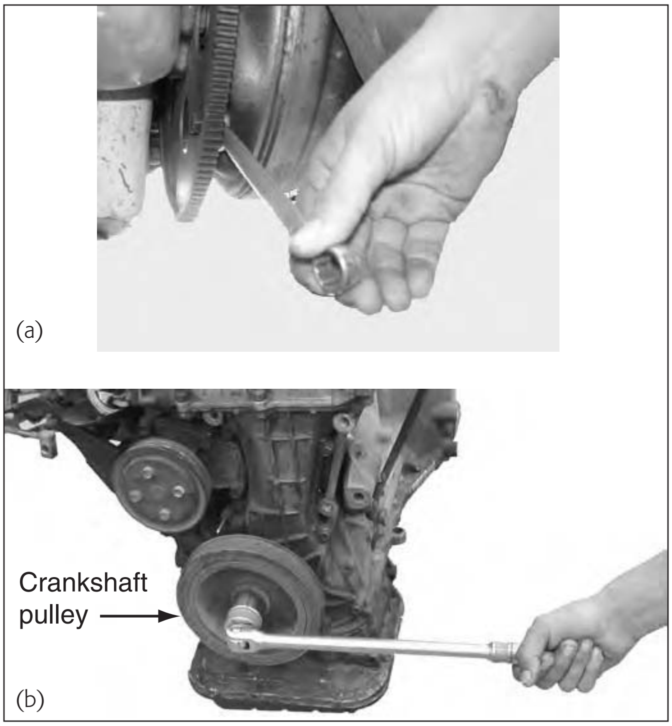


FIGURE 4.32 (a) Remove the torque converter-to-flexplate bolts. (b) Turning the crank using the damper bolt. *(Courtesy of Tim Gilles)*

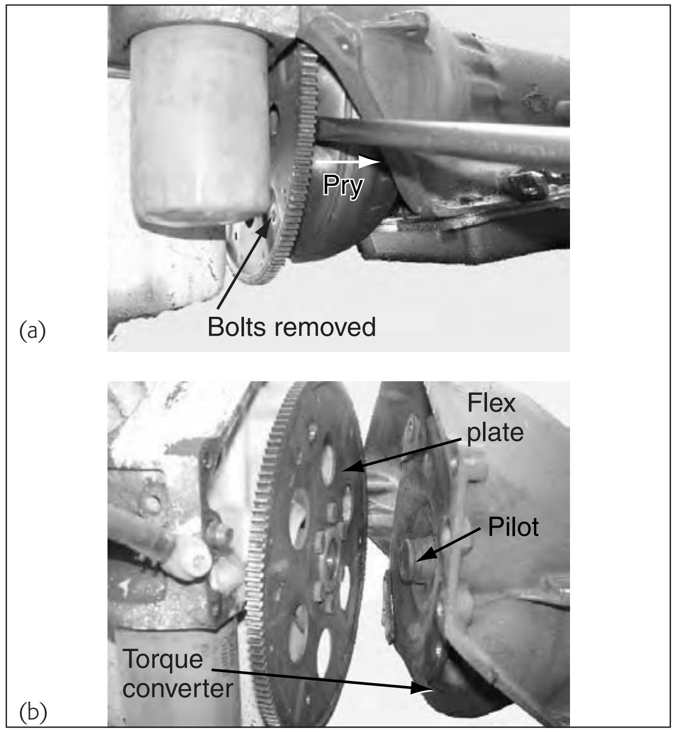


FIGURE 4.33 (a) Pry the torque converter away from the flexplate. (b) Leave the converter in place in the front of the transmission to prevent fluid from leaking out. *(Courtesy of Tim Gilles)*

Pry the torque converter away from the flexplate (**Figure 4.33a**). Do not remove the converter from the transmission during engine removal; if the converter remains in place in the transmission, fluid will not be able to pour out of it (**Figure 4.33b**). Occasionally the converter hub is rusted to the crankshaft, requiring considerable effort to pry the two apart. **Figure 4.34** shows the pilot hole in the engine's crankshaft. If the transmission dipstick tube is attached to the cylinder head, unbolt it.

Remove the engine-to-transmission bolts. On rear-wheel drive vehicles, these bolts are easily loosened by using a very long extension and a universal socket from underneath the car (**Figure 4.35**).

NOTE

When a long extension is used with an impact wrench, a larger impact wrench might be needed because some of the impact is absorbed by the long extension.

Sometimes it is necessary to unbolt the rear transmission crossmember and allow the rear of the transmission to drop. This gives the technician easier access to the top engine-to-transmission attaching

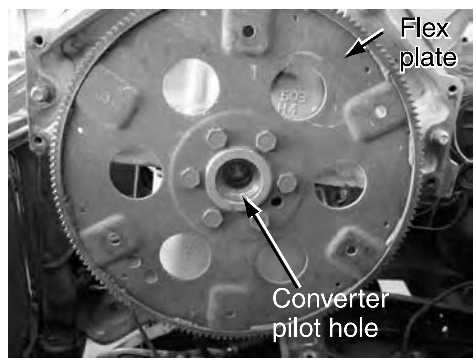


FIGURE 4.34 A pilot hole in a crankshaft aligns with the hub on the front of the torque converter. *(Courtesy of Tim Gilles)*

bolts and also to the transmission cooler lines located high on some transmissions.

Figure 4.36 shows a C-clamp installed to keep the converter in place in the pump in the front of the transmission. If the converter slides too far forward, it will come out of the transmission pump. It must be realigned with the pump drive gear to prevent damage to the pump and flexplate when the engine is reinstalled.

A rear-wheel drive transmission *must* be supported during and after engine removal. It can be wired up so that it will not hang.

SHOP TIP

When the engine and transmission are first separated, clearance from the edge of the converter housing to the front of the converter can be measured and recorded. Although this step is not necessary, it can give peace of mind to a beginning technician during reassembly. Besides using a C-clamp, a converter can be held into the transmission with safety wire or a bar bolted across the front of the converter housing.

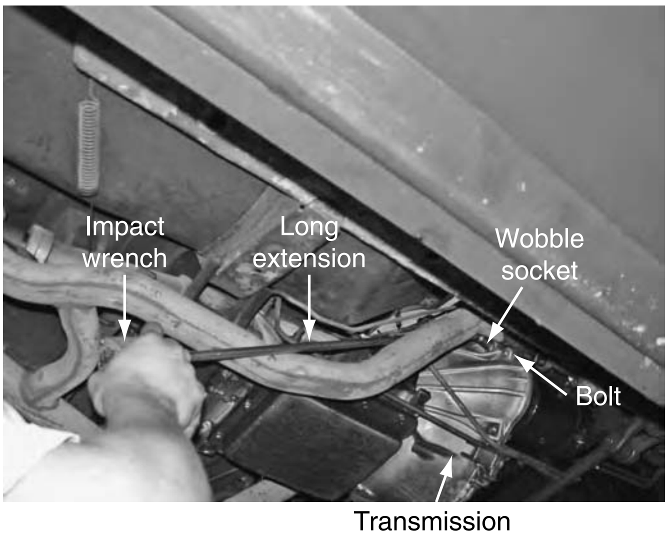


FIGURE 4.35 On rear-wheel drive vehicles like this van, the top transmission-to-engine bolts are most easily removed from the bottom like this. *(Courtesy of Tim Gilles)*

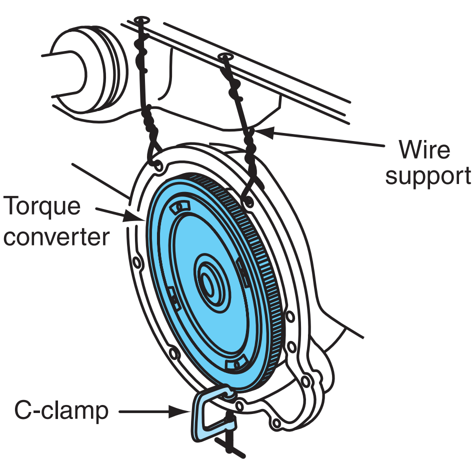


FIGURE 4.36 A C-clamp is installed to keep the torque converter in place when the engine is removed without removing the transmission. Attach the wire to the transmission so it does not hang.

NOTE

Ideally, converters without studs should be only ⅛" from the flexplate when pushed as far into the transmission as possible. This is to ensure that the transmission front pump drive gear is sufficiently engaged by the torque converter drive lug. If the distance is more than ⅛", shims can be installed.

When a torque converter is removed from an automatic transmission or transaxle, quickly rotate it upward so the transmission fluid does not empty out and make a mess (**Figure 4.37**). A typical torque converter can hold 3 or 4 quarts of transmission fluid.

CASE HISTORY

An engine with an automatic transmission was replaced with a rebuilt unit. While the engine was out of the car, the torque converter, which was no longer supported by the rear of the engine crankshaft, hung on the old seal, which had become brittle with age. When the new engine was started, oil came pouring from the front of the transmission. The transmission had to be removed to make the repair. Removing the engine would have been more difficult. The customer blamed this leak on the shop because the transmission was not leaking when he brought the car in for the engine.

FIGURE 4.37 When removing a torque converter, immediately flip its open end up so fluid does not leak out. *(Courtesy of Tim Gilles)*

If the transmission is to be removed from a rear-wheel drive vehicle, disconnect the shaft linkages, electrical wires, speedometer cable, and the drive shaft. Tape the rear U-joint cups with masking tape so they will not accidentally fall off the U-joint (**Figure 4.38**).

NOTE

Some two-piece drive shafts are splined where they join at the center. The U-joints on both sections must be in "phase" (in the same plane), or serious vibration will occur. If the halves are to be separated, mark them for easier reassembly.

Plug the end of the transmission after removing the drive shaft so the transmission fluid will not leak out (**Figure 4.39**). Disconnect the speedometer cable or wire from the transmission. It is a good idea to replace the transmission front pump seal while the engine is out of the vehicle (see Chapter 16).

Before removing the transmission from a vehicle with a standard transmission, the clutch activating fork and gearshift linkages must be disconnected.

15. **Unbolt the engine mounts** (**Figure 4.40**). Mark them with a center punch or marker to show which side of the mount is the front and which side is left or right.

    In some vehicles, the engine can actually be installed with the mounts reversed. The rear transmission mount stretches until there is metal-to-metal contact with the mount and the frame. This causes engine vibration to be felt as the vehicle is driven.

CASE HISTORY

An apprentice was installing an engine in an Oldsmobile and was having a very difficult time. Further investigation showed that the engine mounts were installed on the wrong side of the engine, which caused the engine to be at least 1 inch too far forward in the chassis.

16. **Remove the engine from the vehicle.** Attach a cable sling, a chain, or a special lifting tool to the heads or block (**Figure 4.41**). Some engines are equipped with lifting brackets (**Figure 4.42**).

FIGURE 4.38 Tape loose universal joint caps so they do not fall out. It is very easy to lose one of the small pinion rollers if the cap is dropped. *(Courtesy of Tim Gilles)*

FIGURE 4.39 The end of this transmission was plugged with an old slip yoke to prevent oil from leaking out after the drive shaft was removed. *(Courtesy of Tim Gilles)*

FIGURE 4.40 Label one of the engine mounts (L or R) when you remove it. Sometimes they are for the left or right side only.

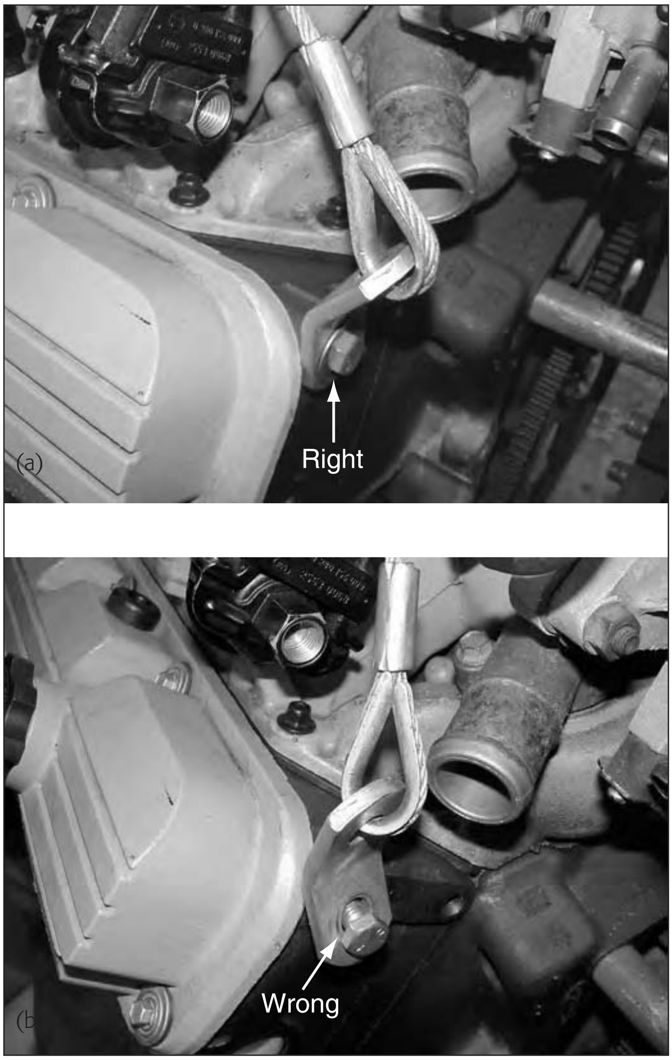


FIGURE 4.41 Right and wrong ways to install a lifting sling. *(Courtesy of Tim Gilles)*

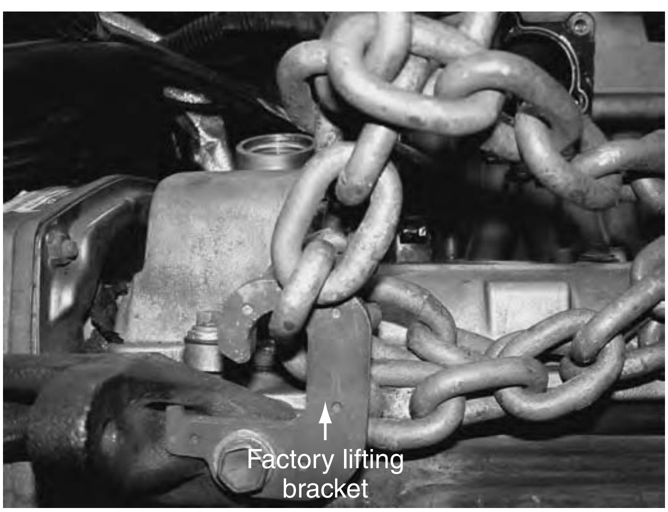


FIGURE 4.42 Many engines have lifting brackets that make it easier to attach a lifting sling or chain. *(Courtesy of Tim Gilles)*

Make sure the bolts are tightened all the way up against the sling brackets or chain to protect them from excessive stress that can break them (**Figure 4.43**).

SHOP TIP

Make some spacers from old piston pins or pieces of pipe cut to different lengths (**Figure 4.44**).

FRONT-WHEEL DRIVE ENGINE AND TRANSAXLE REMOVAL

The following is a generic procedure for front-wheel drive engine removal. Check related service information for instructions before attempting to remove the engine. Some engines can be removed

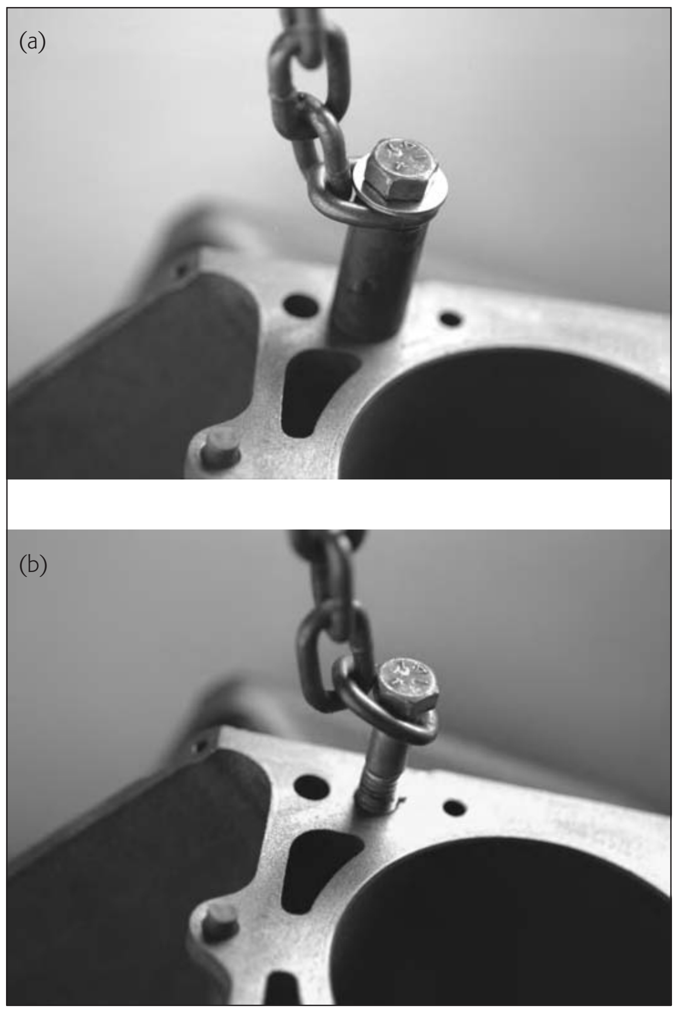


FIGURE 4.43 Attaching the lifting device to the engine. Avoid excessive stress on sling bolts.

leaving the transaxle in the vehicle (**Figure 4.45**). Other engines are more easily removed with the transaxle (**Figure 4.46**). Some engine/transaxle assemblies are removed through the hood opening, whereas others are more easily lowered from the bottom of the vehicle (**Figure 4.47**). On some front-wheel drives, the *cradle*, or *subframe*, that holds the engine and transaxle is unbolted from the vehicle and lowered as a unit from the bottom.

Removing the Transaxle

If the transaxle is to be removed, follow this procedure:

- First, disconnect the speedometer cable and clutch cable (if this is a manual transaxle).
- Next, remove the front wheels and disconnect the outer tie-rod ends on both sides.
- Remove the ball joint nut. Use a puller and pry as necessary to remove the ball joint from the control arm.
- Remove the internal CV joint from the transmission. Pry or unbolt as needed, depending on the axle design. Repeat this procedure on the other side of the vehicle.
- Disconnect the transmission shift linkage (**Figure 4.48**).
- Remove the torque rod, as applicable.
- Use an impact wrench to disconnect the exhaust pipe from the exhaust manifold and move it out of the way.

FIGURE 4.44 Spacers made from old piston pins.

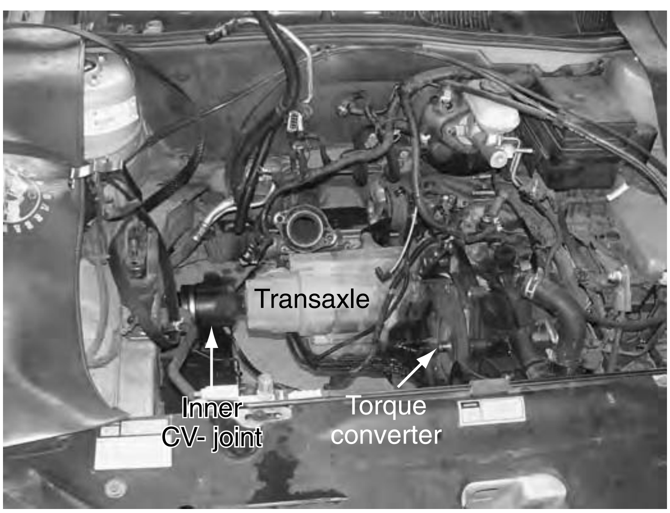


FIGURE 4.45 Sometimes the engine can be removed while the transaxle is left in the vehicle. *(Courtesy of Tim Gilles)*

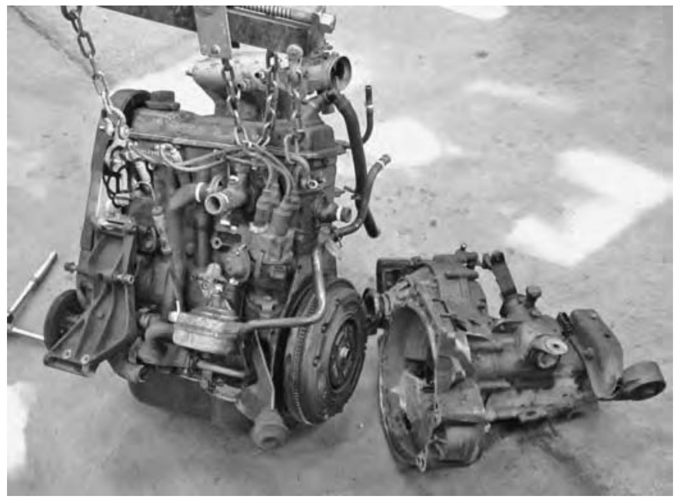


FIGURE 4.46 Some front-wheel drive engines are easiest to remove with the transaxle. Then the engine and transaxle are separated. *(Courtesy of Tim Gilles)*

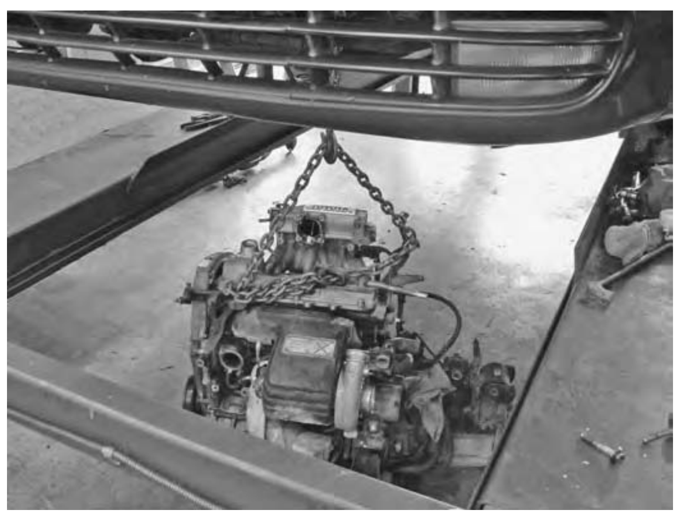


FIGURE 4.47 Some front-wheel drive engine and transaxle assemblies are more easily removed by lowering through the bottom. *(Courtesy of Tim Gilles)*

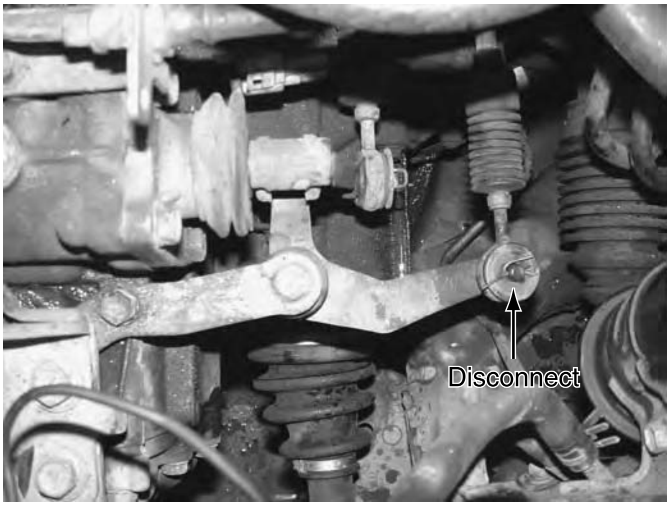


FIGURE 4.48 Disconnect the front-wheel drive transmission shift cable or linkage. *(Courtesy of Tim Gilles)*

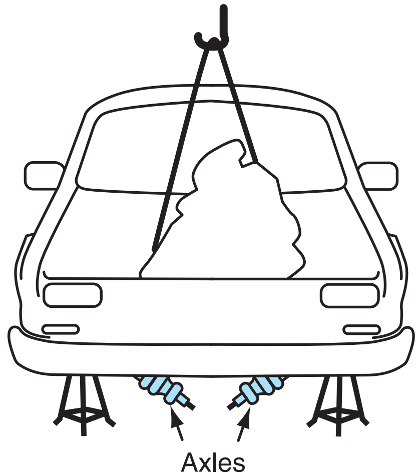


FIGURE 4.49 Before removing a front-wheel drive engine and transaxle, the axles are removed.

- Attach a sling to the engine and transaxle assembly at each side (to allow for balance during engine removal).
- Attach an engine hoist to the sling and put a small amount of tension on it. Apply just enough tension to the sling to unload the engine mounts for easy removal of their bolts.
- Remove the bolts that hold the front engine mount to the cylinder head. Then remove the mount from the body to allow room for the engine to clear during removal.
- Remove the nuts or bolts from the front and rear engine mounts.
- Remove the bolts attaching the front and rear torque rods to the engine.
- Loosen the bolts attaching torque rods to the vehicle body and swing the torque rods to move them out of the way.
- Raise the engine a few inches. Be sure to double-check for anything still connected between the engine and the vehicle.
- Remove the engine.

Removing the engine is best done with two people. One person raises the engine slowly while the other guides it until it clears parts of the vehicle body and frame. When the engine and transaxle are free of the vehicle, roll the shop crane until the engine can safely be lowered. If the transmission is to be removed with the engine as one unit, the drive axles are removed first (**Figure 4.49**). This will require removal of the lower ball joints from both sides of the vehicle so that the wheel hubs can be moved out far enough to allow the splines on the ends of the axles to be disengaged from the transaxle. Be ready with a drain pan. When the axles are removed, oil will spill from the transaxle.

CASE HISTORY

An apprentice removed an engine and transmission from a front-wheel drive vehicle. After the new engine was installed and tuned, the customer left with the car. Later that day, the car was towed into the shop with the complaint that it would not go into fifth gear. Further investigation showed that the transmission did not have any oil in it. The apprentice forgot to replenish the oil that had drained out when the axles were pulled. The transmission required extensive and costly repair.

SAFETY NOTE

Be careful when moving an engine with a cherry picker (engine hoist). Let the engine down as low as possible in order to keep the center of gravity low. If the center of gravity is too high, the cherry picker can tip over (see Case History in Chapter 2).

A chain hoist, also called a chainfall, is sometimes used for removing an engine from a vehicle.

Unlike a hydraulic engine hoist, with a chainfall it is harder to maneuver an engine back into position during reinstallation. Also, raising an engine for access to engine mounts or oil pan removal requires that the hood first be removed.

The grille in front of the radiator is an area where paint can be damaged by a chainfall (**Figure 4.50**). Even if the engine rebuild is perfect in every other respect, you can be sure that this is the one thing the customer will notice.

CASE HISTORY

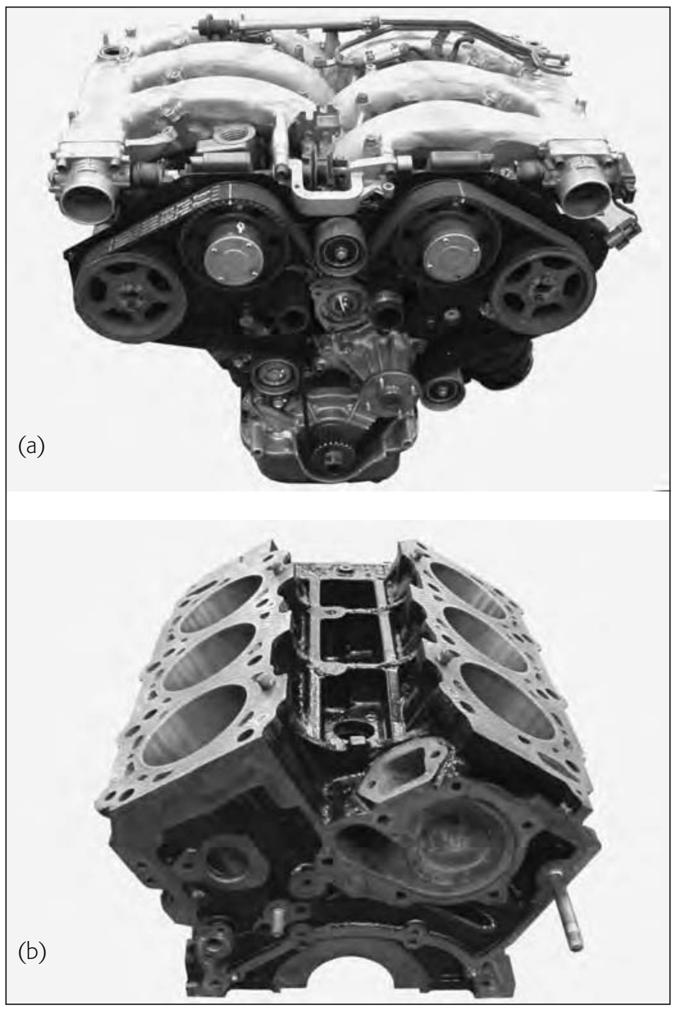
An apprentice technician was using a chainfall to remove an engine from a car that had just been painted. As the chain was being pulled, it rubbed against the paint on a fender, damaging it. The paint can be protected with a fender cover.

Vans and motor homes often require special solutions when removing engines from them. Sometimes it is easier to remove an engine from a van by dropping it out of the bottom. Other times the cylinder heads might need to be removed first.

ENGINE DISASSEMBLY

A typical engine has many parts (**Figure 4.51**). Rebuilding an engine is not difficult, but a successful outcome depends on being organized. Professional technicians can skip some of the more basic steps described here once they have a track record to build on. But the first time you undertake a large project like this, you will want to be more careful not to forget any important steps. When a repair job is undertaken in a repair shop, it is usually completed within a day or two. After all, the customer is waiting for his or her car. A school or hobby project, on the other hand, often takes weeks or even a month to complete. The professional will not need to separate nuts and bolts into baggies with labels, but this can be a time and error saver on the first-time rebuild. **Figure 4.52** shows an example of one student's organizational efforts. When this engine was reassembled after several delays caused by back-ordered parts, needless to say, everything went back in the same places from which they came.

FIGURE 4.50 The chain hoist can damage paint. *(Courtesy of Tim Gilles)*



(a)

(b)

FIGURE 4.51 Before and after all the parts are removed from a V6 engine. *(Courtesy of Tim Gilles)*

FIGURE 4.52 This student was very organized, making reassembly much easier. *(Courtesy of Tim Gilles)*

SHOP TIP

The tops of used oil containers can be cut off and used to store nuts and bolts. Plastic baggies are handy for storing small parts that could be easily lost.

Before and during an engine disassembly, inspect for problems that might add to the cost or feasibility of the rebuild. Items like broken castings, stripped threads, broken studs, or damaged sending units or vacuum switches should be noted on the W.O. and be included in the estimate to the customer. Noting such items now can eliminate controversy later should the customer dispute whether such items were damaged when the vehicle or engine entered the shop.

It is wise to save all old parts, including gaskets, until the engine is reassembled and running again. Parts might be needed for comparison. Sometimes on the assembly line a damaged engine will be salvaged by machining a valve lifter or main bearing bore oversize (see Chapter 11) or a crankshaft undersize.

CAUTION

Before beginning engine disassembly, make sure that the engine is cold. Tearing down a hot engine can cause warped cylinder heads, especially on engines with aluminum heads.

The following information is necessary before performing an engine disassembly. Pushrod and overhead cam engines are very similar but have slightly different procedures, which are outlined here also.

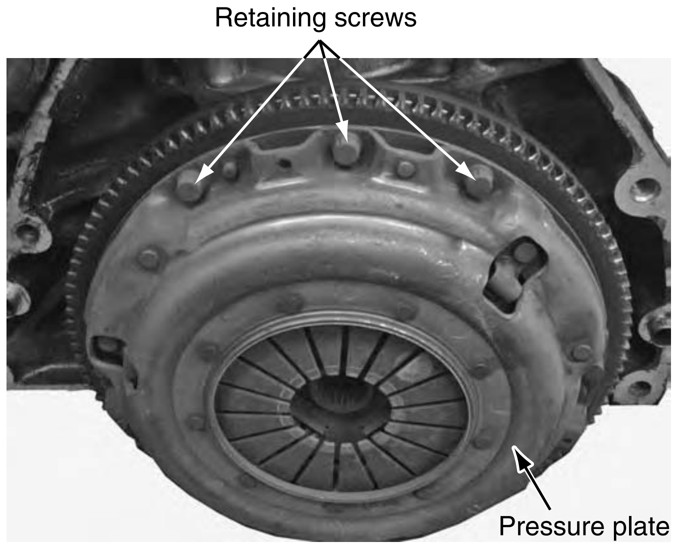


FIGURE 4.53 To remove the clutch pressure plate, loosen each retaining screw a little at a time. Do not remove all of them, leaving one tight. The screws on this clutch will require the use of a 12-point socket. *(Courtesy of Tim Gilles)*

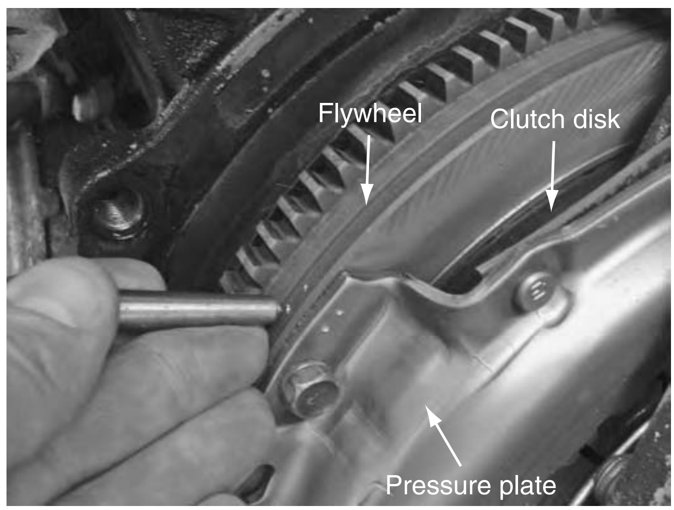


FIGURE 4.54 Marking the flywheel and pressure plate. *(Courtesy of Tim Gilles)*

1. **Remove clutch parts.** If the engine is equipped with a standard transmission, remove the transmission and bell housing before installing the engine stand mounting head. Remove the clutch pressure plate (**Figure 4.53**). If the pressure plate is the original one and will be reused, mark it so it can be replaced with its original orientation to the flywheel and crankshaft (**Figure 4.54**). The pressure plate and engine were balanced together at the factory and although this is not crucial, it is

the professional approach to mark it to maintain the original balance. Loosen each retaining screw a little at a time (see Figure 4.53). Then move on to the next, until all of them are loose enough to remove. The pressure plate is spring-loaded against the clutch disc. Leaving one screw tight after all the rest have been removed can bend the pressure plate. It is possible to install some clutch discs backwards. Mark the clutch disc on the flywheel side so that it (or its replacement) can be reinstalled in the same direction. Clutch parts and installation are covered in detail in Chapter 17.

NOTE

Hybrid Armature Removal

On hybrid cars, the motor/generator is usually behind the engine. Instead of the flywheel or torque converter on a conventional engine, the motor/generator's permanent magnet rotor is bolted to the back of the crankshaft. The rotor magnet is extremely strong; a puller is required to remove it. **Figure 4.55** shows the back of a Honda hybrid engine with the transaxle removed. A large puller is being used to remove it from the center of the three-phase coil stator.

2. **Mount the engine on a stand.** Attach the engine stand adapter to the engine while the engine is still on the floor, using four bolts of the proper length with washers (**Figure 4.56**). The bolts should have a minimum amount of thread contact into the block of at least 1.5 times the diameter of the bolt. On some engines, at this point you can leave the flywheel or flexplate bolted to the crankshaft. When the crankshaft is removed from the engine, the flywheel or flexplate will make a convenient stand to use while storing the crankshaft on end. If the flywheel must be removed from the crankshaft in order to remove the crankshaft from the engine, keep the flywheel bolts and washers separated and do not lose them. They are special; their heads are thinner and the washers are thinner than normal bolts and washers (**Figure 4.57**).

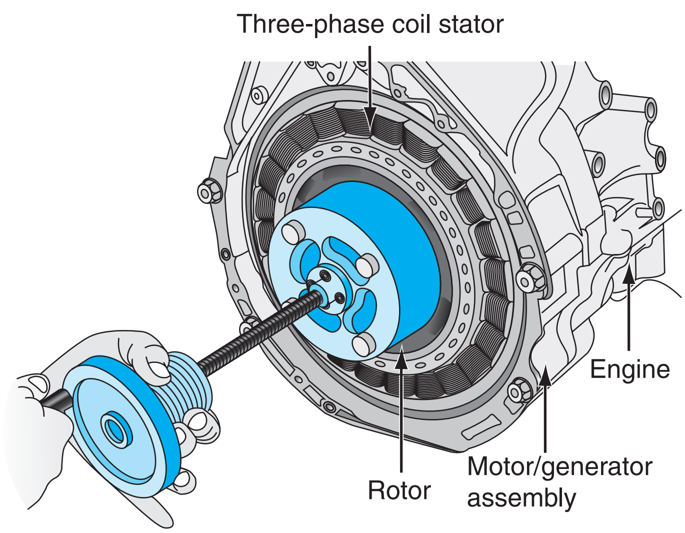


FIGURE 4.55 Removing a hybrid-assist rotor from the rear of the engine's crankshaft.

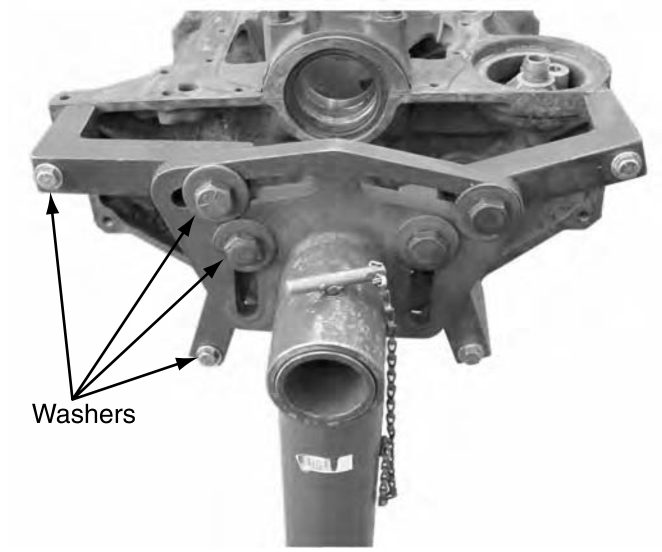


FIGURE 4.56 Mount the engine stand head to the engine. Use washers under the fastener heads. *(Courtesy of Tim Gilles)*

FIGURE 4.57 Flywheel screws have thin heads and thin lock washers. Do not install standard bolts or washers in their place. *(Courtesy of Tim Gilles)*

SAFETY NOTES

- Do not work on the engine while it hangs in the air. It should be mounted on an engine stand or resting on the floor.
- The mounting head should be mounted so that its center of gravity when it is on the stand will not force the engine to rotate, possibly causing injury to a technician.

NOTE

Be sure that all oil and coolant are out of the engine. Remove the plug from the side of the block and rotate the engine on the stand to eliminate any remaining moisture (see Figure 4.14).

3. **Remove the coolant pump.** Inspect the impeller to see that it is undamaged. Also, feel the bearing for roughness and check to see that there is no evidence of leakage from the pump's vent hole. Some shops routinely replace the coolant pump during an engine installation.
4. **Remove the oil pan.** Loosen all bolts to the oil pan. Keep the engine upright and disassemble the top end. It is better to remove the pan before turning the engine over on the stand so that any oil in the bottom of the pan will not pour back into the engine. Sometimes the pan will loosen by itself. If not, wedge a gasket scraper or a rolling head prybar between the pan and block and carefully loosen the pan, being careful not to bend or distort it. If necessary, break the seal by tapping a scraper blade all along the gasket.

NOTE

Be especially careful not to damage the block surfaces of aluminum engines.

5. **Remove the valve cover(s).** On V-type engines label the valve covers ("left" or "right") before removing them. Sheet metal parts on engines assembled in the factory by robots are often sealed with RTV sealants (see Chapter 16). Valve covers and oil pans sealed in this manner can be very difficult to remove. Slip a knife blade between the head and sheet metal to break the seal. Sheet metal parts can be tapped with a rubber mallet to loosen them. Tap on a curved (strong) area to avoid damaging a part.

For engines with pushrods:

- Stud-mounted rockers (see Chapter 8) need not be removed from their studs before disassembly and cleaning. Simply loosen the rocker arm nuts and turn the rocker arms to the side. These nuts are self-locking. When loosening them, there should be some resistance; if not, discard them. After cleaning, remove them one at a time to inspect the parts for unusual wear.
- Shaft-mounted rockers (see Chapter 8) should be loosened slowly and evenly. If all the bolts but one are loosened, the pressure of all the valve springs will be exerted on only one rocker tower and damage can result. Remove the pushrods.

SHOP TIP

It is a good practice to keep all parts in order, because it makes inspection for worn parts easier. It is very important to find the cause of any problem and repair it so it will not happen again. Also, parts become "wear-mated" to each other; they should be returned to their original positions if they are to be reused. Pushrods can be pushed through holes in a piece of cardboard. Some engines use pushrods of varying lengths. These must be kept in order.

- Remove valve lifters. Wipe oil off the bottoms of them and label them with a felt marker to keep them in order for reassembly. If they are to be reused, flat tappets must be used on the cam lobes that they have been run on before (see Chapter 9). Inspect the lifters for unusual signs of wear. Nonroller cams and lifters are usually replaced during a major engine overhaul because of wear factors.

  The bottoms of lifters often have varnish built up on them in the area that extends out of the lifter bore (**Figure 4.58**). This makes them difficult to remove. Varnish can be softened with a spray chemical cleaner. If the lifters are hard to remove, wait until the camshaft is removed and try to push them out from the bottom or remove them with a special puller (**Figure 4.59**). If the puller is not available, or if the lifters will not be reused, tap them out from the top with a drift punch after the cam is removed. Be careful not to nick the lifter bores. Excessively dirty lifters that are forced out from the bottom can damage lifter bores also.

FIGURE 4.58 Varnish builds up on the bottom of a lifter below its travel area in the lifter bore. Spray this area with a chemical cleaner before attempting to remove the lifter. *(Courtesy of Tim Gilles)*

For overhead cam engines:

- Before the cam belt or chain is removed, position the number one piston at TDC and note the location of the timing marks on the cam and crank sprockets. **Figure 4.60** is an example of typical timing marks.
- Locate a sketch in the repair manual that shows how the camshaft and crankshaft are timed and compare it to the marks on the engine before disassembling it.
- Draw a sketch or take a picture of the cam timing to keep for future reference.
- Do not remove the OHC camshaft(s) yet. This procedure is described in Chapter 7.

CAUTION

When an OHC head is removed, the camshaft will be holding some of the valves open. Be careful not to set the head face down or the open valves can be bent.

6. **Remove the vibration damper.** Most engines have a bolt that holds the vibration damper on the crankshaft. Some vibration dampers will slip off after the bolt is removed. Others are pressed-fit. A puller is required to remove these. Using the wrong puller can ruin the damper. Grabbing the damper by the outer ring can pull the ring off the damper or pull it off center (**Figure 4.61**).

FIGURE 4.59 A slide hammer lifter puller. *(Courtesy of Tim Gilles)*

FIGURE 4.60 Typical cam timing marks.

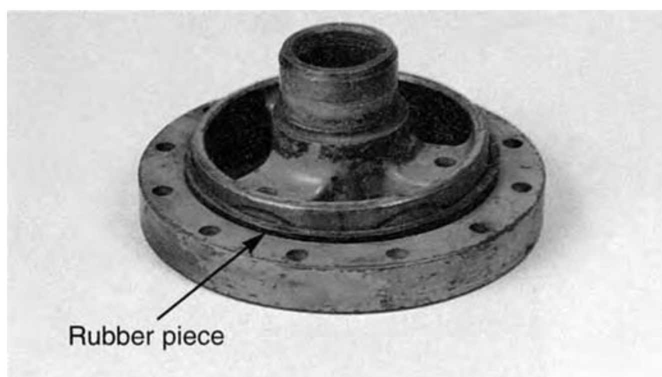


FIGURE 4.61 Attempting to pull this damper from its outer ring ruined it. *(Courtesy of Tim Gilles)*

When using a puller, protect the damper bolt threads in the end of the crankshaft. Sometimes a puller will have a replaceable tip. Select the largest one that fits (**Figure 4.62**). Other times a special adapter called a step plate is used under the puller tip.

SHOP TIP

It is easiest to remove the damper bolt with an impact wrench on the puller screw because the crankshaft will not have to be held to keep it from turning. *Wear safety goggles during this operation.*

On some engines the timing cover seal can be removed before removing the timing cover. Many timing cover seals are removed and replaced from the inside of the timing cover. These will need to be removed after taking off the timing cover (see Chapter 16).

7. **Remove the timing cover and the cam drive assembly.**

    - *Pushrod engines*. Unbolt the cam sprocket and slide or pry it off the cam. Then remove the chain. Reinstall the sprocket and tighten one bolt finger tight. The sprocket will be used to help remove the cam later.
    - *Overhead cam.* Remove the chain or belt tensioner to remove the cam drive.

8. **Remove the cylinder head(s).** Mark one of the cylinder heads (if there are more than one) "left" or "right" and remove the heads (**Figure 4.63**).

> **REMEMBER:**
> **Left when viewed from the flywheel end.**

Most repair manuals now give a head bolt removal sequence. The AERA reports that on some heads, loosening the four outside corner bolts 90° before loosening any other bolts reduces the chances of cracking the head. This is especially important when the engine has been overheated. Removal of head bolts in the opposite order of the tightening sequence can also help prevent heads from cracking. This

FIGURE 4.62 This puller has two sizes of replaceable tips. To protect the threads in the crankshaft snout, use the largest one that will fit. *(Courtesy of Tim Gilles)*

FIGURE 4.63 On V-type engines, mark one head "L," for left. This is the left side when viewed from the flywheel side. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Some older engines had composition head gaskets that could be very difficult to remove. An old trick for loosening heads while the engine was still in the car was to loosen all of the head bolts and crank the engine to use cylinder pressure to assist in loosening the heads.

also prevents warping the head, especially with aluminum. Aluminum heads should be cold before removing them to prevent warpage.

Some engines have cast-in pry points. Be careful not to break a casting by using excessive force when prying.

During the entire engine disassembly process, be absolutely certain that all bolts have been removed before using force. If a part cannot be pried loose easily, recheck the repair information.

During removal of the head bolts, look to see if any of them are of different lengths. If they are all the same length, they do not need to be kept in order. Sometimes a special bolt is designed with a smaller shank area to allow for the passage of oil to the rocker arm area of the head.

After removing the head, look for evidence of coolant or oil leakage (see Chapter 3). It is a good idea to save the head gasket(s) until the job is completed. This is handy for diagnosis purposes, and in many areas the customer has the right to inspect all old parts. Inspect the head gasket for signs of detonation damage and compression leakage. A properly seated gasket will leave a well-defined line of thin carbon around the combustion chamber on both the head and block (**Figure 4.64**). Carbon deposits on the metal rings of the gasket or a poorly defined combustion chamber seal indicate possible compression leakage.

9. **Remove the dipstick tube.** If the engine has a metal oil level dipstick tube, remove it so it will not be accidentally damaged.

Cylinder Block Disassembly

1. **When a cylinder wears, a ridge forms at the top of the cylinder** (**Figure 4.65**). Until the 1980s a pronounced **ring ridge** was a routine occurrence during engine service. Ring ridges are not as common as they used to be, but they are important. If the engine has a ridge at the top of its cylinder walls, it will require reboring

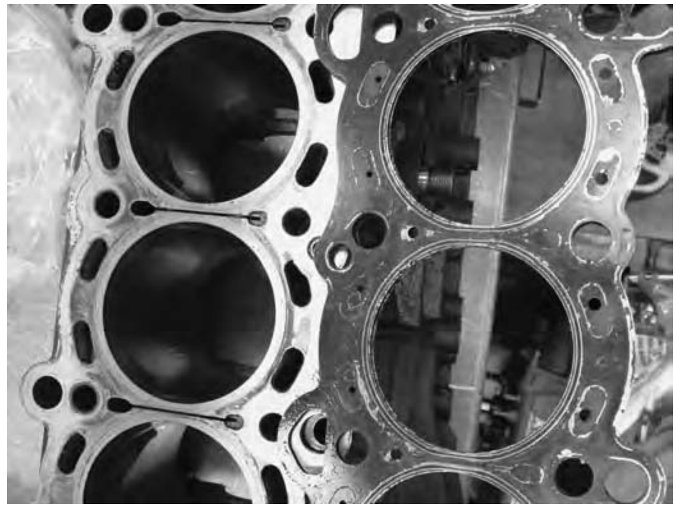


FIGURE 4.64 Look at the head gasket and block to see if there is any sign of compression or coolant leakage. *(Courtesy of Tim Gilles)*

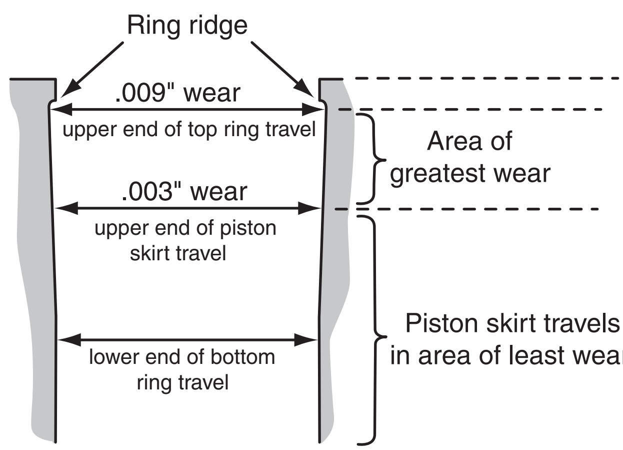


FIGURE 4.65 A ring ridge forms when the cylinder wears.

VINTAGE ENGINES

In-line six cylinder engines with carburetors experienced more wear on the inner two cylinders, numbers 3 and 4. The uneven wear was the result of uneven fuel distribution, especially during cold engine operation. This condition, called fuel wash, resulted from the rich air-fuel mixture when the engine was choked during cold operation. Fuel wash removed more oil from the inside cylinders than from the outer cylinders.

and honing for oversized pistons. If a stop-gap repair is to be made, regular iron rings must be used. (Modern engines use premium piston rings that will not accommodate a worn cylinder bore.)

A ring ridge can result from two conditions: combustion pressure, which forces the top piston ring against the cylinder wall, and fuel wash, which washes lubricant off the cylinder wall at the top (**Figure 4.66**).

Sometimes the ridge is simply an edge of carbon that can be easily removed with a scraper. Other times it can be quite deep. The ridge is removed so that the new square ring will not strike the rounded edge of the ring ridge and possibly break a piston land (see Chapter 3).

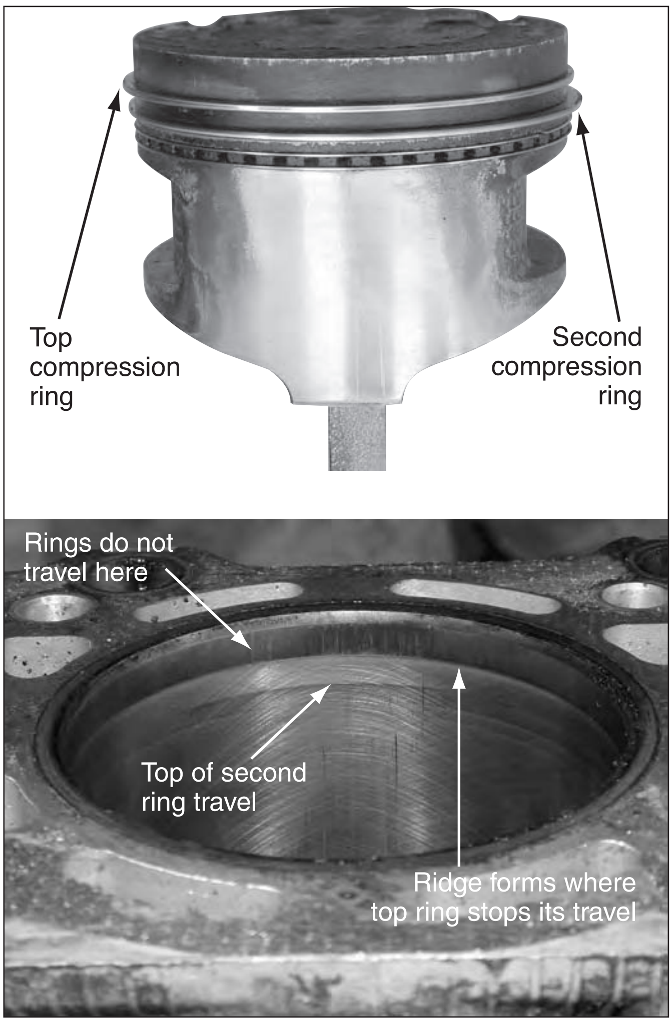


FIGURE 4.66 The pattern in this cylinder shows wear from the top and second compression rings. *(Courtesy of Tim Gilles)*

NOTE

A good rule of thumb is: When a ring ridge is large enough to catch a fingernail moving upward, the engine is a candidate for a rebore and new oversized pistons and rings. Sometimes, when the engine remains in the vehicle for an in-chassis overhaul and cylinder bore taper is less than 0.006", a new set of ordinary cast iron rings will be installed after removing the ring ridge.

The pistons can only be removed through the top of the block, because main bearing webs are in the way at the bottom. Use a ridge reamer to remove the ring ridges before removing the pistons. There are several types. One that is easy to use is shown in **Figure 4.67**.

- First it is centered in the cylinder. During ridge removal it is turned, rising on a thread and cutting away the ridge.
- Be careful not to pull the tool off-center.
- The cutter should be run over the ridge only once, or it will cut away too much of the cylinder wall.

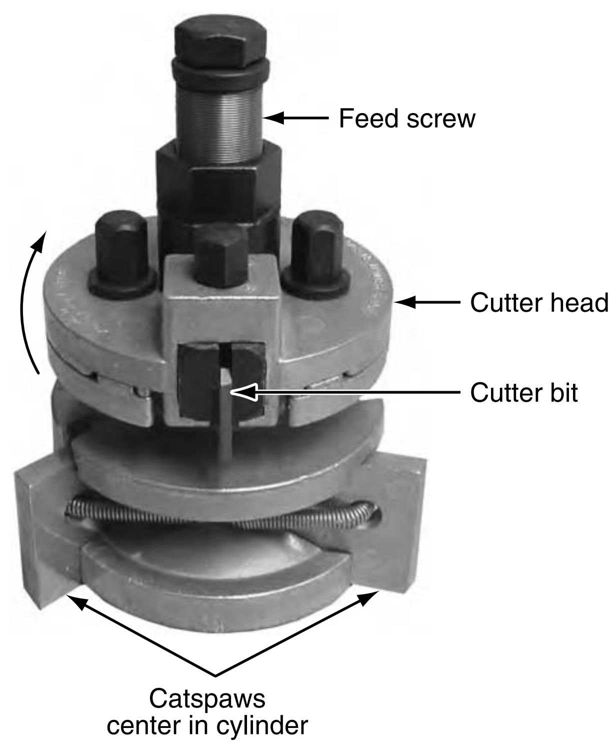


FIGURE 4.67 A ridge reamer. As the cutter bit is turned, it advances up the ridge as the cutter head turns on the feed screw. Ridge reamers are rarely necessary today. *(Courtesy of Tim Gilles)*

- Be careful not to accidentally cut the area of the cylinder where the rings travel.
- After removing the ridge, move the piston to TDC and wipe the chips from the top of the cylinder. Then do the next cylinder that is at BDC.

SHOP TIP

If both the damper and the flywheel have been removed from the engine, turn the crank by adjusting an adjustable-end wrench (crescent wrench) to the size of the crank. When the jaw contacts the woodruff key on the crank, the crank can be turned (**Figure 4.68**). There are also special tools that fit over the end of the crank and engage the woodruff key (**Figure 4.69**). Be especially careful not to damage the front of the crankshaft. A damaged snout will make the crankshaft unacceptable as a core return.

2. **Mark main bearing and connecting rod caps.** Turn the engine over so that the crankcase is facing up. Mark the mains and rods if they have not been previously marked.

   Main and rod caps are not interchangeable! Main caps go only one direction. Sometimes they can be installed backwards and other times they cannot (**Figure 4.70**). Some main caps are labeled with casting numbers (**Figure 4.71**). Numbering begins at the damper end of block (number one) and progresses to the flywheel end. Some main caps have an arrow labeling the direction that the cap should face (**Figure 4.72**). Unless you write down whether it faces front or rear, you will need to locate that information when you reassemble the engine.

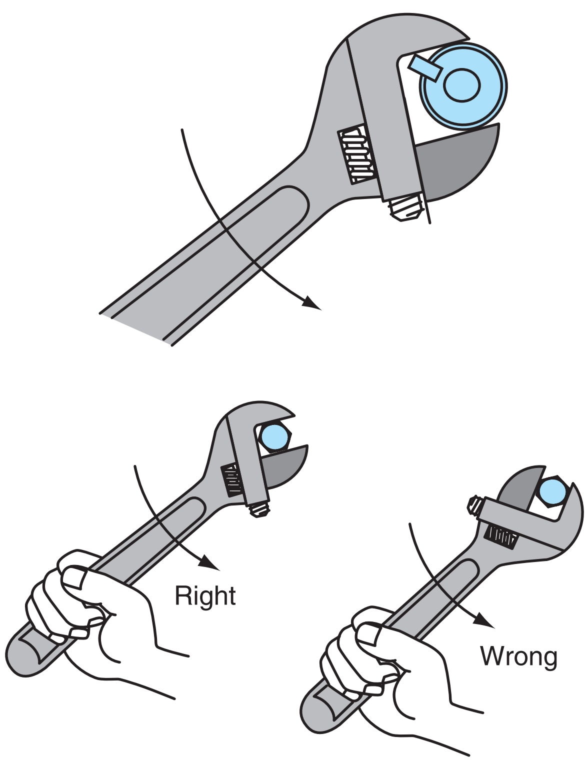


FIGURE 4.68 An adjustable-end wrench grasps the woodruff key to turn the crank. Is the wrench in this example being used properly?

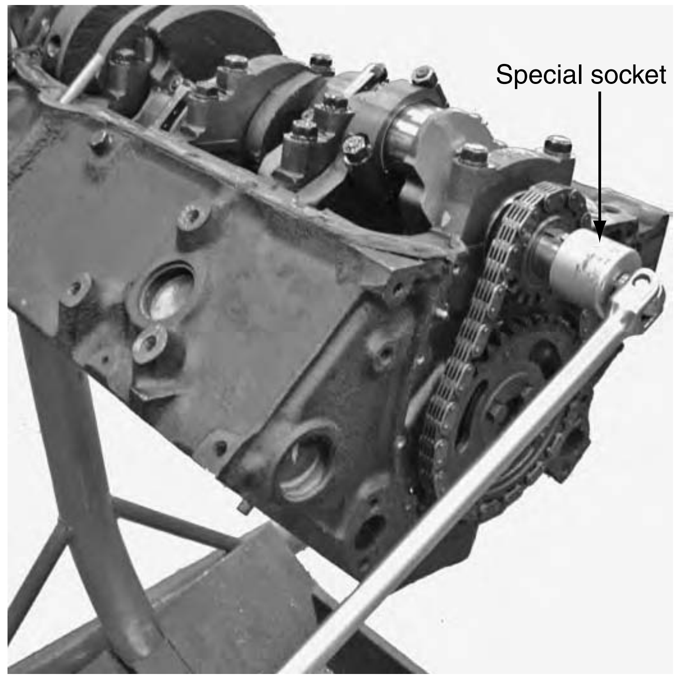


FIGURE 4.69 A special tool for turning the crankshaft. *(Courtesy of Tim Gilles)*

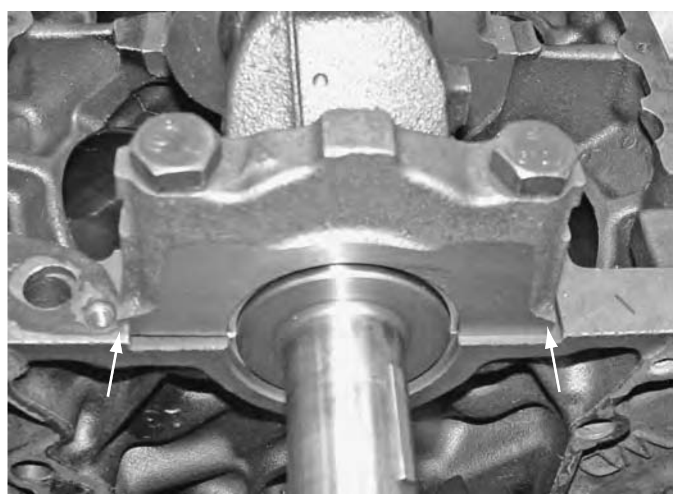


FIGURE 4.70 This main cap would be impossible to install backwards with the crankshaft in position. Many engines are not like this one, and main caps can be accidentally installed wrong if not marked during disassembly and referenced during reassembly. *(Courtesy of Tim Gilles)*

FIGURE 4.71 Some main caps have a cast number. How would you know which direction it faces? *(Courtesy of Tim Gilles)*

FIGURE 4.73 A main bearing cap and block marked with a center punch. This is a reliable way to mark main caps. *(Courtesy of Tim Gilles)*

FIGURE 4.72 Some main caps have a cast arrow that tells which way they should face. The problem is that you do not know which way they should face unless you regularly work on this make of engine. *(Courtesy of Tim Gilles)*

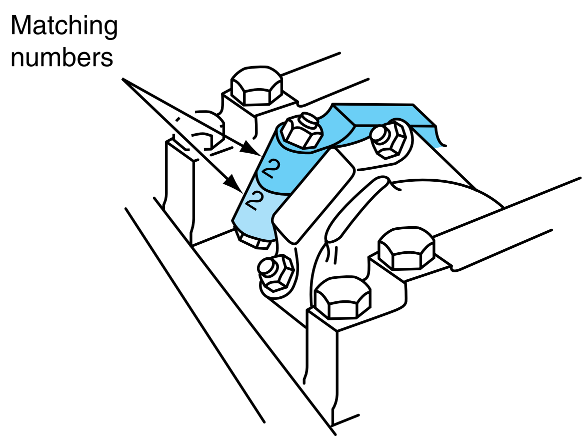


FIGURE 4.74 A good way to mark the connecting rod and cap. Mark them before loosening the rod nuts.

SHOP TIP

Remember, "Time is money." Searching the service literature for unnecessary information, like the direction that main caps face, is a waste of time. Mark main and rod caps the same way when you disassemble **any** engine. Then you will not need to locate difficult-to-find service information when reassembling your engine.

Figure 4.73 shows a fast, easy way to mark main caps using a center punch. Mark on both the main cap and the block so you know which direction the cap goes when you put it back. When marking connecting rods, **Figure 4.74** shows the correct place to stamp the numbers.

Marking the rod and cap on the side in this manner does not distort the connecting rod and makes it easy for you to reinstall the correct cap in the right direction on the rod. Rod caps should always be marked while they are still installed on the crankshaft.

NOTE

The rule-of-thumb for bearing clearance calls for 0.007″ per inch of shaft diameter. An average engine has 0.0015–0.002″ bearing clearance. This amounts to less than 0.001″ on each side of the crankshaft. For reference, the thickness of an average human hair is about 0.0025″. If a main or rod cap goes on backward, it could easily be off by 0.001″ and have no oil clearance. Connecting rods and main caps are malleable. This means they can distort when hammering on them with a number stamp or center punch. There is a slight bit of extra clearance at the bearing parting line. That is the reason for marking rods and mains in the positions shown in the previous illustrations. If you mark a main or rod cap at a point 90° to the bolt, you can distort the bearing housing enough to eliminate bearing clearance.

Be certain to inspect connecting rods that were previously marked (at the factory or during a previous engine rebuild) to see that they are labeled correctly. **Figure 4.75** shows a rod and cap as it was removed from a running engine. Bearing wear was minor, but this was lucky.

NOTES

- Powdered metal connecting rods should not be marked using number stamps.
- Do not file notches on the rod beam. This can cause **stress raisers** that can weaken the rod (see Chapter 13).

When marking rods on a V-type engine, mark them according to the cylinder's number. The only side of the rod that is easily accessible is the side that faces the outside of the engine (away from the cam on a pushrod engine) (**Figure 4.76**). Figure 1.39 shows many of the firing orders used by various manufacturers. On V-type engines, the number one cylinder will almost always be the one that is the farthest forward on the block. Because cylinders on V-type engines share crank pins with cylinders on the opposite side of the block, the cylinders must be staggered (see Figure 1.40). Connecting rods must not be installed backwards. **Figure 4.77** shows two V8 connecting rods. Notice that they are machined more on one side than the other.

3. **Remove and inspect the piston and rod assembly.**
   - Move each piston to BDC so the rods will clear the crank during piston removal.
   - Loosen each connecting rod nut. The amount of torque required to loosen the nuts can be determined using a dial indicator torque

FIGURE 4.75 The wrong rod cap was installed on this connecting rod. *(Courtesy of Tim Gilles)*

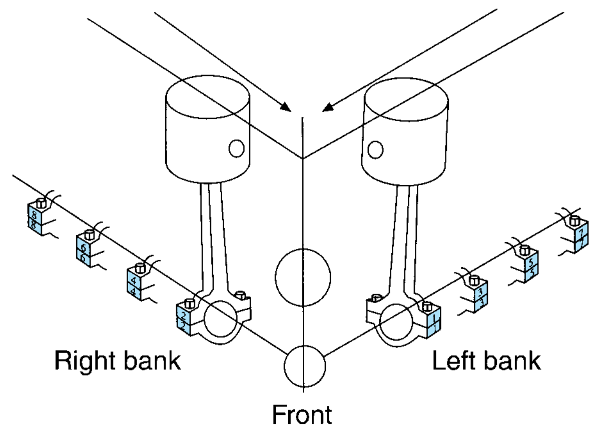


FIGURE 4.76 Mark rods on V-type engines on the side that faces outside, away from the center of the engine.

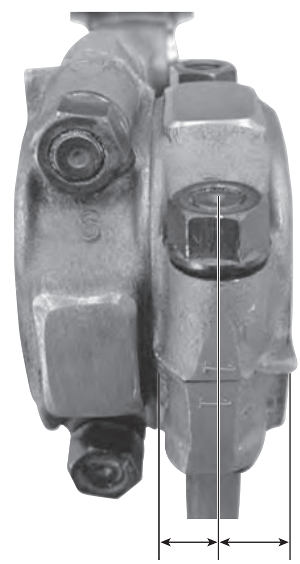


FIGURE 4.77 Offset connecting rods from a V-type engine. *(Courtesy of Tim Gilles)*

wrench. This will tell you whether nuts were correctly torqued previously.

NOTE

The click-type torque wrench should not be used for loosening (see Chapter 16).

- Use a brass hammer to lightly tap on the end of the rod bolts to loosen the rod caps for easy removal (**Figure 4.78**).
- Use Plastigage® to check the clearance of one of the connecting rod bearings before you remove the piston and rod assembly from the block. Chapter 13 gives directions for using Plastigage.
- The crankshaft is soft and it nicks easily. To protect the crank, install rod bolt protectors (available from your parts source) or pieces of fuel hose 3 to 4 inches long on the rod bolts before removing the rods (**Figure 4.79**). If you use pieces of hose, do not cut them too short. Longer ones can be removed easily, even though they become slippery when coated with oil.
- Carefully push the rod and piston assembly out of the top of the bore. Use a long wooden dowel, the handle of a soft mallet, or a piece of hickory, like a sawed-off baseball bat or shovel handle, to push the piston and rod from the bore. The connecting rod is relatively soft and can easily be damaged by contact with hard materials, such as a screwdriver or prybar. **Figure 4.80** shows a connecting rod that was ruined as it was driven from the cylinder using a steel prybar.

NOTES

- Keep the old bearing in place in the rod for future diagnosis.
- Be very careful not to drop a piston. When a piston is lying on a bench with the connecting rod attached, it is unbalanced and can very easily be knocked off a bench (**Figure 4.81**). In fact, this is a common occurrence with apprentice technicians. Lay piston and rod assemblies on their sides to prevent a costly mishap.

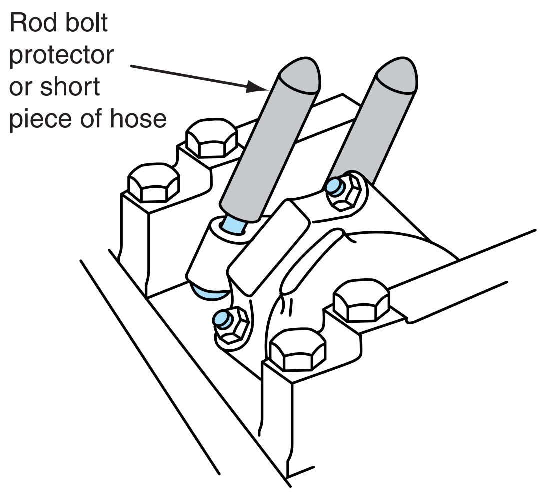


FIGURE 4.79 Install hoses or rod bolt protectors on the rod bolts before removing the piston and rod assembly.

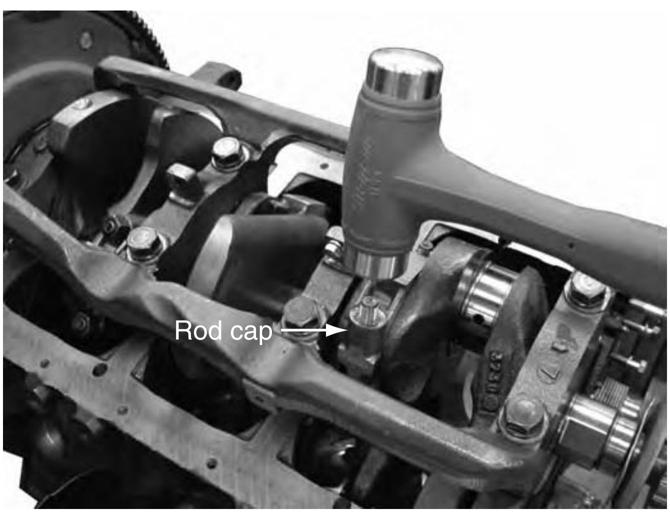


FIGURE 4.78 Use a brass hammer to tap lightly on each side's rod bolt. This will loosen the cap from the enlarged area of the bolt that aligns the cap precisely to the rod. *(Courtesy of Tim Gilles)*

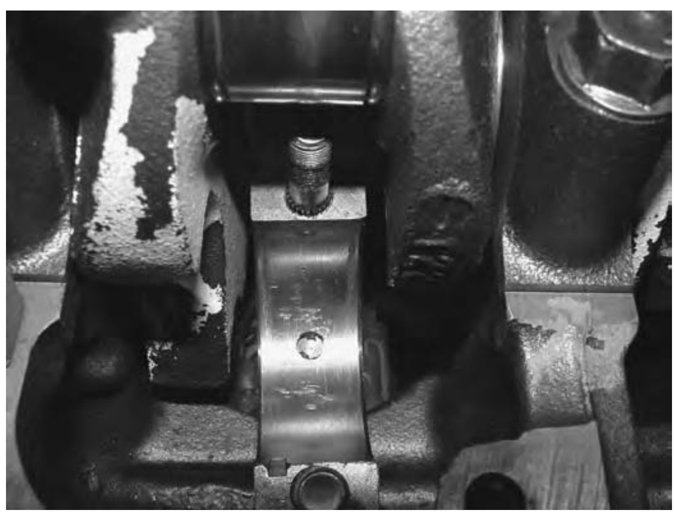


FIGURE 4.80 This connecting rod was damaged when a steel prybar was used in an attempt to push the piston and rod from the bore.

REMEMBER:

Connecting rod caps are not interchangeable. Immediately reinstall the rod cap on the rod.

4. **Inspect the piston, rings, rod, and bearings.**
   - Detonation (see Chapter 3) can affect the rod bearing. If the rod bearing falls out as the piston and rod are removed from the cylinder, check for detonation damage, especially on the upper rod bearing.
   - Inspect the pistons for obvious wear and breakage.
   - This is also a good time to visually inspect each cylinder for corresponding wear.
   - Inspect oil rings to see if they are plugged.
   - If compression rings were working properly, the piston land between the top and second rings should be relatively clean. Chapter 13 describes a procedure for checking piston ring wear.
5. **Remove the crankshaft and bearings.**
   - Remove the main cap bolts using a dial indicator torque wrench to see how tight they were.
   - Remove the main caps. They fit tightly in a register in the block so they will need to be pried loose (**Figure 4.82**).

   Some rear main caps are sealed to the block to prevent oil leakage. These main caps will have threaded holes. Turn a slide hammer tool into these holes and pull the cap (**Figure 4.83**). If you have only one slide hammer, pull first on one side and then the other. Some main caps have only a single hole in the center.

FIGURE 4.81 This piston can very easily be knocked off the bench. Lay it on its side to prevent this from happening. *(Courtesy of Tim Gilles)*

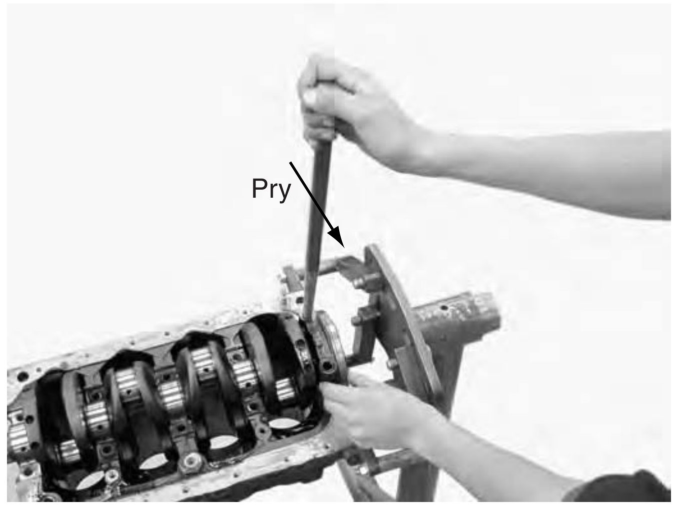


FIGURE 4.82 Pry the main caps loose from the block. *(Courtesy of Tim Gilles)*

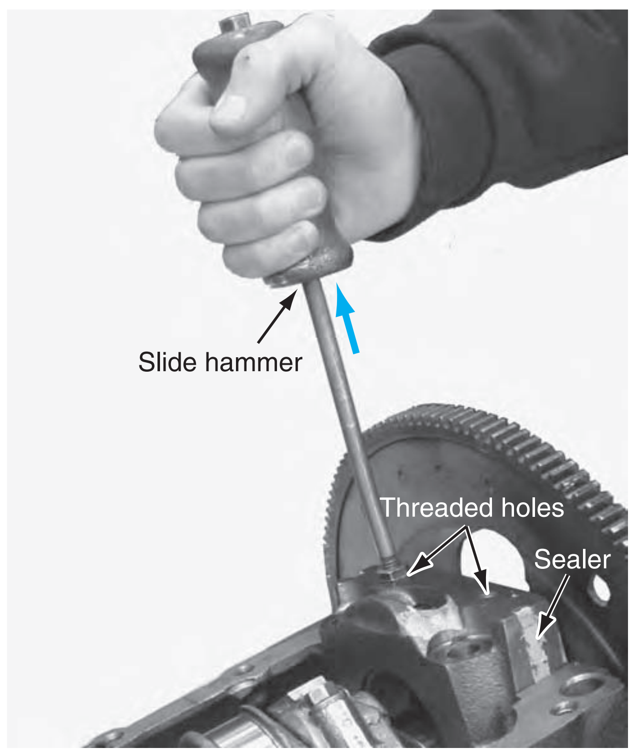


FIGURE 4.83 Using a slide hammer to remove a rear main bearing cap that is sealed to the block. *(Courtesy of Tim Gilles)*

NOTE

Main caps are not interchangeable and must be returned to their original positions. Normally, bearings are replaced. If bearings are reused, they *must* be returned to their original positions, because they have been wear-mated to the crankshaft bearing journals.

- Use Plastigage to check the clearance of the front bearing.

NOTE

Be sure that the surfaces of the block and main cap are really clean before checking clearance! Dirt between these surfaces during reassembly will result in main bearing knock and lower oil pressure at idle.

- Carefully lift out the crankshaft. Leave the flywheel or flexplate bolted to the crank to help hold it upright during storage to prevent damage (**Figure 4.84**). The crankshaft should be stood on end during storage or hung in a rack to prevent warping.

FIGURE 4.84 Store a crankshaft upright to prevent damage. Leave the flywheel installed. *(Courtesy of Tim Gilles)*

- Check for a pilot bearing or bushing in the rear of a standard transmission crankshaft. This can be removed with a puller as shown in Figure 17.72.
- Check the condition of the crankshaft surface where the rear main seal rides.
- Inspect the bearing surfaces of the crankshaft for wear. Measure the main and connecting rod journals with a micrometer and compare them to specifications.
- Inspect the **thrust bearing surfaces** (see Chapter 12). These surfaces control fore and aft movement of the crankshaft. Wear, which is unusual, is usually located on the rear side.
- Inspect the front upper bearing to see if there is any sign of wear that might result from belts that were too tight.
- Label the backs of the main bearings with a felt marker according to their positions. The number one upper main bearing is marked 1U, the number one lower is marked 1L, and so on. As the main bearings are removed from the block, lay them in a row (**Figure 4.85**). If the crankshaft is bent or the crankcase is out of alignment, you will be able to see the wear pattern on the bearings.

  Bearing wear problems are discussed in Chapter 12.

6. **Reinstall the main bearing caps in their proper sequence on the block.** Retorque them before hot-tanking the block.

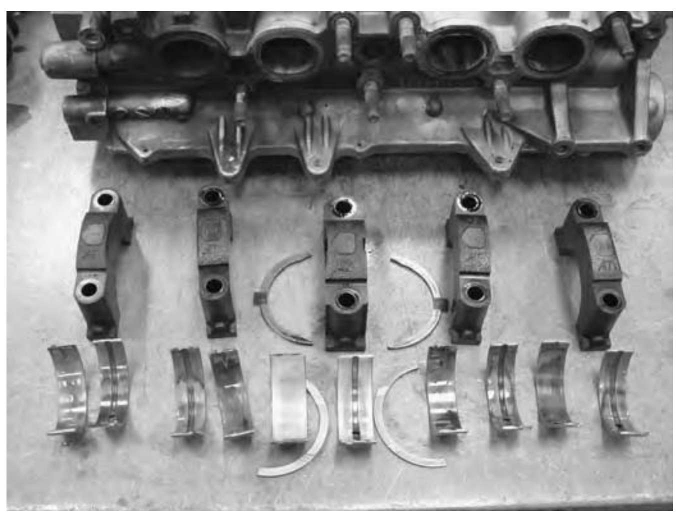


FIGURE 4.85 As main bearings are removed, lay them in a row. If the crankshaft or crankcase is misaligned, you will be able to see the resulting wear pattern on the bearings. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Vintage engines with gear-driven camshafts had thrust plates as well. The thrust plate retaining screws were accessed through holes in the camshaft gear (**Figure 4.87**). These engines often had Phillips head screws, which are often difficult to remove.

7. **Remove the camshaft.** Some engines use a bolt-on cam thrust plate (**Figure 4.86**).

SHOP TIP

An impact screwdriver (**Figure 4.88a**) is usually all it takes to remove a tight Phillips head screw without damaging the screw head. Hold the impact screwdriver firmly while twisting it counterclockwise with one hand. Then strike it with a hammer to loosen the screw (**Figure 4.88b**). The ⅜" drive end of the tool also makes it possible to use the screwdriver bits with a ⅜" drive ratchet or air impact wrench.

Varnish often builds up on the edges of the cam journals (**Figure 4.89**), making it difficult to remove the cam. Squirt some penetrating oil on the varnish. Reinstall the cam sprocket and use it as a "handle" to remove the cam.

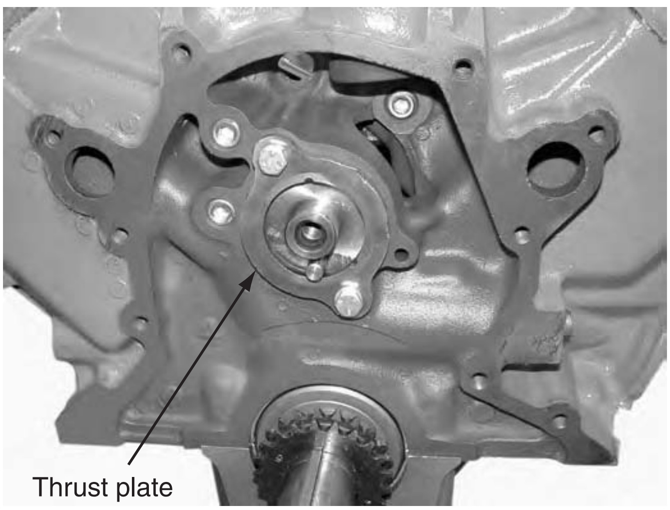


FIGURE 4.86 A bolt-on cam thrust plate. *(Courtesy of Tim Gilles)*

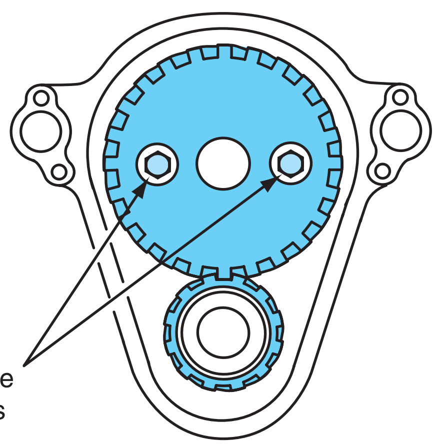


FIGURE 4.87 To access the screws in the thrust plate on this vintage engine, line up the holes in the cam gear.

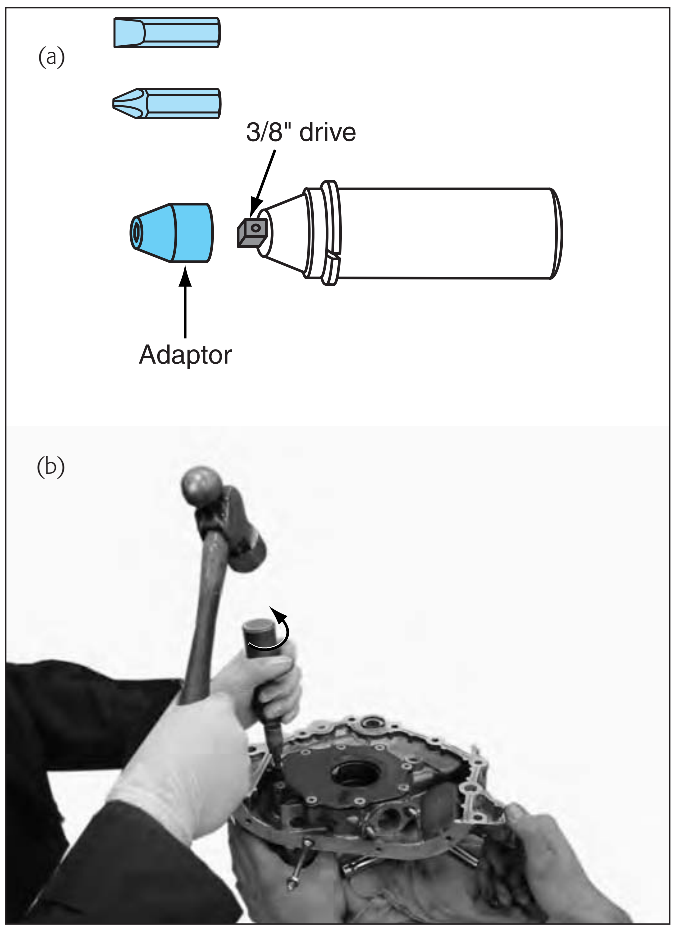


FIGURE 4.88 (a) Impact screwdriver parts. (b) An impact screwdriver turns forcefully when struck with a hammer. *(Courtesy of Tim Gilles)*

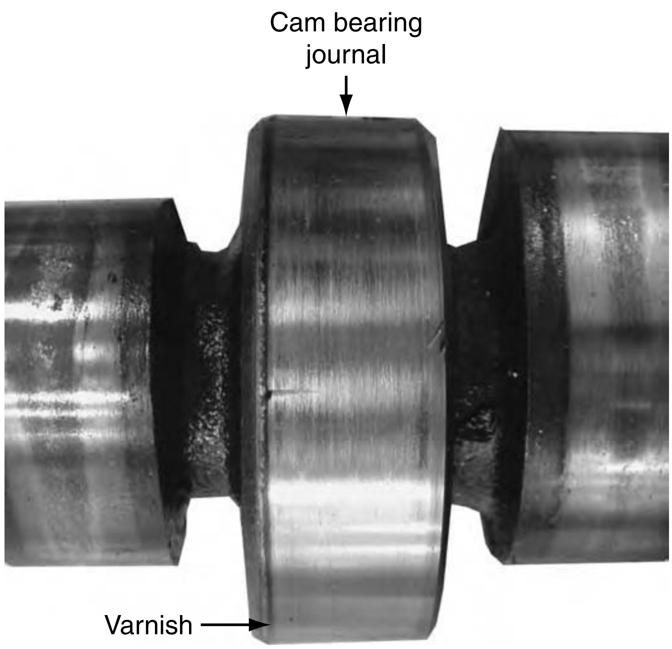


FIGURE 4.89 Varnish on the edge of the cam journal can make it difficult to remove a camshaft on a cam-in-block engine. *(Courtesy of Tim Gilles)*

FIGURE 4.90 Flat tappets (on vintage engines) must be kept in order if they are to be reused. *(Courtesy of Tim Gilles)*

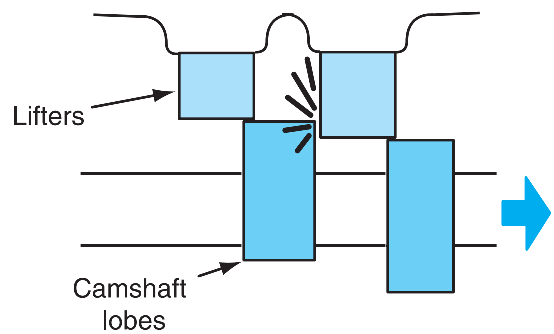


FIGURE 4.91 On vintage engines with flat tappets, the lifters must be moved high enough in their bores to allow the cam to be removed.

SHOP TIP

If the engine is mounted on an engine stand and the cam will not come out, try supporting the cam gear end of the block. Sometimes the block will sag just enough to bind the cam. This is especially true on in-line six cylinder engines.

On OHC engines, the camshaft is usually removed with the cylinder head. Follow the manufacturer's instructions for removal of the cam from the head. This varies with the design of the head.

Inspect the cam lobes and journals for visible wear. If several cam lobes are excessively worn, look for a fuel leak or an internal coolant leak causing a loss of critical lubrication. Nonroller lifters are called *flat tappets*. These lifters **must** be kept in order if they are to be reused.

SHOP TIP

An ice cube tray with 16 slots is a handy way to do this, or holes can be bored in a piece of wood (**Figure 4.90**).

Most of the time a flat-tappet cam and lifters will be too worn to be reused and will be replaced. A roller cam and lifters are most often reused. The following procedure may save time in removing the cam when the bottoms of lifters are coated with varnish.

- With the engine in the upside-down position, move the lifters to their highest positions (toward the head) by turning the camshaft one complete revolution.
- Use a piece of wooden dowel to finish pushing the lifters into their bores so that they will clear the cam (**Figure 4.91**).
- Now the cam can be carefully removed. This is a *delicate* operation. Be careful not to nick any cam lobes.

8. **Remove and label cam bearings.** Cam bearings are usually inexpensive and are routinely replaced. Caustic hot-tanking with the bearings in place will ruin most types of cam bearings, except copper ones (see Chapter 5).

- Before removing the cam bearings with a cam bearing tool (see Chapter 11), note and record their oil hole locations.
- The rear cam plug can be knocked out with the cam bearing tool.
- Label the bearings with a felt marker, or put them in labeled baggies. They may need to be referred to when determining which block positions the new bearings will go into.

9. **Remove core plugs.** Remove core plugs before hot-tanking the block. Use a large punch to knock them sideways (**Figure 4.92a**). They can then be removed easily with a roll-head punch or a large pair of pliers (**Figure 4.92b**). Core plugs cannot be reinstalled once they have been removed.

NOTE

Be careful not to pound core plugs against the side of a cylinder wall. Sometimes a cylinder wall may be directly behind a core plug (**Figure 4.93**). Distorting a cylinder wall can result in a scuffed piston.

CASE HISTORY

An apprentice technician was overhauling an engine and removed the core plugs. One of the cylinders was positioned directly behind a core plug. The core plug became wedged between the block and the cylinder wall, so he forced it out. During reassembly, he attempted to reinstall the piston and rings but the piston would not go into the cylinder. When the shop master technician measured the cylinder, he found that it was out of round by 0.005″. The piston clearance specification was 0.002″. The block had to be sent out to a machine shop for boring and honing.

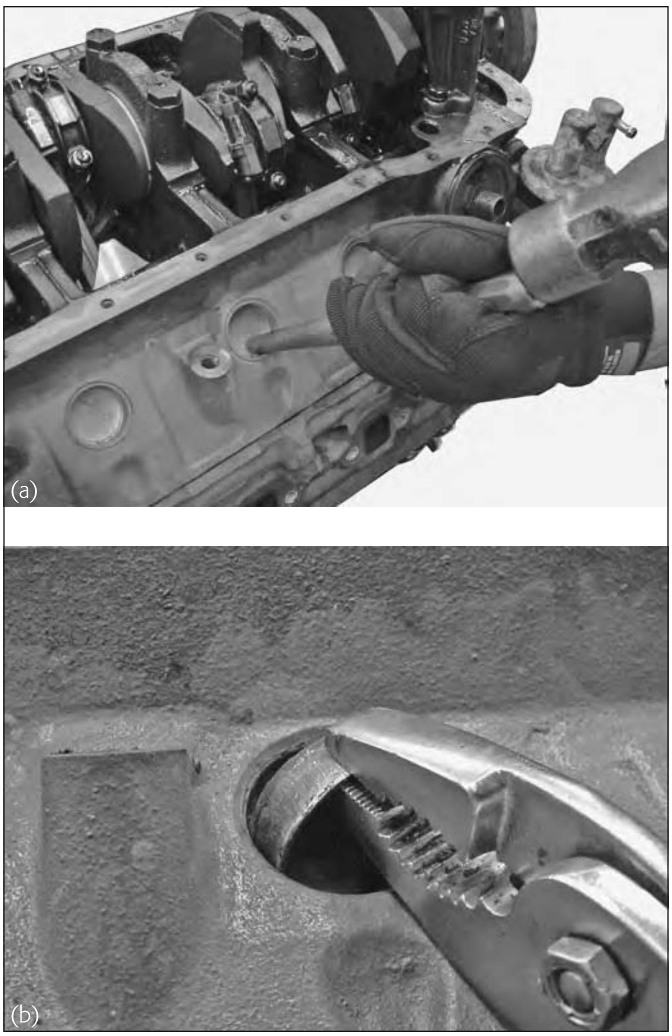


FIGURE 4.92 (a) To remove a core plug, first knock it sideways with a large blunt punch. (b) Using pliers to pull the core plug from the hole in the block. *(Courtesy of Tim Gilles)*

Some engines have shoulders in the bottom of the core plug bore that prevent the core plug from being driven inward. Punch a hole in the core plug and pry it out or use a slide hammer with a screw (**Figure 4.94**).

10. **Clean the engine.** Engine parts are cleaned following procedures covered in Chapter 5. Some cleaning tanks use a strong alkaline solution that can damage materials other than iron or steel. You can check with a magnet to see if something is safe to put into an alkaline cleaning solution. Prior to cleaning, remove anything from the block that is nonferrous. Brass and copper can be cleaned in an alkaline

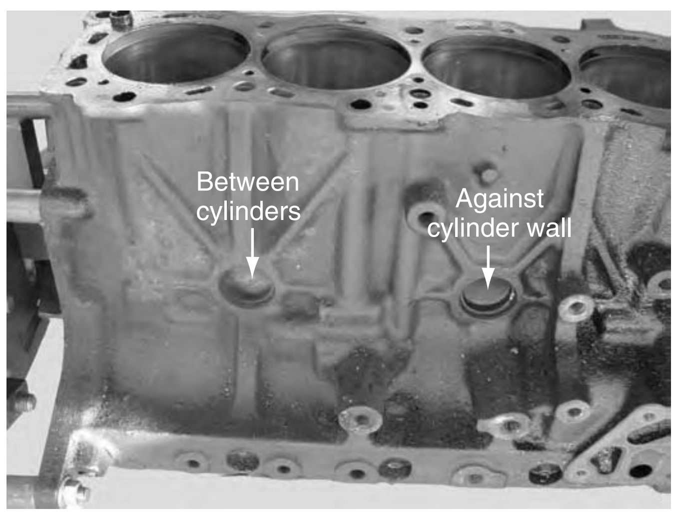


FIGURE 4.93 Be careful when removing a core plug located next to a cylinder wall. *(Courtesy of Tim Gilles)*

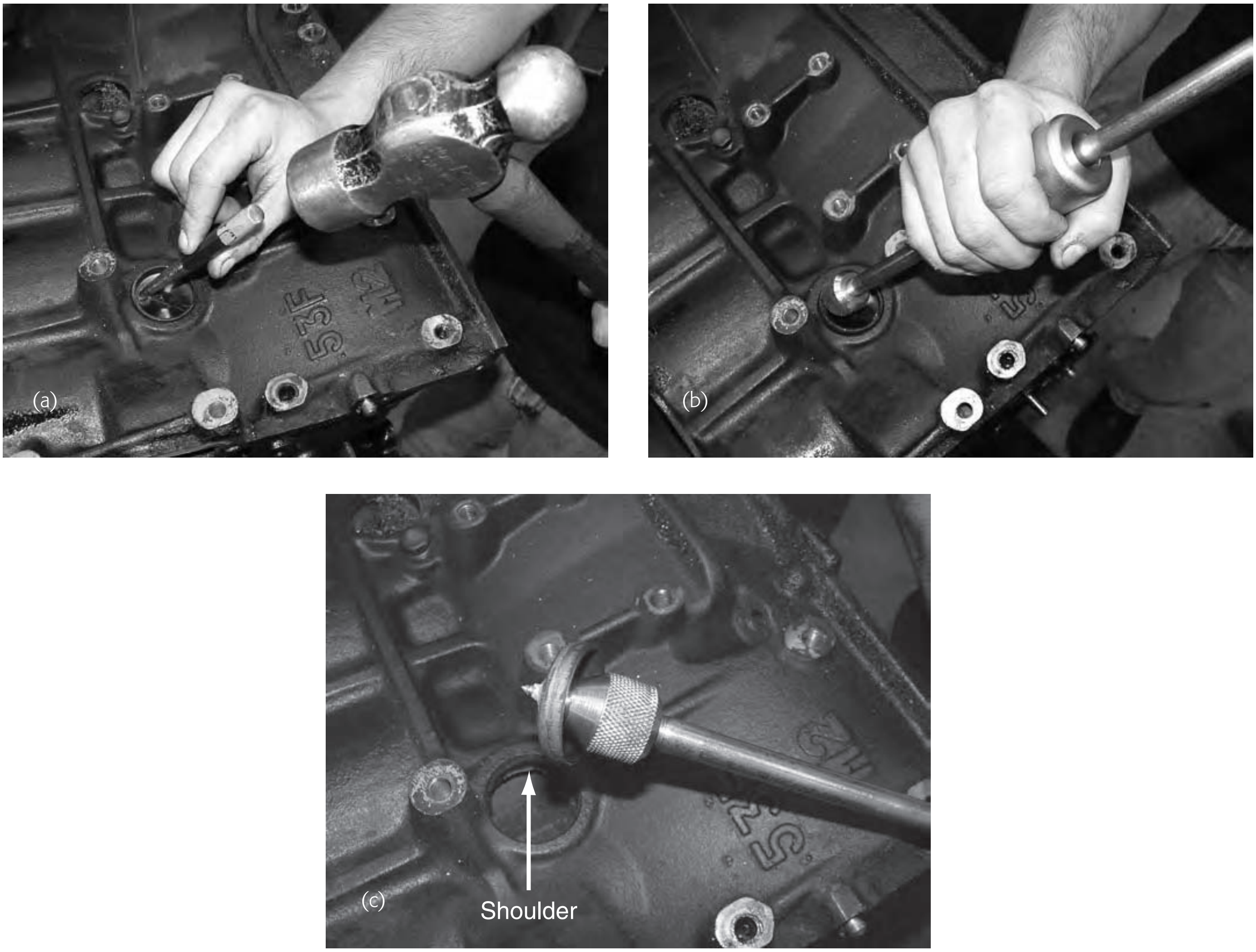


FIGURE 4.94 Removing a core plug when there is a shoulder beneath it. (a) Punch a hole in the core plug. (b) Using a slide hammer to remove the core plug. (c) Notice the shoulder beneath the core plug. *(Courtesy of Tim Gilles)*

solution as well, but aluminum will be quickly damaged.

Following cleaning, oil galleries *must* be cleaned with a brush after the plugs that are sealing the ends of the galleries are removed. Grime builds up in the oil galleries over many miles of driving under various maintenance conditions. This material is loosened during the cleaning process. If it is not physically removed, it will end up ruining new engine bearings and possibly more. Chapter 11 covers the procedure for removing oil gallery core plugs from the block before using a long rifle brush to clean the galleries.

When the block is clean, replace the main caps and torque the bolts to help keep the block properly stressed during any engine machining processes.

ORDERING PARTS

After the block has been stripped, inspect all parts for wear and make a list of new parts that are needed (see the checklist in **Figure 4.95**).

Replacement Engine Parts

Factory replacement parts are categorized as OE (original equipment). **Stock** means the part is the same as intended by the manufacturer. **Aftermarket** is a broad term that refers to parts that are sold by the non-OE market. Many OE engine parts are manufactured by the same manufacturer as aftermarket parts. Diagnosis of worn parts is covered later in the book in the chapters that deal with specific parts.

Engine year and size ____________________ NOTE: Be sure to save all old engine parts.

Piston and ring size: STD ______ .020″ over ______ .030″ over ______ .040″ over ______ .060″ over ______
(Check one)
Crank and bearing sizes: MAINS: STD ______ .020″ under ______ .020″ under ______ RODS: STD ______ .010″ under ______ .020″ under ______
(Check one)
Core plug size ____________________

✓ Those items needed	Quantity	Price
*1. Reground crankshaft and bearings (Crankshaft kit) *Note: Be sure to save the old woodruff key.*		
**2. Piston and pins		
*3. Piston rings		
**4. Camshaft		
*5. Cam bearings		
**6. Valve lifters. *Roller lifters are usually reusable.*		
**7. Cam and crank sprockets.		
*8. Timing chain or belt. The chain tensioner and guides, and idler bearings are customarily replaced, as well.		
**9. Oil pump		
**10. Core plugs, Including rear cam plug and oil gallery plugs. (Brass can be purchased at extra cost)		
**11. Complete gasket set (includes many of the following) A. Head gaskets		
B. Valve guide seals		
C. Valve cover gaskets		
D. Intake manifold gaskets		
E. Timing cover gaskets		
F. Oil pan gaskets		
G. Rear crankshaft seal		
H. Front timing cover seal		
I. Exhaust manifold gaskets		
J. Water outlet housing gasket		
Note: Sometimes valve guide seals and the rear main seal are not included in the gasket set.		
12. Replacement cylinder head bolts. (These are often required because many engines use torque-to-yield bolts, which are not reusable.)		
13. Oil		
14. Oil filter		
15. Spray paint		
16. Large garbage bag (to keep the engine clean during assembly)		
Engine master kit (parts marked * or ** are included in a high quality kit) Engine overhaul kit (parts marked * only are included in this kit)		

	Quantity	Price
The following items are inspected during engine repair and may require replacement at extra cost to the vehicle owner.		
17. Miscellaneous Hoses A. Radiator hose		
B. Heater hose		
C. Thermostat bypass hose		
D. Vacuum hose		
E. Fuel hose		
18. Hose clamps A. Heater		
B. Fuel		
C. Radiator		
19. Fuel filter		
20. Thermostat		
21. Coolant outlet housing		
22. Radiator cap		
22. Coolant (mandatory)		
24. Engine mounts		
Note: With some engine kits, some parts, like the crankshaft, must be returned as rebuildable cores.		
25. Ignition parts (as needed) A. Spark plugs (recommended)		
B. Rotor and distributor cap *Note: Many late-model engines do not have distributors.*		
C. Spark plug cables		
26. Air filter		
27. PCV valve		
28. Accessory drive belts (all accessory drive belts should be replaced)		
29. Ground straps, or battery cables		
30. Valves A. Intake		
B. Exhaust		
31. Valve springs		
32. Pushrods		
33. Clutch parts		
34. Automatic transmission pump seal (this should be replaced)		
35. Automatic transmission fluid		

FIGURE 4.95 An engine parts checklist. *(Courtesy of Tim Gilles)*

Engine Kits

Parts kits are available at wholesale prices for most of the more common foreign and domestic engines. There are kits that contain various groups of parts—for example:

- A crank kit
- A timing chain set
- An overhaul kit
- A master kit

A crankshaft kit includes a reground crankshaft and bearings. A timing chain set includes the chain and sprockets, or chain guides and a tensioner for OHC engines. An overhaul kit includes gaskets, piston rings, crankshaft bearings, and, sometimes, a timing set.

The parts normally found in an engine "master kit" are pistons, rings, reground crank and bearings, reground cam and bearings, new or rebuilt oil pump, timing chain set, and a complete gasket set (**Figure 4.96**). Lifters may or may not be included. Many different types and qualities of kits are available. Be sure to compile the parts list carefully. It is not uncommon to spend twice as much on separate engine parts and not get as many new parts as would come in a packaged engine kit.

NOTE

Sometimes a jobber will promise parts that are not in stock. If you have a deadline, be certain that none of the parts in your order are to be back-ordered.

FIGURE 4.96 An engine master kit.

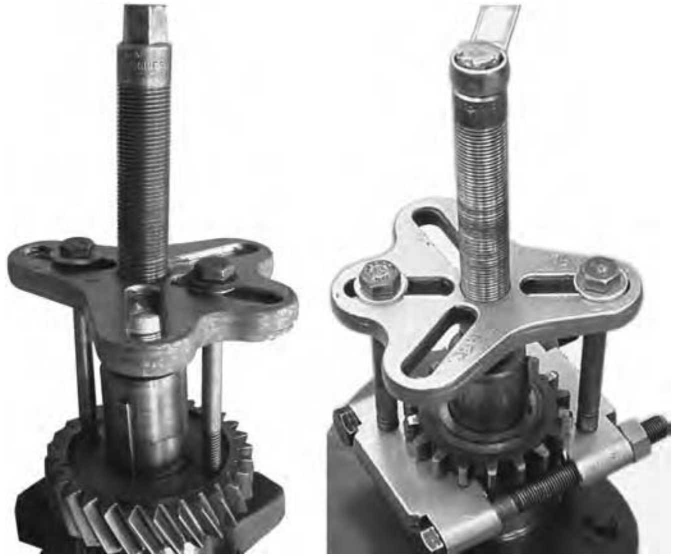


FIGURE 4.97 Puller setup for crankshaft gears and sprockets. *(Courtesy of Tim Gilles)*

Cores

When an engine or an engine kit is purchased from a parts source, the old crankshaft and camshaft are usually returned to them as *cores*. The "core charge" that is paid will be refunded when these parts are returned.

Removing the Crankshaft Timing Sprocket and Woodruff Key. Before returning a crankshaft as a core, remove the timing gear or sprocket. Some sprockets and gears slide easily onto the crankshaft, whereas others are pressed-fit. **Figure 4.97** shows the puller setup for removing a gear or sprocket with and without threaded holes for the puller.

The gear or sprocket is driven by a woodruff key or bar key fitted into a groove on the front crankshaft snout. Remove and save the key. They are not always easy to locate in the correct size. Use a brass punch to prevent damage to the woodruff key. The procedure is shown in **Figure 4.98**. First, strike it on its rear end. Then roll it out of its channel by striking the underside of the front of the key.

When the vehicle is a rear-wheel drive equipped with a manual transmission, be sure to remove and save the pilot bushing or bearing from the rear of the crankshaft.

Determining Part Sizes

The engine size can be determined in several ways. The cylinder bore diameter and the diameter of the crankshaft journals can be measured and compared to specifications.

During inspection of engine parts, watch out for unusually oversized or undersized parts. When errors are made at the factory, an engine block is often salvaged. An original engine might have a crankshaft that has been ground undersized on its main and/or rod journals. Cylinder bores, core plug holes, and valve guides and stems can be oversize as well. Occasionally, one or more lifter bores will be machined oversize and fitted with oversize lifters. Manufacturers have codes (usually in their service information) to indicate the use of nonstandard parts. Numbers or letters may be stamped on the parts or on the oil pan rail or crankshaft, or there may be paint on the part (green is a favorite color). Do not leave this to chance. Measure all parts.

Engine rebuilders use books or computer programs that list casting numbers (**Figure 4.99a**). These numbers identify blocks, crankshafts, cylinder heads, and other parts by groups as they were cast in the factory. The block usually has numbers stamped somewhere on it that can be used to identify the

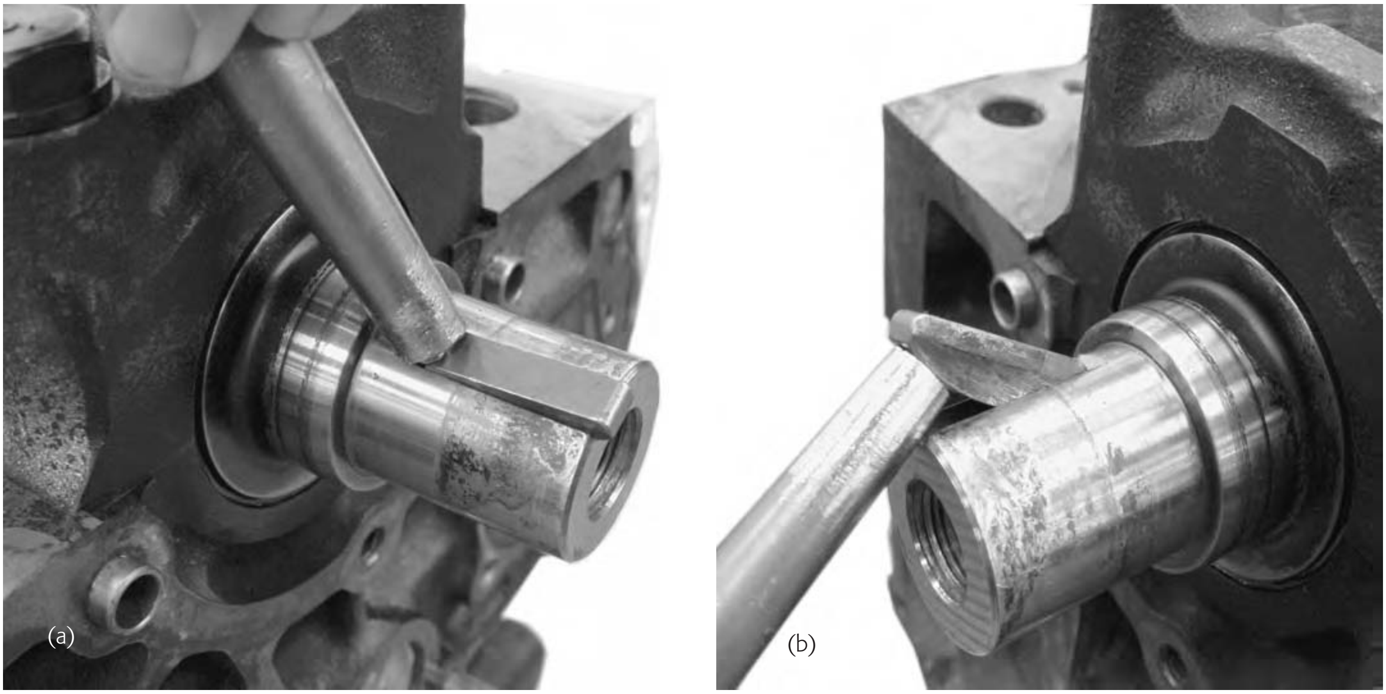


FIGURE 4.98 Removing the woodruff key. (a) Pound on the back of the key. (b) Lift the key out of its groove. *(Courtesy of Tim Gilles)*

engine before ordering parts (**Figure 4.99b**). Casting numbers are raised numbers that were part of the mold when the head or block was cast at the foundry. They can indicate various things but do not always tell you exactly which engine you have. For instance, heads with the same casting numbers could have different sized valves. Some manufacturers use casting numbers that give information regarding the date and place of manufacture.

The top of a piston can be cleaned to see if it is oversize.

CAUTIONS

- Do *not* use a wire brush on the sides of the skirt or the edges of the ring lands; the piston will be ruined (see Chapter 13).
- Do *not* soak piston and rod assemblies in solvent or carburetor cleaner unless they are disassembled from each other. Varnish that has built up on the piston pin can loosen and flow in between the piston pin bore and the piston pin, freezing the piston to the rod.

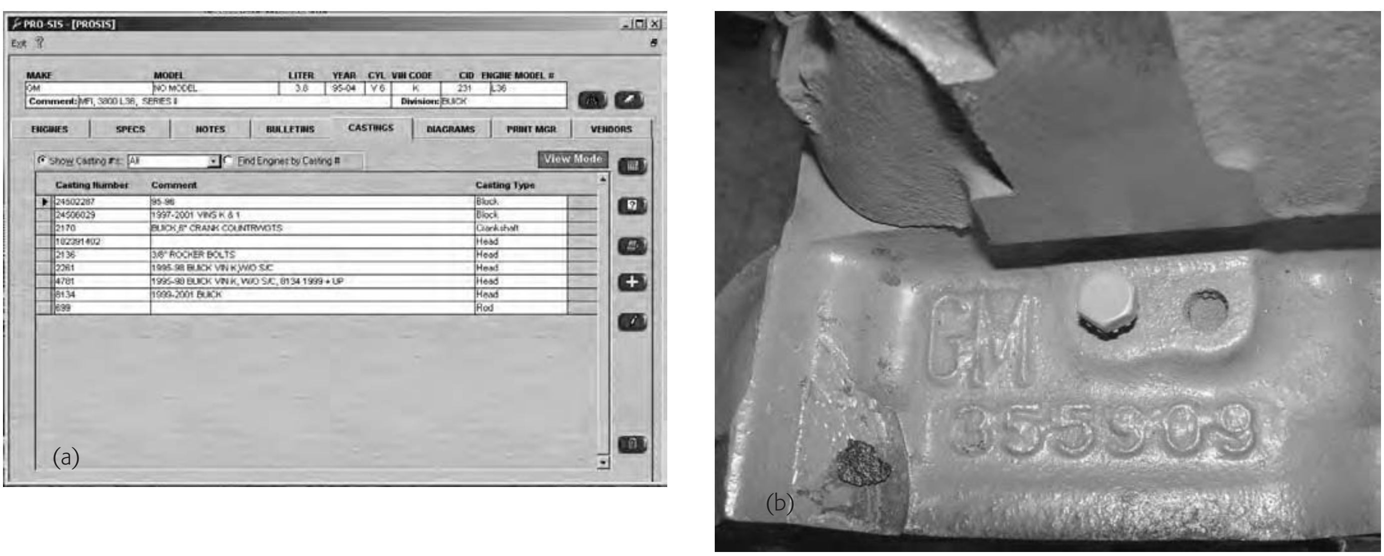


FIGURE 4.99 (a) Casting numbers are available in books and on computers. (b) Typical casting number on a cylinder block. *(Courtesy of Tim Gilles)*

FIGURE 4.100 Clean the carbon off the top of the piston to see if it is oversize. This piston is 0.040″ oversize. *(Courtesy of Tim Gilles)*

The piston shown in **Figure 4.100** is an inch standard piston that is 0.040″ oversize. This tells you that the engine block has been bored oversize before and might be at or near its overbore limit.

SHOP TIP

North American pistons and bearings and many aftermarket import engine replacement parts still use the inch standard system. To quickly convert metric to inch standard, each 0.25 mm is equal to 0.010″. The piston shown in **Figure 4.101** shows a metric oversize piston that is 0.020″ oversize.

FIGURE 4.101 For easy metric conversion, every 0.25 mm is roughly equal to 0.010″. This metric piston is 0.020″ oversize. *(Courtesy of Tim Gilles)* .

Inspect the block and crankshaft as described in Chapters 11 and 12. Check the cylinder bore and the crankshaft for size, taper, and out-of-round wear. The procedures for cleaning, measuring, and repairing parts are found in later chapters.

TYPES OF ENGINE REBUILDS

A **custom engine rebuild** is when a customer's engine is rebuilt for use in the same vehicle from which it was removed. There are also short blocks and long blocks available from engine rebuilding companies. Some larger companies rebuild engines on an assembly line. Some of these rebuilders are factory authorized by automakers, and they rebuild engines to the authorizing manufacturers' standards.

Short Blocks

Short blocks are sometimes used by independent shops and dealerships. Short blocks are completely assembled rebuilt blocks purchased from automotive machine shops and engine rebuilding companies (**Figure 4.102**). They do not include any external parts such as mounting brackets, sheet metal, pumps, or accessories.

A *fitted block* is a term that applies to the block and pistons only. The pistons and crankshaft are matched in size to the bores in the block.

The repair shop will often do the head reconditioning, install the heads on the short block, and install the engine in the car. In this way, they earn the money for a valve job and engine **R&R**

FIGURE 4.102 A short block. *(Courtesy of Jasper Engines and Transmissions)*

(remove and replace), as well as earning the markup price from wholesale to retail on the short block assembly.

Lifters, gaskets, and/or an oil pump may have to be purchased in addition to the short block. An assembly that needs these parts is known as a "short" short block.

Remanufacturing is when an engine is returned to standards that are as close to new as possible. Original core parts are checked against OEM specifications and remachined to return the engine to original equipment tolerances. Parts that normally experience wear are replaced rather than tested to see if they are still serviceable.

Some larger companies that rebuild engines on an assembly line are known in the trade as production engine remanufacturers (PER). Some of these rebuilders are factory authorized by automakers, such as Chrysler or Ford, and rebuild engines to their standards. The Production Engine Remanufacturer's Association (PERA) has about 80 members that build engines. PERA membership is limited to shops that rebuild a minimum of 100 engines a month and their suppliers.

Long Blocks

Most shops prefer a long block to a short block. A **long block**, which includes the cylinder heads assembled on a short block, might be a brand-new factory engine or a rebuilt engine. Long blocks are tested in run-in stands or spin testers (see Chapter 17) so problems can be spotted before installation.

An advantage to the shop owner over buying an engine kit is that a long block carries a time and mileage guarantee from the rebuilder.

When buying a short block or a long block, the old block assembly is returned to the rebuilder as a core. If the block core is unacceptable (**Figure 4.103**) or if the crankshaft, camshaft, cylinder block, or heads are found to be defective, a core charge is assessed. Typical practice is for the core charge to be returned only after the rebuilder inspects the parts.

When you swap one engine for another, be sure that you have the correct replacement. Check such things as the location of the dipstick, which can vary. Sometimes crankshafts are different, too. Check the forging numbers on them. Engines can have different mounting points and fittings also.

FIGURE 4.103 This engine ran low on oil and threw a rod. It will not be an acceptable core, and one of the heads might even be damaged. *(Courtesy of Tim Gilles)*

NOTE

If a customer asks for an engine with a different displacement than the vehicle originally came with, he or she could have problems with emission certification. Also, the engine could have more power than the driveline was designed for.

If an engine failed due to an overheating problem, it is possible that sensors for coolant temperature and the fan relay could be defective.

MAJOR ENGINE REPAIR—ENGINE IN THE VEHICLE

Technicians often perform major repairs to an engine while it is still in the vehicle. In addition to rebuilding the cylinder heads (valve job), they might do lower end work. This could be the replacement of a single defective piston, or it might be a piston ring and crank bearing replacement, called an engine *overhaul* (**Figure 4.104**). This job often includes replacing the timing chain and sprockets. OHC engines usually require a new chain tensioner (see Chapter 9). In-the-car repair is often less expensive for the vehicle owner. An engine that is to be completely rebuilt must be removed from the vehicle.

Valve Job or Head Gasket Repair

The engine should be cold before removing the head. When the head is bolted to the block, it forms

FIGURE 4.104 This engine is getting an in-chassis overhaul. The head and oil pan have been removed so the pistons and rods could be removed for new rings and rod bearings. *(Courtesy of Tim Gilles)*

a rigid unit. Unbolting a hot cylinder head (especially aluminum) can cause parts to warp.

- It is a good habit to unbolt the head in a direction opposite to the normal tightening sequence. A flat rate technician will often leave the manifold(s) bolted to an in-line head during a head gasket repair.
- Check the cleanliness of head bolt threads as each one is removed. A flat rate technician will use a tap to chase only the bolt holes in the block that correspond to dirty head bolt threads. A small wire brush on a die grinder is also effective in cleaning threads.
- When reinstalling the head, be careful that nothing is accidentally pinched between the head and the block (**Figure 4.105**).

FIGURE 4.105 This ground strap was clamped between the head and block during a careless installation. *(Courtesy of Tim Gilles)*

CAUTION

Before reinstalling a cylinder head, use a suction gun or air nozzle to remove any oil or water from blind head bolt holes. Never use an impact wrench to tighten the bolts or the block can be cracked next to the bolt hole because the water or oil does not have time to seep between the threads.

Maintaining Valve Timing. During a valve job, it is essential to keep the timing chain or belt in place to maintain correct valve timing. Position the engine at TDC on the number 1 cylinder. Some OHC engines use a single long chain for a cam drive. The chain can be wedged against its guides with a tapered block of wood (**Figure 4.106**). If the engine is turned over, an unsecured chain tensioner can fall out, causing much extra work. Some engines have lower and upper chains. These engines do not require special attention to wedging the chain.

Be sure to look for hidden head bolts and check the service information before removing an OHC head.

Valve Job or Complete Engine Overhaul?

The question of whether to do a valve job only or an engine overhaul is an important one. Valve

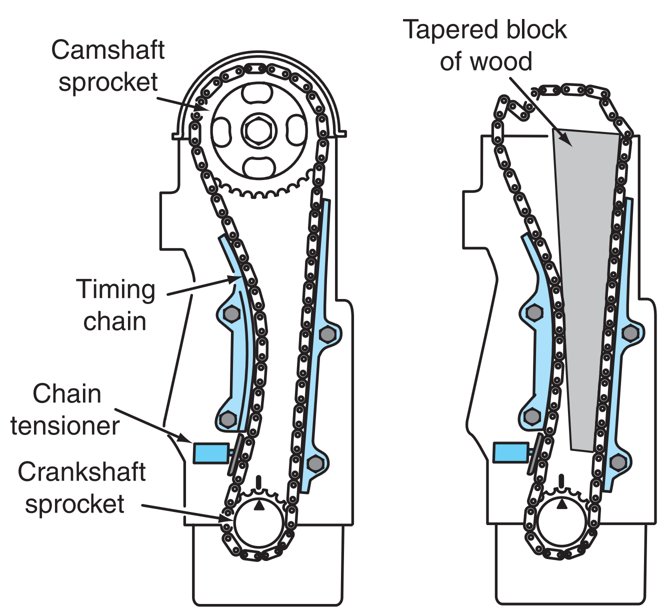


FIGURE 4.106 The chain tensioner on some OHC engines must be wedged to keep the chain in position during cylinder head removal.

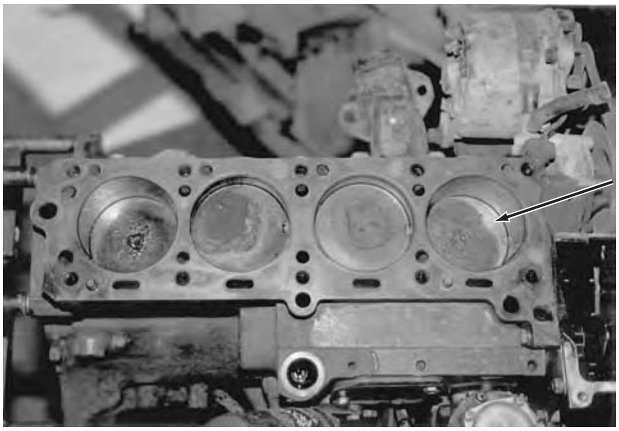


FIGURE 4.107 A clean area around the outside edge of a piston indicates excessive oil consumption past the rings. *(Courtesy of Tim Gilles)*

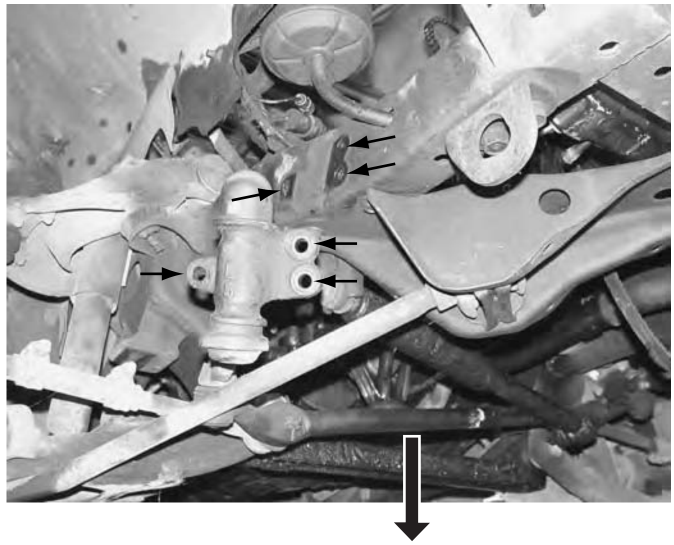


FIGURE 4.108 Remove the idler arm bracket to allow the center link to drop far enough to remove the oil pan. *(Courtesy of Tim Gilles)*

FIGURE 4.109 Appearance of the bottom of an engine with the oil pan removed to allow access to the connecting rod nuts. *(Courtesy of Tim Gilles)*

guide seals are responsible for a good many oil consumption complaints (see Chapter 7). **Figure 4.107** shows what pistons look like when rings have not been controlling oil. There is a band around the top of each piston where no carbon is present. A valve job on this engine would not solve the oil consumption problem.

Head Gasket Problems

Inspect the head gasket for damage. A faulty head gasket often points to a need for head surfacing, cooling system service, or repair to the engine's fuel or ignition system. Excessive temperatures can turn a metal head gasket blue or black. A Teflon head gasket can turn brown. Look for signs of coolant leaks and damage from abnormal combustion. Carbon buildup around the combustion seal can indicate the use of a gasket of the wrong size (too large).

Remove the Oil Pan

Removing the oil pan could require the removal of some steering linkage. Often, simply unbolting the idler-arm bracket (**Figure 4.108**) will provide enough clearance for the oil pan to be removed (**Figure 4.109**). If not, one or more of the steering linkage "tapers" (**Figure 4.110a**) might have to be broken loose. Many technicians use a "pickle fork" with an air chisel (**Figure 4.110b**) but this procedure often tears an otherwise good tie-rod seal. A better way to break a taper is to use a special tie-rod puller (**Figure 4.110c**) or two large hammers, as shown in **Figure 4.110d**.

Sometimes the engine mounts must be loosened and the engine raised a few inches in order to remove the pan. Be careful not to damage the radiator or the fan shroud when raising the engine off its mounts. Sometimes the radiator hoses must be removed or the radiator unbolted before the engine is raised. Use a piece of plywood to protect the oil pan, and jack the engine up with a hydraulic jack. The engine can then be blocked up at the motor mounts (**Figure 4.111**).

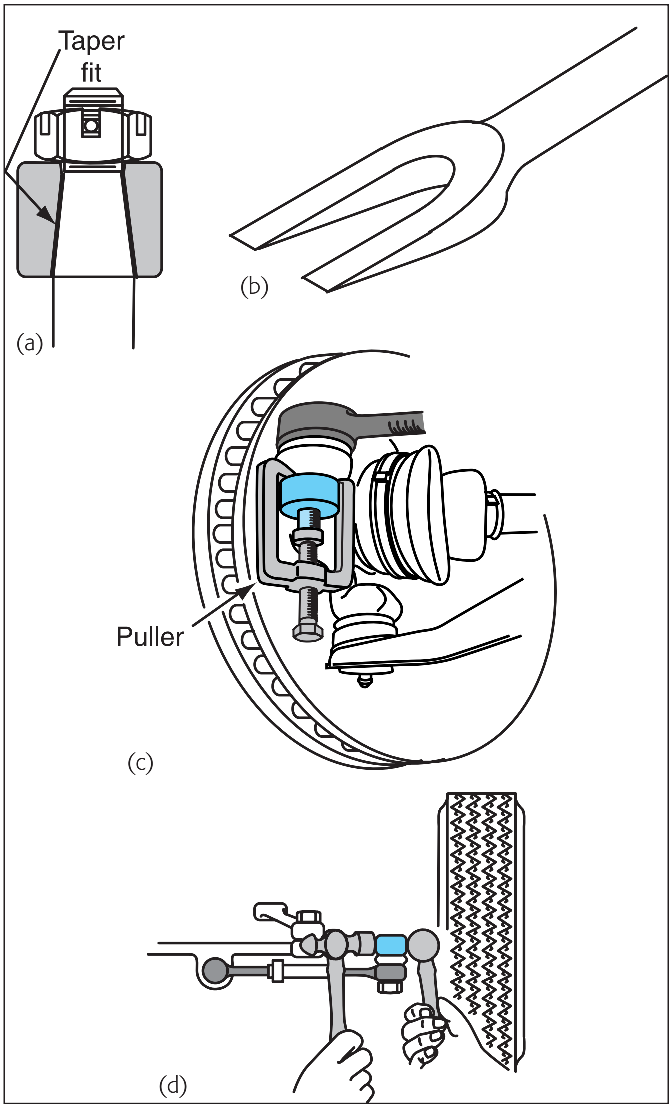


FIGURE 4.110 Separating steering linkages. (a) A steering-linkage taper. (b) A pickle fork can tear a tie-rod seal. (c) A tie-rod puller. (d) Using two large hammers to separate steering-linkage tapers.

SAFETY NOTES

- Be sure to use plywood when jacking or supporting something. The many layers of wood are laminated with the grain running in different directions, which makes plywood unlikely to split under pressure like ordinary lumber would.
- If the oil pan is to be removed with the car on a lift, the safest choice is a drive on lift that lifts the car by the wheels (see Chapter 2). Raising the engine from the bottom can upset the balance of the car on a frame-contact hoist.

If a frame-contact hoist is to be used, there are special fixtures that can raise the engine from its top side **(Figure 4.112a)** or from the bottom (**Figure 4.112b**).

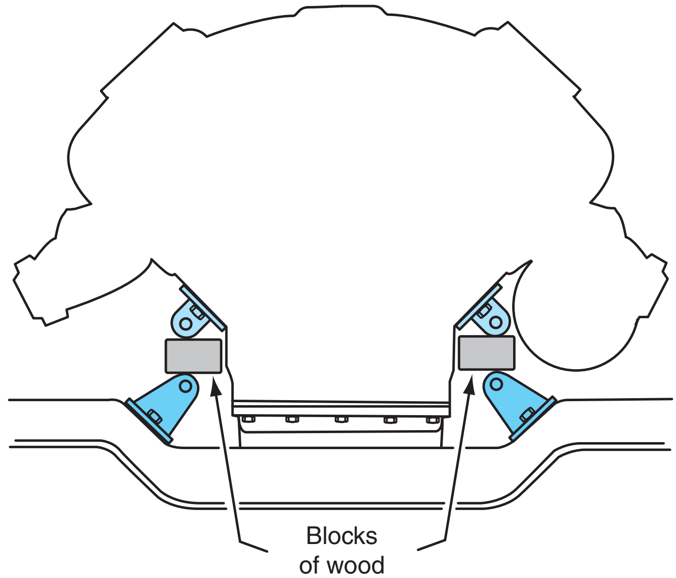


FIGURE 4.111 This engine has been raised and blocks of wood installed under the motor mounts in order to remove the oil pan.

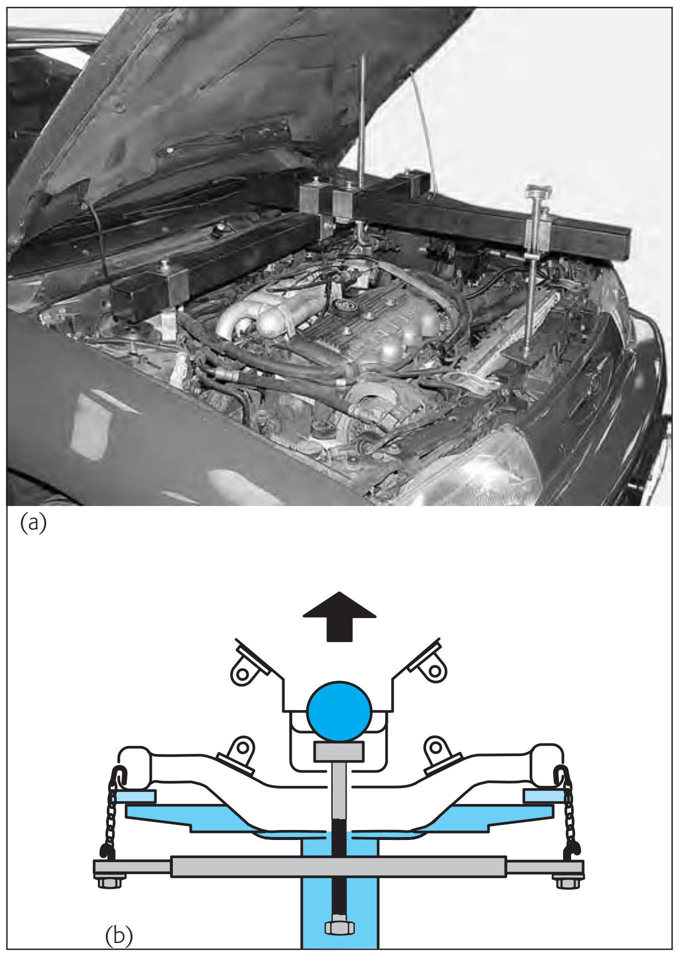


FIGURE 4.112 Raising the engine. (a) The engine can be lifted from the top *(Courtesy of Tim Gilles)* or (b) raised from the bottom.

SHOP TIP

Sometimes it is necessary to unbolt the oil pump after the pan is loosened in order to get enough clearance to remove the pan. The pump is dropped into the pan and removed along with it. When reinstalling the pump, use a rubber band wrapped in a figure eight shape to prevent the bolts from falling out of the holes in the pump while you reinstall it on the engine through the small opening between the pan and the block.

Remove the Piston and Rod Assembly

If the lower end is to be repaired, remove the cylinder head(s). If there is a ring ridge, remove it before removing the piston and rod assemblies. With the piston at BDC, place a rag in the cylinder to catch the metal chips. With the pan removed, the connecting rods can be unbolted and the pistons removed according to the procedure described earlier in this chapter.

Rod Bearing Replacement

Although bearings are usually replaced, an in-car repair might call for the replacement of only one defective piston. In this case, an unworn rod bearing might be reused. The piston shown in **Figure 4.113** is just one example of such a case. If a rod bearing is to be reused, mark the back of the bearing with a felt marker so it can be returned to its original position. If a bearing has lost its spread (see Chapter 12), it may have to be spread slightly before reinstallation.

Main Bearing Replacement. Main bearings are replaced with the crankshaft in the engine using a tool installed in the oil feed hole in the journal (**Figure 4.114a**). The bearings must be rolled out from the side opposite the *bearing locating lug*, or tang (**Figure 4.114b**).

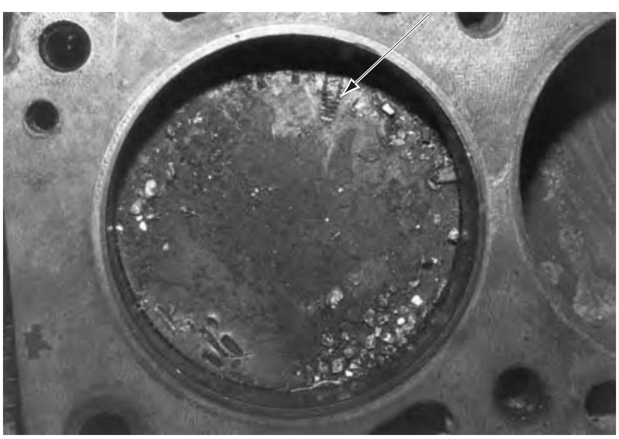


FIGURE 4.113 This piston was damaged when a bolt accidentally fell into the intake manifold. *(Courtesy of Tim Gilles)*

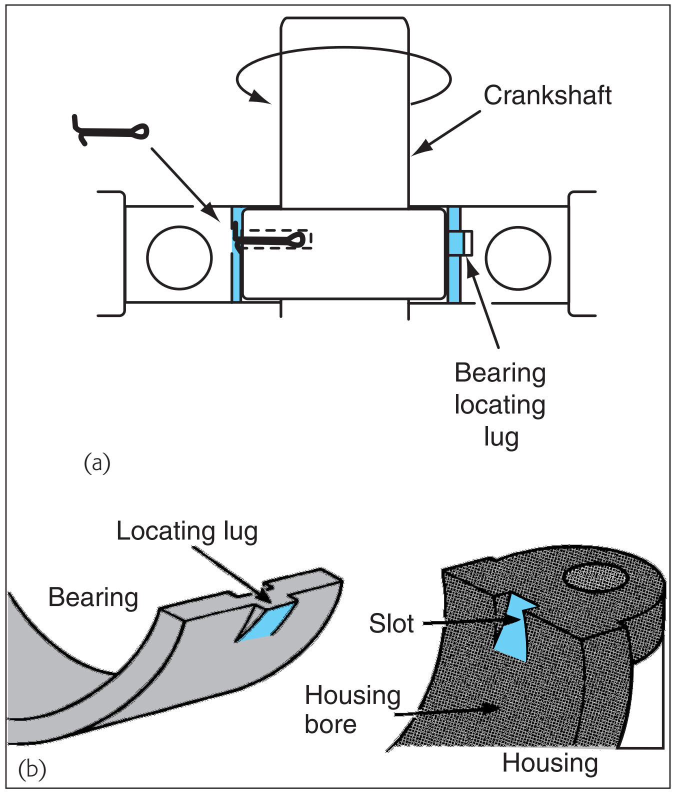


FIGURE 4.114 Main bearings can be rolled out and new bearings rolled back in. (a) If the special tools are not available, you can make one out of a cotter pin. (b) Be sure to turn the right direction. The locating lug must roll out of the bearing housing first.

Remove the Timing Cover

To remove the timing cover, first remove the radiator, accessory drive belts, and vibration damper. The damper bolt is loosened using a large socket and impact wrench.

SHOP TIPS

- When loosening a damper bolt an angle attachment is available for use with an impact wrench in case an air-conditioning condenser (in front of the radiator) is too difficult to move. However, using the attachment lowers the amount of torque available to the damper bolt.
- Some technicians use the starter motor to free the damper bolt (**Figure 4.115**). Be certain you know which way the engine turns before trying this. If you position the breaker bar on the wrong side, you could be hurt or you could damage the vehicle.

FIGURE 4.115 With the breaker bar forced against the car frame, the starter motor can sometimes be used to loosen a tight damper bolt. Be certain you know which way the engine turns. *(Courtesy of Tim Gilles)*

Timing Chain and Belt Service

Some OHC engines use a chain drive; others use a belt drive. Service to these components is covered in detail in Chapter 9. Service on belt drives is relatively simple, because no oil is sealed by the timing cover as with chain drives. Removing the timing cover on some OHC engines with timing chains is more difficult because the cover often fits between the oil pan and the cylinder head. There are special procedures for replacing cam timing components in these engines. Sometimes the head and pan might have to be loosened, which can result in leaks after the repair. When the cover intersects the pan, the front part of the pan gasket is cut, and then part of a new pan gasket is cut and installed to match the intersection of the oil pan and timing cover (see Chapter 16).

When doing a maintenance replacement of a timing belt, the time requirement can vary widely among vehicles. Most require 3 or 4 hours, but some take 6 or more. Refer to Chapter 9 for specifics on timing belts. Here is a typical generic procedure for removing and replacing a timing belt:

- Position the crankshaft timing mark at TDC.
- Remove the front wheel on the side of the vehicle toward which the crankshaft pulley faces.
- Remove the inner fender panel.
- Support the engine with a sling like the one shown in Figure 4.112.
- Remove the engine mount bolts.
- Remove the crankshaft pulley bolts and pulley.
- Remove the upper and lower timing covers (if there is more than one part to the timing cover).
- Verify that the crankshaft timing marks are aligned correctly.
- Loosen the tensioner bolt and remove the timing belt.
- Verify that there is no oil leakage into the area surrounding the belt. If camshaft seals or a valve cover are leaking, repair them prior to replacing the timing belt or premature failure will occur.
- Install the new belt and adjust the belt tension to specification.
- Turn the crankshaft two revolutions and recheck the timing marks to be certain they are accurately positioned. Failure to do this can result in valve interference and a costly repair.
- Loosen and retension the belt.
- Reassemble all of the parts and affix a sticker to the fenderwell that tells the mileage when timing belt service was done.

Freewheeling and Interference Engines

An engine that has enough piston-to-valve clearance to prevent contact is known as a **freewheeling engine**. Whenever timing chain service is performed because the chain has broken or skipped, it is possible that valves have come into contact with pistons (**Figure 4.116**). Cracked pistons or bent valves can result (see Chapter 9). Before a chain repair job, perform a leakage test on nonfreewheeling (interference) engines to check for bent valves so that an accurate repair estimate can be made.

Replace the Timing Components

When reinstalling the head on an OHC engine it is very important that the number 1 piston be at TDC and the cam turned in the head until it is timed properly. Otherwise, it is possible that a valve could be open and up against a piston. If the head is tightened in that position, one or more valves will be bent. The valves are adjusted before installing the head (see Chapter 8).

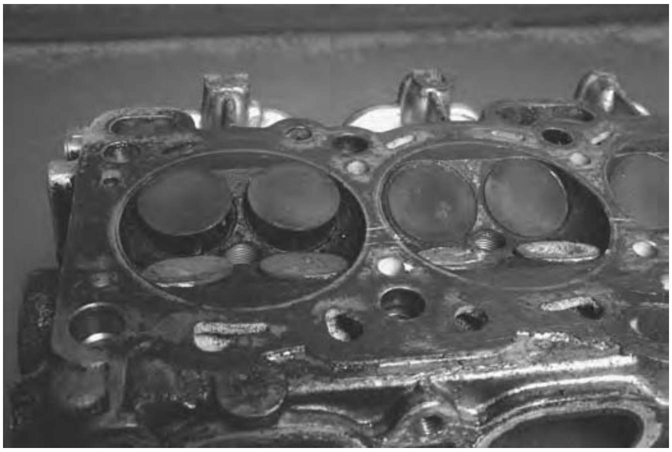


FIGURE 4.116 These intake valves were both bent when the timing belt broke.

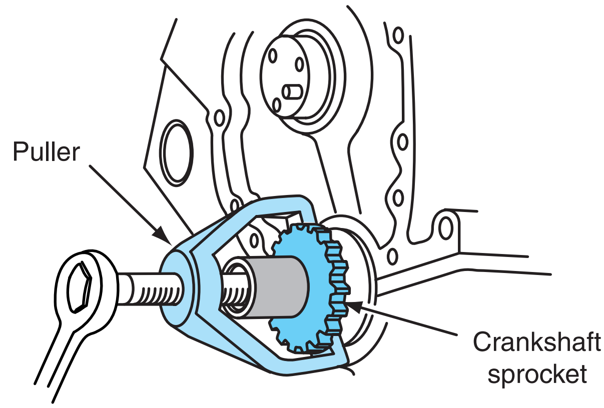


FIGURE 4.117 The crank sprocket can be removed with the crankshaft still in the engine.

Valves in heads that have four valves per cylinder are small and are easily bent. Some service information instructions recommend having the number 1 piston slightly off TDC during head installation to prevent accidental damage to valves.

If the camshaft and crankshaft drive gears require replacement, this can be done with the engine in the car.

NOTE

If the cam sprocket is the nylon type and chunks of gear teeth are missing, the oil pan *must* be removed in order to extract teeth from the oil pump screen and oil pan. Failure to do this will result in oil pump failure at a later date when pieces get sucked into the pump and block oil flow or cause interference in the pump (see Chapter 14). **Figure 4.117** shows a crank gear being removed while the crankshaft is in the block.

When replacing a pressed-fit camshaft gear, pull it off the camshaft using a puller. When reinstalling the gear, take care that the camshaft does not move to the rear; it could knock loose the core plug in the rear of the block, or chip cam lobes on neighboring lifters.

Replace Crankshaft Seal

Crankshaft front and rear seal replacements can be performed with the engine in the car. The procedures are covered in Chapter 16.

SHOP TIP

For single piece (full round) seals that are in a casting bolted to the rear of the engine block, remove the seal by prying between the crankshaft and seal. Do this before removing the casting. The casting is fragile and is easily broken during seal removal unless it is bolted to the block (see Chapter 16).

NOTE

It is very important that the crankshaft pulley bolt be correctly tightened. A case history in Chapter 9 describes the results of improper tightening.

Flywheel Ring Gear Service

Vehicles with manual transmissions/transaxles have a replaceable ring gear on the flywheel

VINTAGE ENGINES

Manufacturers of engines with pressed-fit camshaft gears make special tools to be used to hold the cam forward during gear installation.

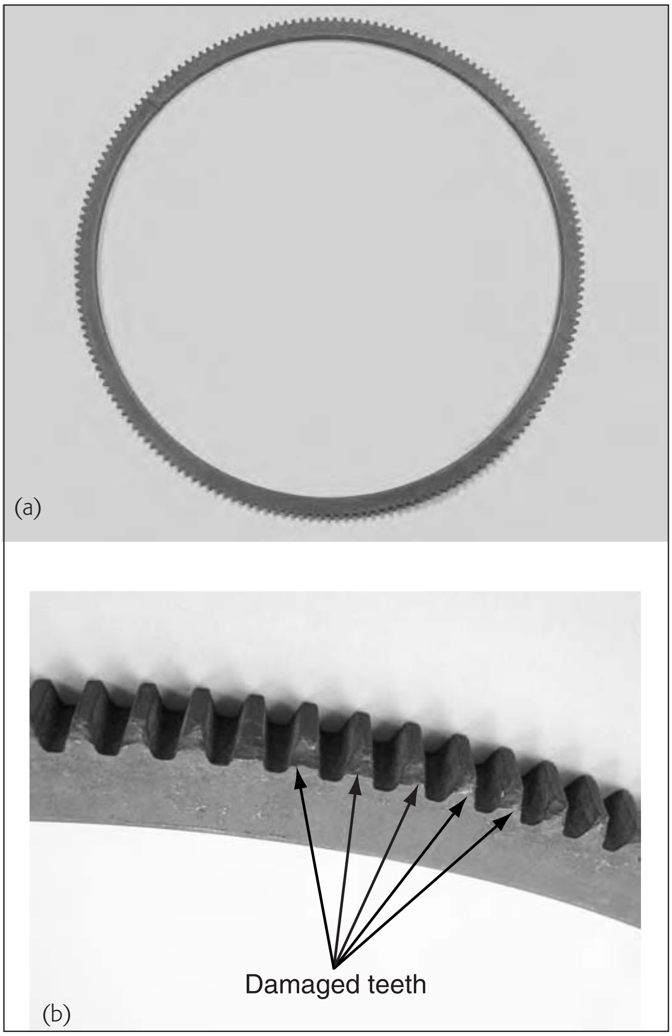


FIGURE 4.118 (a) A replaceable flywheel ring gear. (b) Damaged ring gear teeth. *(Courtesy of Tim Gilles)*

(**Figure 4.118a**). A defective starter sometimes results in damage to teeth on a flywheel ring gear (**Figure 4.118b**). To remove the worn ring gear from

FIGURE 4.119 A temperature indicating stick melts when it contacts metal heated to its rated temperature. This one melts at 250°F (121°C). *(Courtesy of Tim Gilles)*

the flywheel, drill a hole between the teeth and break the ring with a chisel.

Heating a Ring Gear. Heat the new ring gear evenly around its circumference during installation. It should not be heated to more than about 400°F (204°C); too much heat can remove the hardness from the gear. The temperature of the ring gear can be checked with a tempilstick. Tempilsticks are pencil-shaped sticks that melt at different temperatures (**Figure 4.119**). A 400°F (204°C) tempilstick will leave a melted film on the ring gear when it is stroked across a surface hotter than 400°F (204°C).

Temperature can also be checked by polishing several spots on the ring gear using emery cloth or sandpaper. Heat the ring gear until the spots turn blue.

Solder can also be used to check the temperature of a ring gear. When the solder melts, the ring gear is hot enough and can be positioned onto the flywheel.

NOTE

The chamfered side of the teeth should be on the same side as they were on the old ring gear.

Other types of in-car repairs are covered elsewhere in this book. Be sure to check the appropriate service literature for proper procedures.

Key Terms

aftermarket
custom engine rebuild
freewheeling engine
long block
R&R
ring ridge
short blocks
stock
stress raiser
thrust bearing surfaces

Study Questions

1. What number is used by manufacturers to identify a particular vehicle?
2. Which character of the VIN on a domestic car tells the engine code?
3. What is another common name for the *Parts and Time Guide* used to determine the length of time to complete a job?
4. What are bulletins that are produced by manufacturers and associations called?
5. What part usually connects the engine to the fire wall or bulkhead electrically?
6. Why should air-conditioning lines *not* be disconnected?
7. Why must a fuel line be plugged even if no fuel leaks out when it is disconnected?
8. Why should the oil pan be removed before turning the engine over (upside down) when mounted on an engine stand?
9. Describe three ways to turn the crankshaft.
   a.
   b.
   c.
10. What is installed on rod bolts to protect the crank when removing the piston and rod assembly?
11. If nonroller lifters will be used again, what caution is necessary?
12. Can core plugs be reinstalled after they have been removed?
13. How can metal be checked to see if it is safe to clean in a caustic cleaner?
14. Besides measuring it, how can a piston be checked to see if it is oversized?
15. What is the name that describes a used crankshaft and camshaft when they are to be returned to the parts house when a complete engine kit is purchased?

ASE-Style Review Questions

1. Technician A says that cylinder heads are more easily removed after warming up the engine. Technician B says that to avoid warping the head, the engine must be cold before removing it. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says to use an air impact wrench to remove rusted exhaust nuts. Technician B says that when installing a flywheel ring gear, heat it until it is red hot. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that one reason all main and rod bearings should be kept in order during engine disassembly is in case they will be reused. Technician B says that there is no need to keep bearings in order if new parts are to be used. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that the vibration damper is removed with a puller that grasps the damper's

outer ring. Technician B says that when an air impact wrench is used on a puller to remove the vibration damper, the crankshaft need not be kept from turning. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

5. Technician A says that it is usually easier to remove the engine with the automatic transmission on a rear-wheel drive car. Technician B says to disconnect the positive battery cable first. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. Technician A says that some crankshaft sprockets slide easily onto the crankshaft snout. Technician B says that some crankshaft sprockets are pressed-fit. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that a freewheeling engine is one that does not slow the vehicle down when decelerating. Technician B says that a freewheeling engine is one in which the valves cannot contact the pistons if the timing chain or belt breaks. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says that an automatic transmission heat exchanger is often located within the radiator. Technician B says that an automatic transmission heat exchanger is often found in the bottom of a radiator. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that when using a flare-nut wrench, two wrenches must often be used. Technician B says to use an open-end wrench on fuel fittings. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Technician A says to check the cylinder bores for size, taper, and out-of-round wear. Technician B says to check the crankshaft journals for size, taper, and out-of-round wear. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 5

Cleaning the Engine

Contents

- Cleaning Methods
- Cleaning the Inside of the Engine

Objectives

Upon completion of this chapter, you should be able to:

- Safely and correctly use cleaning tools and equipment.
- Describe the best choice of cleaning method for a particular application.

Introduction

This chapter deals with methods for cleaning the engine. Different types of materials require cleaning, including hard deposits, dirt, oils, greases, and contaminants. The inside of an engine contains oils and contaminants that cannot be washed down drains. Cleaning methods differ, depending on whether materials to be cleaned are considered to be toxic or not.

The internal combustion engine in the modern automobile produces many by-products during operation, including acids and fuel, both burned and unburned. Moisture also contributes to the accumulation of **sludge** inside the engine (**Figure 5.1**). In addition, carbon builds up in the combustion chambers because of oil that leaks past the rings from the crankcase. Oil that leaks out of the engine combines with dirt and road grime to make a greasy film on the outside of the engine. Also, mineral deposits can build up in the cooling system.

It is estimated that approximately one-third of a shop's expenses can be attributed to cleaning the engine. This chapter deals with the cleaning equipment used when preparing an engine for rebuilding.

CLEANING METHODS

There are several categories of materials that require cleaning in an automotive engine. Water-soluble deposits (dirt), organic soils, scale, or rust all require different methods of cleaning. Cleaning methods include wet cleaning, which includes water and/or chemical solutions, abrasive cleaning, and thermal cleaning. In smaller shops, the most common of the three methods is wet cleaning. Methods and materials covered in this chapter are those that are the most popular ones used in repair and machine shops. Specific information about cleaning materials is best obtained from the supplier of the equipment.

Chemical Cleaning

Chemical cleaning in engine repair includes three main types: *alkaline*, *acid*, and *solvents*. The

FIGURE 5.1 Sludge is formed when water and by-products of combustion combine.

VINTAGE ENGINES

The cylinder head shown in **Figure 5.2** is covered in heavy, greasy sludge. This was a common appearance of the inside of engines until the 1970s. Modern higher-quality oils, crankcase ventilation systems, and unleaded gasoline have resulted in much cleaner engines. When a modern engine accumulates this much contamination, it is likely due to a total lack of maintenance or a defective PCV system. An alkaline cleaner—a base—will be effective in cleaning a mess like this.

Vintage engines are also more likely to have a buildup of cooling system scale (**Figure 5.3**). Better chemical packages in engine coolants and more critical cooling system maintenance in modern bimetal engines have reduced the likelihood of this occurrence. Acid cleaning would be effective in removing this type of scale.

FIGURE 5.2 This vintage cylinder head is heavily contaminated with greasy sludge. An alkaline (base) cleaner will clean it. *(Courtesy of Tim Gilles)*

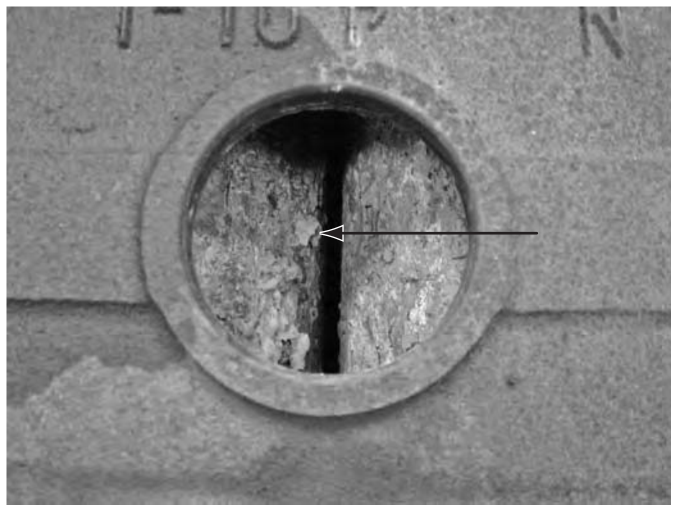


FIGURE 5.3 The water jackets in this cylinder block have rust and scale. This is removable by acid cleaning, but not with a base. *(Courtesy of Tim Gilles)*

strength (or alkalinity) of a solution is measured on the **pH scale**, which ranges from 1 through 14. Pure water is rated at 7. Solutions below 7 on the scale are acidic. A pH rating of 1 is a strong acid; a pH rating above 10 is a strong alkaline cleaner, or *base.*

To clean soils, a chemical must wet the material. Soap is a wetting agent. After wetting, the soap suspends dirt so it can be washed away. Dirt is the only water-soluble material found on auto parts. Organic soils include petroleum by-products, gasket sealers and paints, carbon, and other by-products of combustion. These materials cannot be effectively cleaned with water. Chemicals are used to make these soluble so that water will be able to wash them off.

Cleaning with Bases. Alkaline materials cut grease very well and work best when heated. Most automotive soaps are alkaline. Using soap and hot enough water temperatures are both very important when cleaning grease. Soap lifts grease and makes cleaning easier and much more effective. Temperature is also very important. Remember how much faster hands clean up when using hot water instead of cold? A cleaning chemical will clean about ten times as well at 150°F (66°C) than at

VINTAGE ENGINES

Pressure washing and steam cleaning have become grease removal methods of the past due to environmental considerations. Law requires the sewer drain to capture all of the hazardous contaminants that would otherwise go into the sewer. Also, these cleaning methods are labor intensive, which means that they require an operator. They can also cause damage to air-conditioning and electrical components and connections.

room temperature. From 140°F to 200°F (60°C to 93°C), cleaning time is cut in half by every increase of 20°F (–7°C). **Agitation**, or moving the liquid, also shortens cleaning time.

Other chemicals designed to work at room temperature include Simple Green® or Super Clean Tough Task®.

Cleaning with Acids. Acids are useful only in removing rust and scale. Acid will not cut grease. Before rust can be removed, any oil or grease must first be removed with an alkaline material. When an acid is used to remove rust or scale, it also removes a small amount of the base metal. The chemical used to remove scale deposits from the vehicle's cooling system is an example of an acid used in automotive repair.

The engine shown in Figure 5.3 has water jackets full of rust and scale. Acid cleaning will remove rust and scale, but alkaline cleaners will not. Additional information on rust and scale removal can be found later in this chapter.

Cleaning with Solvents. Solvents are of three types: water based, mineral spirits (Stoddard® solvent), or chlorinated hydrocarbons (carburetor cleaner). Solvent safety precautions are covered in Chapter 2.

CLEANING THE INSIDE OF THE ENGINE

There are many methods of cleaning parts that have been removed from the engine. There are also additives for removing sludge from the inside of the crankcase of a running engine. The vehicle should not be driven while these additives are flushing the engine, because they do not provide sufficient lubrication characteristics. Engine oil is changed immediately following the flushing procedure.

CAUTION

The inside of a dirty engine can harbor *hazardous waste*. When cleaning the inside of the engine, the steam cleaner and pressure washer are to be avoided. Engine bearings are made of lead and other metals. As bearings wear, the metal is deposited in the engine oil. Used engine oil also contains other contaminants that cannot be allowed to enter the sewer. It must be disposed of properly.

Disposal of toxic waste is costly. Shop operators have developed many methods of disposal.

NOTE

Even materials that are called biodegradable will become hazardous waste when they pick up hazardous materials during use.

Methods of cleaning the inside of the engine include chemical cleaning, abrasive cleaning, and thermal cleaning. These cleaning methods must all keep contaminants contained for proper toxic waste handling.

Chemical Cleaning

Chemical cleaning includes solvent tanks, small parts cleaners (carburetor cleaner), hot and cold tanks, spray washers, jet washers, ultrasonic cleaners, and salt baths.

Solvent Cleaning. Solvents are mineral spirits, Stoddard solvent, carburetor cleaner, or water-based

FIGURE 5.4 A water-based solvent cleaning tank. *(Courtesy of Tim Gilles)*

solvent (**Figure 5.4**). Hazardous waste laws regulate disposal of each type of used solvent. Water-based solvents are easiest to dispose of because they can be evaporated to reduce their volume prior to disposal. Stoddard solvent is commonly recycled.

NOTE

The use of gloves is recommended when cleaning with solvent, although it is not a major irritant to most people's skin.

Carburetor cleaners are the most difficult of these three solvents to dispose of and their fumes can be hazardous.

NOTE

Due to safety and environmental considerations, carburetor cleaners (chlorinated hydrocarbons) are not commonly used. Chlorinated solvents are not legal to use in some communities. Consult the local authorities. Most newer solvents are nonchlorinated.

Solvent Parts Cleaning Tanks. The solvent tank is used for cleaning grease from smaller parts. Cold petroleum-based solvent does a good job of cutting grease. Although it would clean better if it were hot, evaporation and fuming would result. Scrape heavy deposits of grease from parts before cleaning them in a solvent tank.

Water-based solvents have become increasingly popular. These solvents clean better when hot. They are usually heated to slightly above 100°F (38°C), which is comfortable to touch. Water-based chemicals are usually available in either liquid or dry forms. Powder weighs less, so it costs less to ship. If a spill occurs, powder can be swept up and used. Spilled liquid would be wasted.

Solvent is applied with a parts brush, which has stiff bristles that will not be softened by the solvent. Using a brass or nylon brush instead of a steel wire brush avoids the possibility of an accidental spark and reduces the chance of damaging the sealing surface of the part being cleaned.

Some solvent tanks have agitators to keep the solvent moving, reducing cleaning time. Dirt settles in sediment trays in the bottom of the tank, where it is periodically cleaned out.

When a petroleum-based solvent becomes too oily, it is recycled. Companies that specialize in waste handling pump the old solvent from the tank and replace it with clean recycled solvent. Recyclers use distillation technology in which used solvent is boiled and reduced to vapors, and contaminants are left behind in the tank. The vapors are passed through a cooling condenser, which returns them to pure reusable liquid solvent.

Some solvent tanks recycle the solvent as it circulates during parts cleaning. These use a filter to remove contaminants and oil.

SAFETY NOTE

Assume that the solvent you are using could contain contaminants that might be dangerous to your health. Make sure to keep the lid on the solvent tank closed when not in use.

Alkaline Cleaning. One cleaning solution for **ferrous** (iron and steel) materials is a mixture of water and caustic soda heated to about 190°F (88°C). This strong alkaline mixture is higher than 10 on the pH scale. The strength of the caustic solution can be tested with a titration kit like the ones used for testing swimming pools. Aluminum is not cleaned in an alkaline solution, although brass, copper, or bronze may be cleaned in full-strength solutions because they do not react with bases.

Parts should be rinsed immediately to avoid a continuing chemical reaction. Following completion of the cleaning cycle, white material often begins to build up on parts. Cleaning solution additives are available to combat this.

Cleaning with an alkaline solution leaves metals completely clean. Rusting begins almost immediately, so lubricate all machined areas as soon as the part is dry. Some shops use a solution for rinsing that includes a rust inhibitor.

Caustic Alkaline Cleaning Safety Precautions

1. If caustic solution contacts skin, rinse the area immediately with water.
2. Wear face protection and gloves when working around caustic solutions.
3. Always add caustic soda to water, rather than adding water to caustic, which is dangerous. Use a scoop and add caustic soda slowly.

SAFETY NOTE

If caustic solution gets into an eye, it must be flushed within 1 minute or blindness may result. Be sure to lift the eyelid and flush under it with water for 15 minutes. Continue repeated 15-minute washings while medical attention is sought. Know where the eyewash and nearest water source are located.

Cleaning Aluminum. Shops that do a high volume of parts cleaning have separate cleaning tanks for aluminum and ferrous materials. If aluminum is cleaned in an alkaline solution, a reaction takes place and it slowly dissolves.

CASE HISTORY

An apprentice mistakenly soaked an aluminum cylinder block in a full-strength alkaline solution. When another employee removed it from the soak tank an hour later, it had started to dissolve and was a very dark gray.

Special solutions are available for cleaning aluminum, and some of them include brighteners.

SHOP TIP

Test a material with a magnet to determine whether it is aluminum or ferrous. Ferrous materials are magnetic, and aluminum is not.

Hot Soak Tanks. The hot tank, or soak tank, is one of the oldest methods for cleaning engine parts. Materials are cleaned by soaking them for a period from 1 to 8 hours, depending on the strength of the cleaning solution. Although hot-tank cleaning takes a long time, it is popular in small shops because the equipment is inexpensive.

One of the disadvantages of a hot soak tank is that the user has to devise a method of locating items soaking in it. One easy solution is to fasten an engine sling or chain to the block and connect it with a piece of wire to the side of the hot tank somewhere above the water level. Some of the more expensive hot tanks have baskets (**Figure 5.5**) or lifting tables built into them.

FIGURE 5.5 A hot dip tank with a basket.

Hot Tank Safety Precautions

1. Articles should be lifted from the tank with a lifting device. Many years ago, a student actually fell into a large hot tank while trying to retrieve a cylinder head.
2. Be sure that lifting slings are securely fastened to items in the tank or a dangerous splash can result.

Spray Washers. A more expensive type of hot tank that is often found in automotive machine shops is the hot spray washer, often called a jet washer (**Figure 5.6**). A jet washer is like an automatic dishwasher. It sprays the cleaning solution, heated to 180°F (82°C) or hotter, from spray heads mounted in a long pipe. The engine block is mounted on a rotating cleaning platform and the spray heads are positioned to spray the solution at the block from the sides, above, and below. Some two-stage spray washers include a soak tank, too.

FIGURE 5.6 A jet washer.

One problem associated with the spray washer is foaming, which lengthens cleaning time. Foaming occurs if a cleaning cycle is attempted before the cleaning solution is sufficiently heated. A chemical is added to cleaning solutions to prevent foaming. Some large tanks have an *agitator* that diverts some of the pump water to the bottom of the tank, where it stirs up any cleaning solution that may have settled out of the water. For the first 5 minutes of operation each day, a control lever is positioned in the agitate position. Advantages of a hot spray tank are:

1. Speed—cleaning is completed in 10–30 minutes.
2. Safety—the chance of a splash is reduced because the machine will not operate unless the door is closed.
3. Drying—the temperature of the solution results in very quick drying of the parts.
4. Newer machines are more energy efficient.

One disadvantage is that spray washers do not clean oil galleries as well as a hot soak tank.

Another type of washer has machinery that throws a large volume of cleaning solution at parts, rather than spraying it through nozzles. The advantage here is that the solution hits the dirty parts with a greater impact than the steady stream of a spray washer.

SHOP TIP

Aluminum cylinder heads can usually be hot-tanked before disassembly (**Figure 5.7**). This confines all oil and grease to the tank, helping keep the shop clean. The head ***must*** be disassembled and all parts lubricated immediately after hot tank cleaning. Also, be sure to inspect the head gasket surface for signs of gasket leakage prior to cleaning.

NOTE

Be sure to rinse and lubricate all parts immediately after cleaning. If valve springs are allowed to rust, they will be ruined. New valve springs have a protective coating that is removed by the hot tank. Ideally, heads would be disassembled before hot-tanking.

Many shops put the disassembled head back in the spray tank for a final cleaning following the completion of machining operations.

When the block has an oil circulation groove behind the cam bearings, the bearings must be

VINTAGE ENGINES

Some small V6 engines came with copper cam bearings. The copper bearings may be hot-tanked and used again if not worn.

FIGURE 5.7 These heads are installed on a special head rack for cleaning before disassembly. *(Courtesy of Tim Gilles)*

removed before hot-tanking to ensure thorough cleaning.

NOTE

Following cleaning in a spray washer, oil galleries *must* be cleaned with a brush after the plugs that seal the ends of the galleries are removed. The first part of Chapter 10 describes this cleaning procedure. Grime builds up in the oil galleries after many miles of driving under various maintenance conditions. This material is loosened during the cleaning process. If it is not physically removed, it will end up ruining a new engine's bearings and probably damage other engine parts as well.

The following case history is very typical of the serious problems that can be caused by carelessness in cleaning.

CASE HISTORY

After an engine rebuild on a motor home, a customer left on a vacation. About 100 miles from home, she noticed that the oil pressure had dropped to about 15 psi. She returned home and had the mechanic check it out. Further diagnosis showed that there was a serious problem. The oil pan was removed, the oil pump inspected, and, finally, the engine main bearing caps were removed. The crankshaft was severely worn so the engine had to be removed once again from the chassis for repair. Further inspection of the cylinder block showed that the oil galleries had not been removed so that the galleries could be thoroughly cleaned. Metal grit from a previous engine failure was lodged in the oil galleries and had come loose upon driving the vehicle.

Removing the engine from a motor home or van can be much more difficult than an ordinary passenger car. In order to remove the engine on this motor home, the cylinder heads had to be removed first. It was very fortunate that the customer monitored her oil pressure and had the presence of mind to return the motor home to the shop where the repairs occurred instead of continuing on her trip. It would have been very costly had another shop performed the repairs. The repair order for the original engine rebuild carried a price tag of $5000.

Preventing Rust. Immediately after cleaning iron or steel with water-based chemicals, it is important to lubricate parts to prevent rust. Because cleaning processes are so thorough, rust can begin to develop within minutes. Some shops use rust prevention products like Cosmoline® (the original GI rust preventive). Other rust prevention products include ARMA®, Braycote®, Rustban®, or Nox Rust®.

SHOP TIP

Ferrous metal parts can be dipped in clean mineral spirits or WD-40 following cleaning.

Caustic Tank Hazardous Waste. Engine bearings must be removed before the block is put into an alkaline cleaner. Bearing lead that settles with other heavy materials in the sludge in the bottom of the tank causes it to become toxic waste.

Rebuilders have several methods of controlling or minimizing toxic waste. Skimming or overflowing the tank removes oily contaminants from the surface of the solution. Some tanks have filtration systems. Others use evaporators to reduce the volume of the sludge. Sludge can be neutralized and solidified with chemicals so that it can be disposed of as nonhazardous waste.

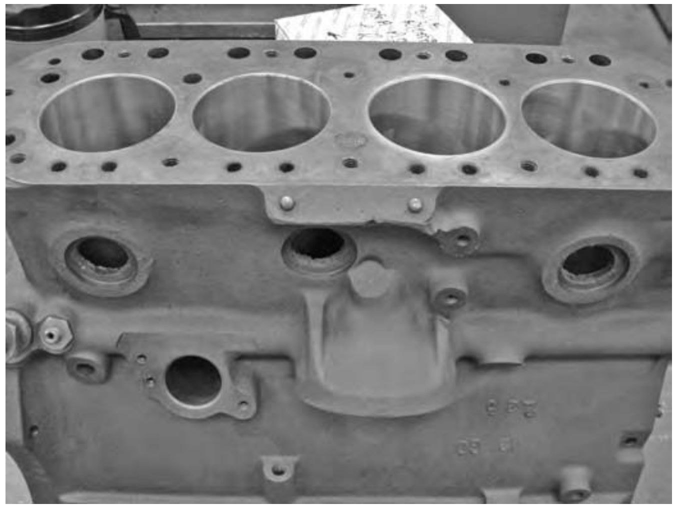


FIGURE 5.8 This cylinder block was acid-dipped by an outside vendor. *(Courtesy of Tim Gilles)*

NOTE

Different communities have different laws governing the handling and disposal of waste materials. Be sure to check with the local agency in charge.

VINTAGE ENGINES

Removing Scale

Older iron engines often accumulated scale in the radiator and water jackets. A chemical cooling system cleanser can be used to help remove **scale** *before* removing the engine. Severe cases of scale buildup can be treated by soaking the block in an acid tank (**Figure 5.8**) or a plastic trash can filled with swimming pool acid.

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In the days before catalytic converters, carbon-removal additives could be added to a running engine through the carburetor. Some technicians like to add carbon-removal additives before removing the engine, so that carbon will be loosened from the combustion chamber, piston, and valves. Combustion chamber cleaner should be used only in a well-ventilated area and technicians should be informed of local pollution regulations.

Manual Cleaning Methods

A wire wheel (**Figure 5.9**) mounted on a bench grinder, on a pedestal grinder, or on a drill motor is a common tool used for carbon removal on iron surfaces.

CAUTION

Wire wheels can damage aluminum surfaces.

Hand-held wire brushes are available for cleaning valve guides and oil galleries in the block, head, and crankshaft. Sandpaper or Scotchbrite® can be used to clean the machined surfaces of the head and block either by hand or with power tools.

Sandpaper is sometimes used to clean machined surfaces, but only very fine sandpaper should be used on bimetal engines that have super-smooth head and block surfaces. An electric or air drill can be fitted with a small wire brush for removing gaskets or carbon from cast iron parts (**Figure 5.10**). These tools can damage aluminum, however. Plastic abrasive discs (**Figure 5.11**) are popular tools for cleaning aluminum surfaces. Some are flat mesh surface conditioning discs and others are plastic dish-shaped bristle discs embedded with abrasive. As the brush wears away, fresh new abrasive is exposed. The grit is determined by the color of the disc; green is coarse, yellow is medium, and white is fine. The bristle discs are available in 1-, 2-, and 3-inch diameters.

FIGURE 5.9 A wire wheel mounted on a grinder. *(Courtesy of Tim Gilles)*

FIGURE 5.10 A wire brush mounted on a drill can be used to clean iron parts. *(Courtesy of Tim Gilles)*

FIGURE 5.11 Scotchbrite™ pads and Roloc discs are popular for cleaning gasket surfaces. *(Courtesy of Tim Gilles)*

Cloth-backed sanding discs, also called Roloc™ discs, come in different grits, differentiated by the color of their plastic holding button. For instance, in the coarse grades, grade 50 is green, grade 36 is brown, and grade 24 is black.

NOTE

The abrasive material is aluminum oxide, the same material of which sandpaper is made. It should not be used on aluminum surfaces and care must be taken that grit is not allowed to enter the engine, where the abrasive can damage engine bearings.

A special wire wheel, called an encapsulated wire wheel, is available for high rpm use. It has molded plastic in between the wires of the brush. The plastic material wears away to expose only the tips of the wire.

Hand-held gasket scrapers (**Figure 5.12a**) are a part of every technician's and machinist's toolbox. The correct way to sharpen a scraper is with a file from one side only (**Figure 5.12b**).

Additional cleaning methods are covered in detail in the chapters dealing with specific parts.

Abrasive Blast Cleaning

Materials to be cleaned by abrasive cleaning methods must be free of grease. Oil and grease can interfere with the proper operation of cleaning machines. Following precleaning, two types of abrasive blasting are used for various cleaning applications. *Shot* is round and *grit* is sharp and angular (**Figure 5.13**). Engine rebuilders use several blast materials for cleaning parts. Steel shot and glass beads are used for automotive part cleaning when removal of the surface of the material being cleaned is not desired. Beads and shot come in various sizes, depending on the application. Smaller beads are used where there are tight corners and crevices (like screw threads or gear teeth) to be cleaned. Large beads are better for cleaning flat surfaces or loosening heavy deposits. Other shot materials, like stainless steel, ceramic, plastic, walnut shells, or aluminum may be used for special applications. Plastic chips, for instance, are used on plastics and soft metals, or when there is a chance of trapped shot dislodging and destroying an engine or a transmission.

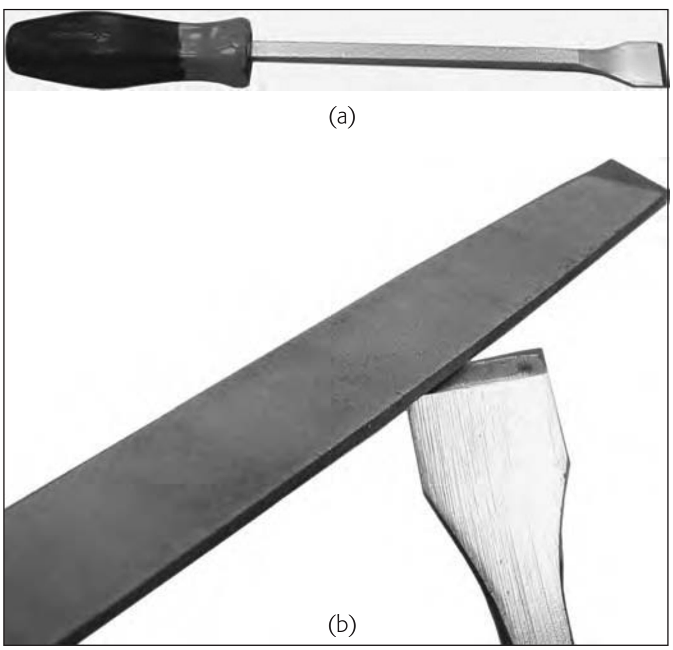


FIGURE 5.12 (a) A hand-held gasket scraper. (b) Sharpen a gasket scraper from one side only, using a file. *(Courtesy of Tim Gilles)*

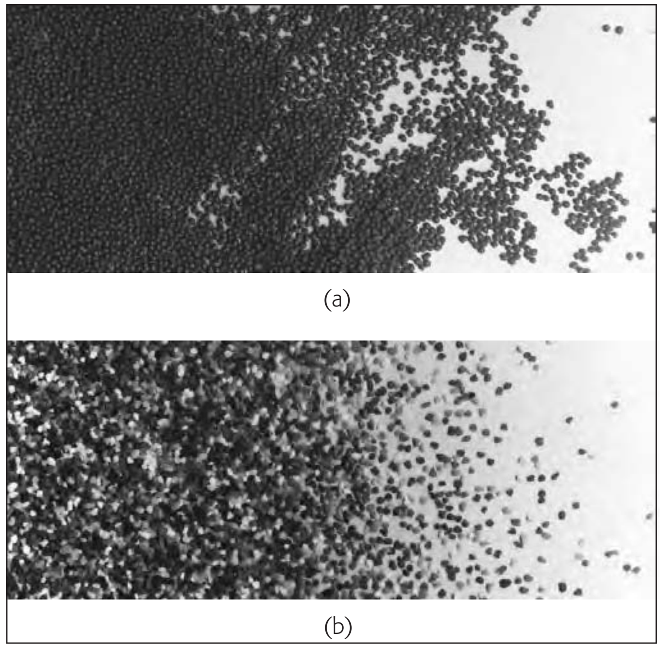


FIGURE 5.13 Blasting media. (a) Shot. (b) Grit.

Beads or shot may be used to improve the strength of parts. Although ordinary shot blast cleaning does impart some strength to a part, it is not *peening*. Peening specifically for strength is done only in heavy-duty or high-performance instances. Peening for strength is a controlled process that uniformly compresses the stressed areas of a part. Steel, which is heavier than glass, is used more often for peening. It peens more intensely and lasts several times as long as glass beads before it wears out.

Grit, used for heavy-duty cleaning, often uses the same blasting material, called *media*. The shape of the media is angular, rather than spherical, so it etches (removes) material from the part surface during cleaning. It provides excellent surface preparation prior to painting. Steel grit and aluminum oxide are the most common grit materials. Grit blasting also causes stress in the surface of machined parts. It is not widely used by engine rebuilders.

Glass Bead Blasters. Glass bead blasting is a very effective means of removing carbon. *Bead blasters* (**Figure 5.14**) are found in most automotive machine shops. The finish left by the beads improves the surface of the material by removing flaws and stress spots. It is also said to provide an ideal bearing surface. A bead-blasted part is shown in **Figure 5.15**.

A costly drawback to glass bead blasting is that the machine is **labor intensive** (requires an operator). Other popular cleaning methods, like shot blasting, do not require a machine operator. To operate the bead blaster, compressed air draws in glass beads and directs them at the parts to be cleaned. Most units have a foot pedal to control the flow of air and beads. The operator watches through a window and aims the nozzle at the parts.

Glass bead cleaning is often done improperly. Here are some examples:

- Bead blasting a part that has oil galleries is not advised. Galleries are often drilled to intersect other oil passages. This process leaves blind spots where beads can become lodged, later to be pulled out into the oil stream by the flow of engine oil (**Figure 5.16**) and embed in soft engine bearings (**Figure 5.17**). The bearings can swell, eliminating bearing oil clearance or causing abrasive wear.

FIGURE 5.14 A glass bead blaster. *(Courtesy of Tim Gilles)*

FIGURE 5.15 One-half of this cylinder head was bead blasted.

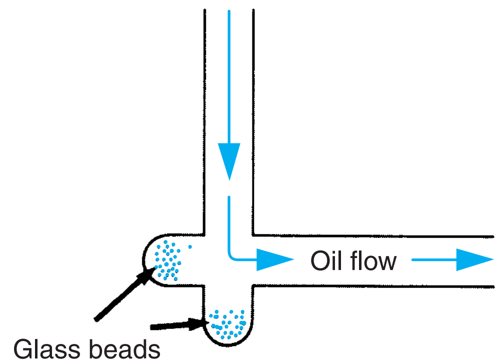


FIGURE 5.16 Glass beads can become trapped in blind oil galleries during cleaning.

FIGURE 5.17 This bearing failed when glass beads became impregnated in it. *(Courtesy of Tim Gilles)*

- Sheet metal parts such as oil pans or valve covers often have spot-welded inserts that can trap beads during the cleaning process (**Figure 5.18**). The cast aluminum valve cover shown in **Figure 5.19a**

FIGURE 5.18 Glass beads can become trapped during cleaning. *(Courtesy of Tim Gilles)*

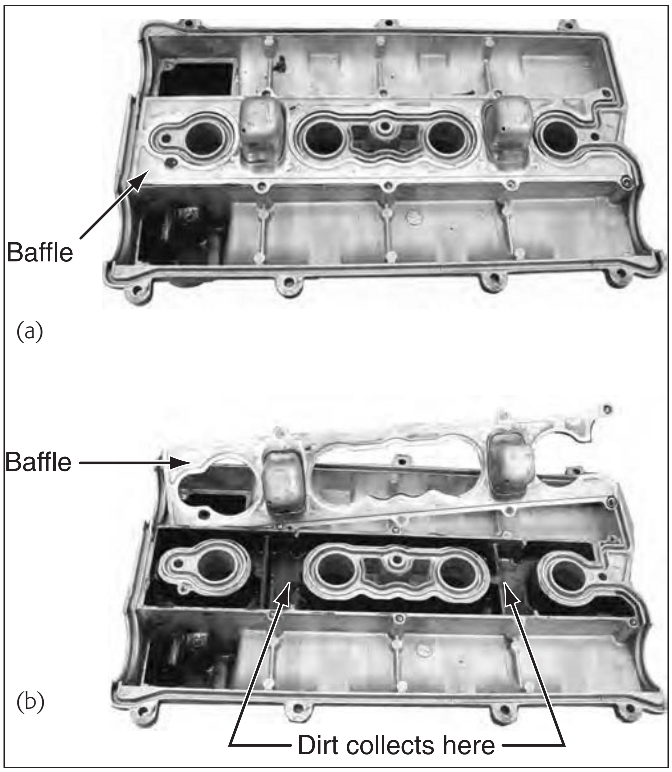


FIGURE 5.19 (a) Appearance of a cast valve cover with a steel baffle. (b) This hidden cavity can harbor contaminants. *(Courtesy of Tim Gilles)*

shows a hidden cavity that can trap contaminants. Do not use the bead blaster on valve covers or oil pans that have sheet metal baffles unless the baffle can be removed (**Figure 5.19b**).

CASE HISTORY

A machinist cleaned an aluminum cylinder head using a glass bead blaster. The engine was reassembled and installed in the car. The customer drove the car home (30 miles). The next morning the engine would not crank over. On disassembly, it was discovered that the engine bearings were embedded with glass beads. The beads swelled the bearings, taking up the normal bearing clearance and preventing the crankshaft from turning.

Glass beads can cause abrasive wear, especially to aluminum. Excessive blasting can round out ring grooves, which must be square if they are to seal effectively (**Figure 5.20**). One Automotive Engine Rebuilders Association (AERA) technical service bulletin states that a piston should never be cleaned with a bead blaster unless the connecting rod has first been removed. Glass beads trapped between the piston pin and bore wear out aluminum piston pin bores, and beads trapped in piston ring grooves can interfere with proper ring function.

Following cleaning, glass beads must be thoroughly removed from all parts. To clean parts after blasting, first use compressed air from the blowgun inside the blaster cabinet. Do not use solvent, which tends to stick the beads to each other.

FIGURE 5.20 Appearance of surfaces of a piston that have been continuously bombarded with glass beads for periods of 3 and 5 minutes. *(Courtesy of Tim Gilles)*

NOTE

It is important that the air supply to the bead blaster be dry or beads will stick together, plugging up the machine.

Parts can be dried in an oven to make removal of glass beads easier. *A tumbler* (**Figure 5.21**), used most often for removing steel shot following shot peening (covered later in this chapter), can also be used to remove glass beads. Machined areas on ferrous metals should be lubricated immediately to prevent rusting.

Bead Blaster Precautions

- Do not accidentally blast the window in the blaster cabinet. The result will be a "frosted" glass that must be replaced.
- Do not blast parts unless the reclaim motor is on. The entire shop will be filled with glass dust.
- Two rubber gloves extend into the cabinet for holding the blaster nozzle (**Figure 5.22**) and maneuvering parts. Do not hold parts with the gloves because the fingers of the gloves get holes worn into them (**Figure 5.23**). A small spring clamp is effective for holding small parts.

CAUTION

Do not use the bead blaster if there are holes in the gloves.

FIGURE 5.21 A tumbler. Engine parts are placed in the center of the tires. As the tires roll, blasting media is shaken out of them. *(Courtesy of Tim Gilles)*

If parts are cleaned in a spray cabinet, it should incorporate a micron filter. The purpose of the filter is to prevent a redeposit of glass bead particles. Components that have been rinsed in spray cabinets lacking filtering systems have been implicated in subsequent engine failures.

Never clean an intake manifold with a bead blaster, because its plenum areas are inaccessible for proper cleaning. Additionally, cast iron and aluminum intake manifolds have somewhat porous surfaces, which can allow the harboring of blasting media. Hastings, a manufacturer of piston rings, has attributed piston ring failures to glass beads that caused rings to become stuck in their grooves.

FIGURE 5.22 The blast nozzle held with a rubber glove. *(Courtesy of Tim Gilles)*

FIGURE 5.23 A worn bead blaster glove. *(Courtesy of Tim Gilles)*

Some bead blasters have separate reclaim cabinets. When glass beads become too small to be useful any longer, they are separated and collected by the reclaimer, which consists of several long cloth tubes (**Figure 5.24**). Service to the reclaim unit includes moving a handle on the side of the cabinet in and out to shake spent beads off. They land in a tray beneath the tubes, which fills with worn-out beads and must be periodically emptied (**Figure 5.25**).

Soda Blaster. A more recent blast cleaning method uses baking soda (**Figure 5.26**). Soda blasting is similar to glass bead blasting but baking soda is used as the cleaning medium. The soda is used only once. There is no reclaiming, as with glass beads. One advantage to soda blasting over glass bead cleaning is that a greasy part can be put into the cabinet and cleaned without having been precleaned of oil or grease (**Figure 5.27**). Another important advantage to soda blasting is that removal of residual cleaning material is not as crucial as it is with glass bead cleaning. Soda dissolves in water and is easily washed out off oil galleries. Soda is not as effective

FIGURE 5.24 This glass bead blaster reclaim unit has a handle that is moved in and out to shake spent beads from the cloth tubes into a catch tray below. *(Courtesy of Tim Gilles)*

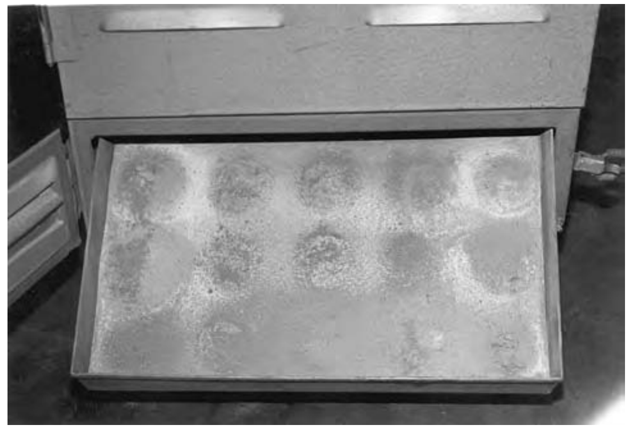


FIGURE 5.25 A reclaim tray full of worn-out glass beads. *(Courtesy of Tim Gilles)*

FIGURE 5.26 A soda blaster. *(Courtesy of Tim Gilles)*

FIGURE 5.27 Half of this greasy cylinder head was cleaned using a baking soda blaster. *(Courtesy of Evans Products)*

as bead blasting for removing rust, but it works very well for carbon removal and is safe for aluminum.

Airless Blaster. An airless centrifugal blasting machine, also called *a shot blaster* (**Figure 5.28**), uses an impeller in a sealed cabinet to scatter steel shot at a part from above and below. Shot blasting has recently become more popular due to environmental concerns with other cleaning methods. Although this cleaning process is not labor intensive, two extra operations are required: precleaning of oil and grease and removal of trapped shot from engine parts before beginning reassembly. A tumbler is used to remove any steel shot that remains in the part.

Shot blasting is widely used to clean ferrous parts such as the block, heads, and, sometimes, crankshafts and connecting rods. It is done before the parts are remachined because the process distorts machined surfaces. Shot blasting can damage valve springs; it changes their spring rate. Most shops use 100% steel shot, although some like to use a mixture of steel and aluminum shot to give a brighter-looking surface.

Shot comes in different sizes and hardnesses. Popular sizes range from 110 (smaller) to 230 (larger). The most popular size is 170.

FIGURE 5.28 A shot blaster.

NOTE

Changing the size of the shot affects the amount of impact on the part; larger shot has more impact.

Using a 110 shot results in an impact that is more than four times less than using a 230 shot. However, a small shot works better for lighter cleaning and smaller surfaces. As shot wears, it becomes smaller. Old, spent shot is automatically separated from the remaining shot. New shot is added and the result is a mixture of larger and smaller sizes. The most widely used steel shot has a Rockwell C hardness of 40–50 Rc. (Hardness is measured using a scale called the Rockwell scale with values listed as Rc.) Harder shot is used for heat-treated parts and for peening.

Thermal Cleaning

Many rebuilders use thermal cleaning, a cleaning procedure in which a *pyrolytic* (high-temperature) oven (**Figure 5.29**) cooks oil and grease, turning it to ash. The hard, dry deposit that is left on the part is removed by shot blasting or jet washing.

There are two types of thermal ovens: convection and open flame. A convection oven is a flameless, insulated oven that is heated by burners from

FIGURE 5.29 A cleaning furnace.

the bottom. Parts are not exposed to flame and are heated gradually as the oven heats up. This is said to be an advantage in that the gradual heating of parts gives less chance of warpage. Depending on the size of the oven and the quantity of parts being cleaned, the cleaning cycle lasts from 1 to 4 hours. Temperatures for cleaning ferrous metals are about 700°F (371°C). Aluminum, which softens at about 650°F (343°C), is cleaned at about 450°F (232°C).

An *open flame oven* is like a rotisserie. Parts are mounted in a cage that avoids hot spots by slowly rotating the parts directly over a flame. The average temperature of the flame is about 1100°F (593°C) but the temperature of the air inside the oven is only about 500°F (260°C), allowing aluminum and ferrous metals to be cleaned together. After about 10 minutes of exposure to the flame, it goes out and a 20-minute baking cycle begins. The total cleaning cycle lasts about 30 minutes.

With oven cleaning, three processes are actually used: precleaning, baking, and postcleaning. Shot blasting is the choice for postcleaning recommended by most oven companies because parts can be blasted without waiting for them to cool down as would be required with jet washing. Ash that remains is soft and the time in the shot blaster is only a few minutes. Fifteen minutes in the tumbler finishes the process. One possible problem with postcleaning using a jet washer is that ash might plug up the spray nozzles.

Advantages of thermal cleaning are:

- Lower cost: not labor intensive so no operator is necessary except for transferring parts between the oven, blaster, and tumbler.
- While lead or heavy metals still remain in the ash residue, there is a lower volume of hazardous waste to dispose of than with some of the other cleaning methods.
- The insides of oil galleries in the block are thoroughly cleaned.
- Heat turns rust and scale in the water jackets to powder. These materials would normally need to be removed with acid.
- Carbon deposits in manifolds and combustion chambers are loosened. These deposits resist other cleaning methods.
- Shot blasting removes stress raisers in the surface of parts. This can strengthen the part, lessening the tendency to crack.
- Aluminum welding is easier after open flame cleaning because contaminants are so thoroughly cleaned.
- Warped cylinder heads can be straightened in the oven (see Chapter 7).

NOTE

Gallery plugs should be removed before cleaning ash with a shot blaster to prevent shot from being trapped in oil galleries. Studs in aluminum cylinder heads should be removed before oven cleaning. They will be difficult to remove afterwards.

Air pollution from vaporization of contaminants is dealt with by oxidizing the pollutants in the smokestack. Minimum temperature in the smokestack is from 1400°F to 2200°F (760°C to 1204°C) so there is no visible soot or unburned hydrocarbons.

Vibratory Parts Cleaner. A *vibratory parts cleaner* (**Figure 5.30**) is a vibrating tub that uses large beads of ceramic, aluminum, or plastic in a cleaning solvent (usually Stoddard solvent). It is very effective on valves and valve springs and does not require a machine operator. It should be installed in a soundproof room. When the tub shakes, it is noisy.

Other Cleaning Methods

Other cleaning methods are used in larger and nonautomotive applications. *Salt bath* cleaning systems are used mostly by large production engine

FIGURE 5.30 A vibratory parts cleaner. *(Courtesy of C&M Cleaning Systems)*

rebuilders. Parts are soaked in a bath of 650°F (343°C) molten oxidizing salt for 5–10 minutes and then rinsed.

Ultrasonic cleaning is used commonly by jewelers and dentists. Some rebuilders use this method for small parts cleaning. It cleans by sound waves cycling through water and detergent that is heated to between 120°F (49°C) and 140°F (60°C). As the sound waves cycle at about 40,000 times per second, bubbles open and collapse, tearing contaminants away from the metal.

Marking Clean Parts

Clean parts can be marked with number or letter stamps or with a colored paint marker (**Figure 5.31**). Colored paint markers have white or yellow paint stored in a tube with a rolling ball point. A rubber bulb on the end is used to prime the ball point. The paint is resistant to oil and solvents. Parts like blocks, heads, or crankshafts can be readily labeled.

FIGURE 5.31 Labeling parts with a paint marker. *(Courtesy of Tim Gilles)*

Key Terms

agitation
ferrous
labor intensive
pH scale
scale
sludge

Study Questions

1. If a hot spray cleaner is run when the cleaning temperature is not high enough, what can happen to the cleaning solution?
2. How can a metal be tested to see if it is ferrous or nonferrous?
3. Be sure to _____ machined areas of ferrous metals after hot-tanking.
4. If the nozzle of a bead blaster is aimed at the window, it frosts the _____.
5. Glass beads are safe to use for cleaning because if they get into the oil they will not cause any damage. True or false?
6. An OHC head has oil galleries. This makes it impractical to clean these heads with a glass bead _____.
7. What is another name for the airless blaster?
8. What is another name for a bake oven?
9. What are two types of materials that thermal cleaning removes that other cleaning methods do not?
10. Two types of thermal cleaning ovens are _____ and open flame.

ASE-Style Review Questions

1. Lubricate all ferrous parts to prevent rust following hot-tank cleaning. True or false?

2. Two technicians are discussing shot peening. Technician A says that larger shot hits a part with more impact. Technician B says that parts can be made stronger by shot peening. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. The best cleaning temperature of a hot-tank solution would be about:
   a. 100°F (38°C)
   b. 150°F (66°C)
   c. 190°F (88°C)
   d. 250°F (121°C)

4. If the temperature of a cleaning liquid is too low, cleaning time will be longer. True or false?

5. A base is very acidic. True or false?

6. Technician A says that steam cleaning and pressure washing are common methods of cleaning internal engine parts. Technician B says that steam cleaning is safe to use with electrical components. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Remove all oil gallery plugs and clean oil galleries with a brush following hot-tank cleaning. True or false?

8. Technician A says that steel shot blasting is commonly used to clean ferrous parts. Technician B says that steel shot blasting is commonly used to clean aluminum parts. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that a bake oven removes rust. Technician B says that a bake oven removes scale. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Two technicians are discussing cleaning solvents. Technician A says that it is not necessary to use gloves with petroleum-based solvents. Technician B says that most newer cleaning solvents are chlorinated. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 6

Measuring

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Perform measurements using any of the tools in this chapter.
- Have a working understanding of the metric and English systems of measurement.

Introduction

This chapter deals with the common measuring instruments and systems of measurement used in repairing automobiles. The two systems of measurement that an engine repair technician must understand are the **British Imperial (U.S.) system** and the **metric system**.

The British system, using fractions and decimals, has been the basic measuring system in England, the United States, and Canada until recently. This system is based on inches, feet, and yards. In the 12th century, 1 inch was decreed to be a length equal to three barley corns end to end. One yard was the distance from King Henry's nose to the end of his thumb. The basis for this system is somewhat ridiculous, but we have used it for so many years that it is hard to dismiss.

American manufacturers are slowly changing their tooling to the metric system in order to be competitive with the rest of the world, which uses the metric system. Technicians working on domestic automobiles are seeing more and more metric parts and will need to own tools of both metric and English sizes.

METRIC SYSTEM

The international system (S.I.) of measurement is known as the metric system. The basis of the metric system is the meter, which is about 39.37'' long, slightly longer than a yard.

Metric Engine Size Measurement

The metric measurement of volume is the liter. A liter is the quantity of liquid that will fill a cube $\frac{1}{10}$ of a meter long on each edge. A liter is slightly larger than a quart.

NOTE

There are 61.02 cubic inches in 1 liter. 1 liter is equal to 1000 cubic centimeters (cc).

Because 1 liter is equal to 1000 cc, a 2000 cc engine is called a 2-liter engine. Using the approximate measurement of 60 C.I. to the liter, 2 liters are equal to about 120 cubic inches.

Weight Measurement. The metric unit of weight is the gram, which is the weight of the amount of water it takes to fill a cube that is $\frac{1}{100}$ meter long on each side. A thumbtack weighs about 1 gram. The kilogram is the most common use of the gram. A kilogram equals about 2.2 pounds. All metric measurement units are related. For instance, 1000 cc of water weighs 1 kilogram.

Pressure Measurement. The metric system equivalent to pounds per square inch is expressed as kilograms per square centimeter. Both of these measurements are used in measuring atmospheric pressure at sea level.

- Atmospheric pressure is one BAR in the metric system (1 kilogram per square centimeter).
- Atmospheric pressure in the English system is called one atmosphere (14.7 pounds per square inch).

Temperature Measurement. On the Fahrenheit scale, water freezes at 32°F and boils at 212°F. In the metric system, temperature is measured in degrees Centigrade, more often expressed as degrees Celsius. The temperature at which water freezes is zero degrees Celsius (0°C). Water boils at 100°C.

Torque Measurement. Torque wrenches are discussed in a later chapter. Torque readings are expressed in **foot-pounds** in the English system. The metric equivalent is expressed in **newtons**. Newtons are approximately 1/10 of a kilogram.

A conversion chart from the English system to the metric system is included in the Appendix at the back of the book.

Metric Measuring

The metric system is based on the number 10. It is a very easy system to use, because multiplying and dividing simply involves adding or subtracting zeros. For example:

- 1/100 (0.01) of a meter is a centimeter (cm).
- 1000 meters is a kilometer (km).
- 1/100 (0.001) of a meter is a millimeter (mm).

Because we know that 0.25 mm equals 0.010", we can make close approximations between the metric and U.S. systems when dealing with engine part sizes. For instance:

- A 0.75 mm oversize piston is 0.030" oversize.
- 0.50 mm undersize crankshaft bearings are 0.020" undersize in the inch system.

The appendix at the end of most repair manuals contains a metric conversion chart.

NOTE

To convert to millimeters when the inch value is known, multiply by 25.4. To convert to inches when the metric value is known, divide by 25.4.

MEASURING TOOLS

The common steel rule is used to make approximate measurements. Common rulers used by technicians measure both in the metric system and in fractions of one inch (**Figure 6.1**). There are several common types of rulers. A tape measure is handy to have in a toolbox. The pocket-style 6" steel rule is also a popular tool. A ruler may be used with a divider or **caliper** to transfer measurements (**Figure 6.2**). Uses of the ruler are shown in subsequent chapters.

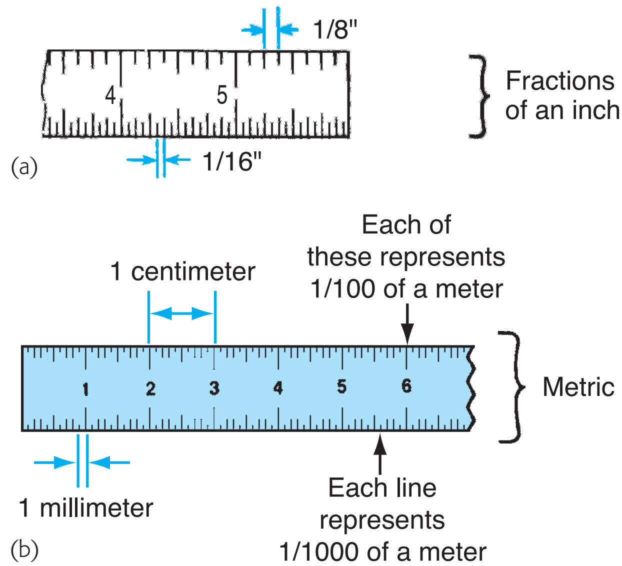


FIGURE 6.1 (a) Common rule measurements. (b) A metric ruler.

FIGURE 6.2 Measuring dividers with a steel rule. *(Courtesy of Tim Gilles)*

FIGURE 6.3 Flat and wire types of feeler gauges. *(Courtesy of Tim Gilles)*

A metric ruler has lines that indicate hundredths and thousandths of a meter (see Figure 6.1b).

- The hundredths are called centimeters.
- The thousandths are called *millimeters*.
- The numbered marks are centimeters.
- Each of the ten small lines between the numbers is 1 millimeter.

Thickness gauges are commonly called feeler gauges. They can be either the flat or wire type (**Figure 6.3**). Feeler gauges are commonly used to measure such things as valve clearance, piston ring side clearance, crankshaft end play, and the gaps of spark plugs, piston rings, and ignition points.

Plastigage is a product used to measure oil clearance in bearings and oil pumps. It is a strip of plastic that deforms when crushed. The deformed plastic gives an idea of the amount of clearance present. Its use is covered in detail in Chapter 12.

PRECISION MEASURING TOOLS

The following tools are available in both English and metric types. Measurements in industry are commonly made in thousandths of an inch, or 0.025 mm. This is one of the advantages of the inch system. The metric system measurement of 0.1 mm is 4 thousandths of an inch (0.004"), which is too large for precision measurement. The next closest metric measurement (0.01 mm) would be ¹⁄₁₀ as large, or 0.0004", which is too precise for most of industry.

NOTE

Many manufacturers are only giving measurement specifications in millimeters on modern cars and trucks.

Vernier Caliper

The vernier caliper was developed in the 17th century. A vernier caliper is one that has a movable scale that runs parallel to a fixed scale. It is a very versatile tool that every technician should own. The tool shown in **Figure 6.4** will measure outside diameter (**O.D.**), and inside diameter (**I.D.**) from 0 to 7 inches in thousandths of an inch, or from 1 to 180 millimeters. The inside measurement is somewhat limited by the length of the jaws, so it cannot be used deep in a hole. The vernier caliper shown here can also measure depth. When the cost of this tool is compared to the cost of a set of micrometers (which are covered later in this chapter), the reason for its popularity becomes apparent. A vernier caliper is the most versatile measuring tool. Every technician should own one.

How to Use a Vernier Caliper. The following explanation of the main and vernier scales deals with the inch-standard vernier caliper. The same principles apply to metric verniers, but measurements are made in decimal parts of a millimeter. The main parts of the scale are shown in Figure 6.4.

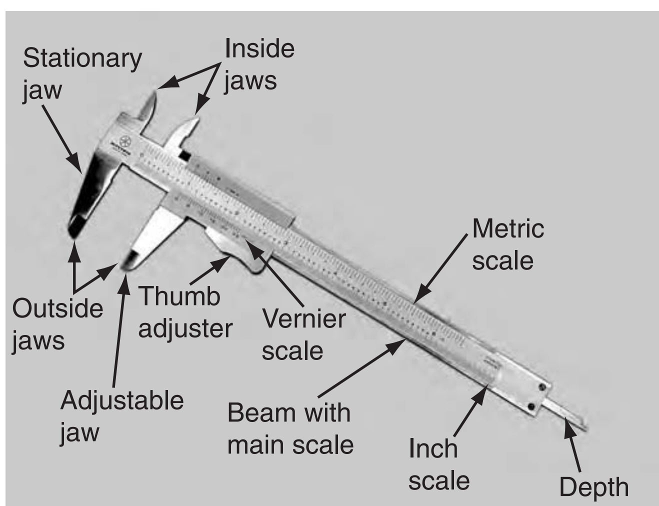


FIGURE 6.4 A vernier caliper. *(Courtesy of Tim Gilles)*

A fine adjustment not found on some vernier calipers is helpful in getting a proper feel.

Main Scale. The main scale of the caliper is divided into inches. Each inch is divided into ten parts of $\frac{1}{10}$" (0.1") each (**Figure 6.5**). It is customary to read precision measurements in thousandths of an inch (0.001"). Therefore, each of these $\frac{1}{10}$" measurements is expressed as 0.100" (one hundred thousandths).

The area between the 0.100" increments is further divided into fourths ($\frac{1}{4}$ of 0.100"). Each of these lines is equal to 0.025".

Vernier Scale. The **vernier scale** divides each of the 0.025" sections on the main scale into 25 parts, each one being 0.001" (**Figure 6.6**). Measurements are determined by combining readings on the sliding vernier scale with those on the main scale. There are actually only 24 divisions on the main scale to the 25 on the sliding vernier. Only one line will line up exactly with another at one time. A magnifying glass is helpful for reading the vernier lines, but they are highlighted in the examples here.

Determining the Measurement. Locate the line on the main scale that the zero on the sliding vernier scale is lined up with or is just beyond. In **Figure 6.7**, the reading on the main scale is 0.025". If the zero lined up exactly on the third line, then 0.075" would be the measurement (**Figure 6.8**). If the vernier scale zero did not line up *exactly* with a line on the main scale, then find the number on the vernier scale that lines up perfectly with *any* line on the main scale. Only one line on the vernier scale will line up perfectly. In **Figure 6.9a**, it is the line representing 0.005". The main scale reading is 0.100", so the total reading is 0.105". In **Figure 6.9b**, the main

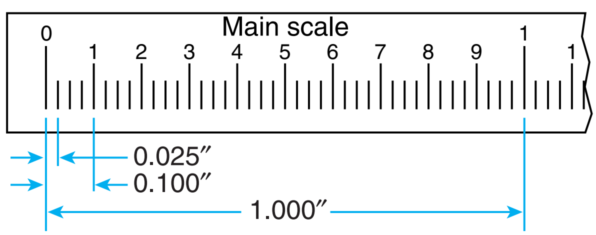


FIGURE 6.5 Measurements on the main scale are $\frac{1}{4}$ of an inch, or 0.025″ (25 thousandths).

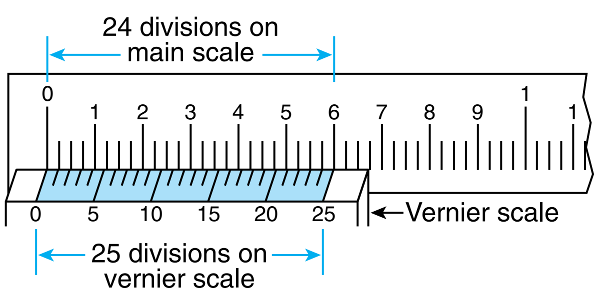


FIGURE 6.6 The vernier scale divides each of the main scale measurements into 25 parts.

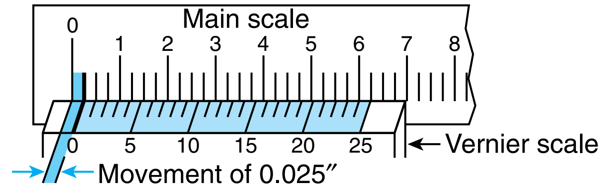


FIGURE 6.7 Measuring 0.025″ on a vernier scale.

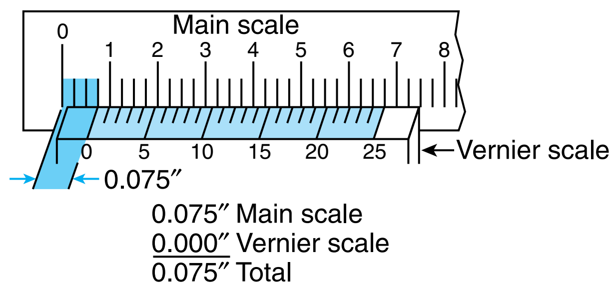


FIGURE 6.8 A 0.075″ reading on the vernier scale.

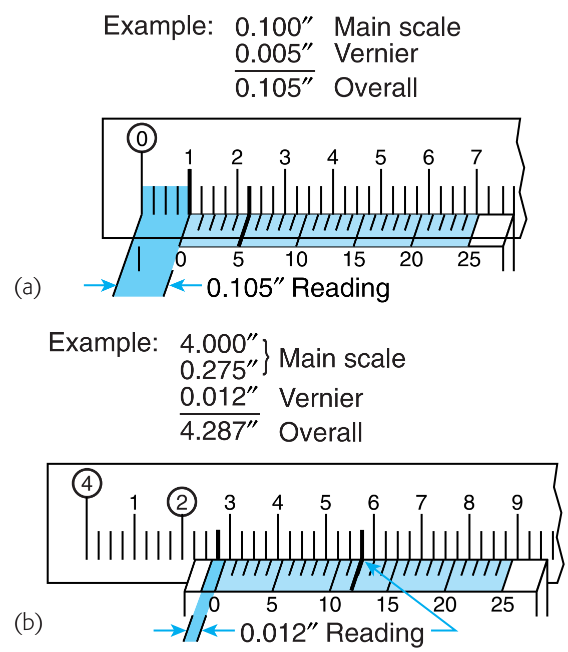


FIGURE 6.9 In examples (a) and (b), select the vernier scale line that lines up exactly with any line on the main scale.

scale reading is 0.275" plus the vernier scale reading of 0.012" for a total of 0.287".

NOTE

The main scale also shows 4", so the total reading is 4.287".

An alternative to a standard vernier caliper is the dial vernier shown in **Figure 6.10**. It registers the 0.001" part of the measurement on its dial. This type of caliper is very popular but more expensive.

Sometimes a vernier caliper main scale is divided into 50 sections instead of 25. There is a scale for reading inside measurement and a separate scale for reading outside measurement. There is only one division between the 0.100" line and the 0.200" line. Each of these divisions represents 0.050" instead of 0.025". Reading this vernier caliper is otherwise the same as reading the 25-section caliper. Be aware of which type you are reading.

A digital caliper (**Figure 6.11**) works the same way as an ordinary caliper does, but its measurement is shown on a liquid crystal display, or LCD, to an accuracy of 0.0005. Measurements can be either English or metric.

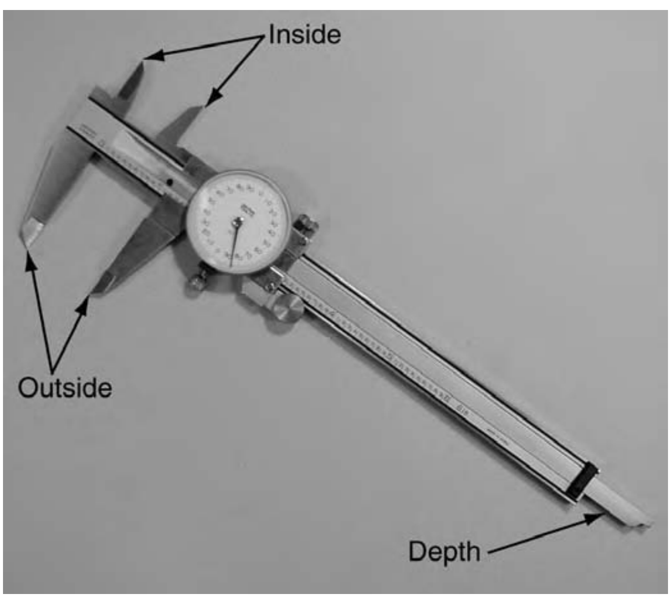


FIGURE 6.10 A dial vernier caliper. *(Courtesy of Tim Gilles)*

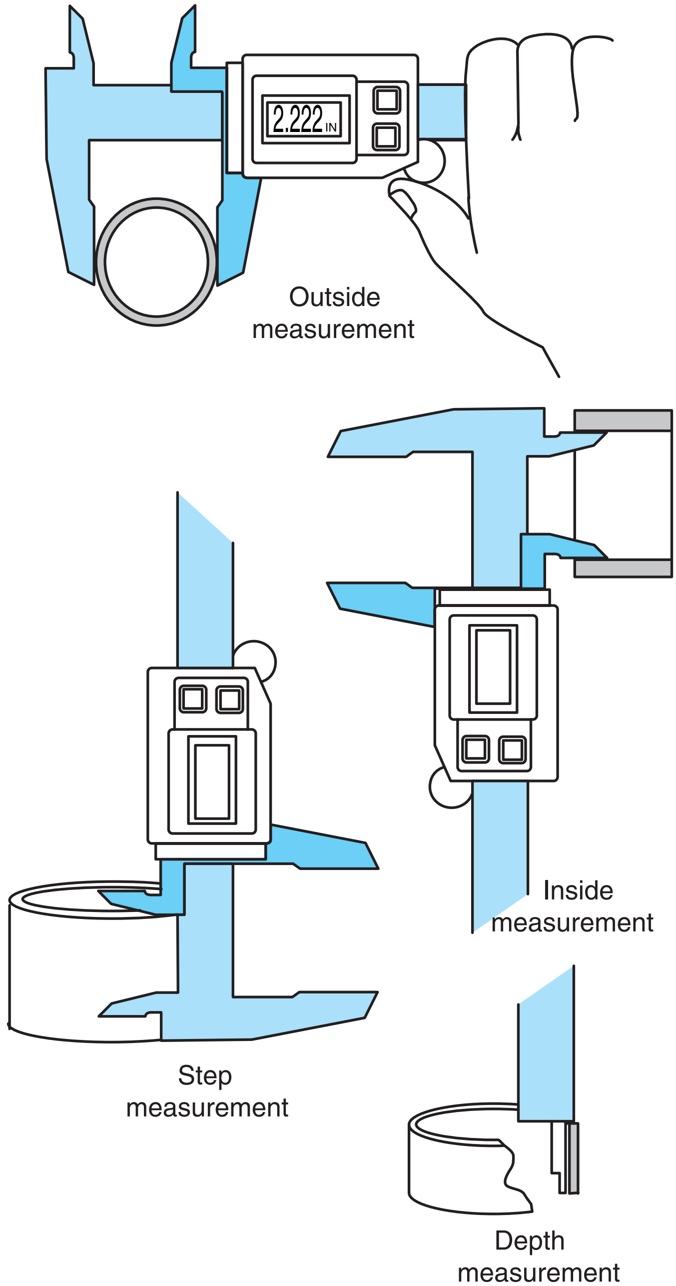


FIGURE 6.11 A digital caliper.

Micrometer

Micrometers are often called "mikes" for short. **Figure 6.12** shows a set of outside micrometers. Each one has a range of only 1 inch. Because of the expense of a complete set of mikes, they are found mostly in machine shops.

Micrometers have several advantages over other types of measuring instruments. They are clear and easy to read. They measure consistently and accurately, and they have a built-in adjustment

FIGURE 6.12 A set of outside micrometers with calibration standards. *(Courtesy of Tim Gilles)*

to compensate for wear. A cutaway view of an outside micrometer is illustrated in **Figure 6.13.**

Some micrometers have the following extra features:

- A ratchet, which sees that spindle pressure is always consistent
- The lock, which can hold a reading so it cannot be changed accidentally
- The decimal equivalent chart stamped on the frame
- A digital readout, which may also give metric readings

If a micrometer spindle must be moved a long way to adjust it, roll the thimble on your arm or hand **(Figure 6.14**).

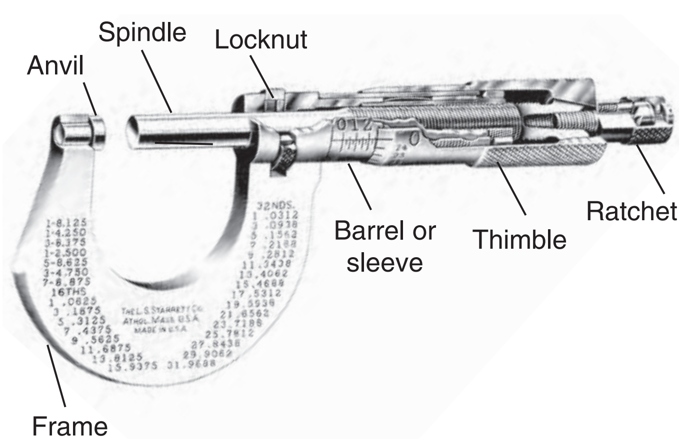


FIGURE 6.13 A cutaway view of an outside micrometer. *(Courtesy of L. S. Starrett Co.)*

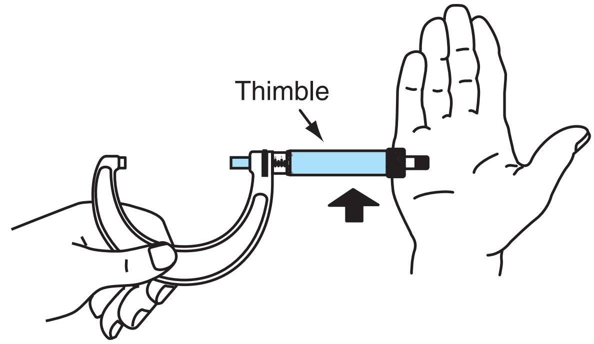


FIGURE 6.14 Roll the thimble on your hand for long spindle movements.

Reading a Micrometer. The micrometer operates on a simple principle. The spindle (**Figure 6.15a**) has 40 threads per inch, so one revolution of the thimble will advance or retract the spindle 1/40 of an inch (0.025") (**Figure 6.15b**). The sleeve, or barrel, is laid out in the same fashion as the frame on a vernier caliper. Each line on the barrel represents 0.025", and a new line is uncovered each time the thimble is turned one revolution. Measurement amounts are shown in **Figure 6.16**.

As each line on the thimble passes the zero line on the hub, the mike opens another 0.001". To read the exact number of thousandths, note the number

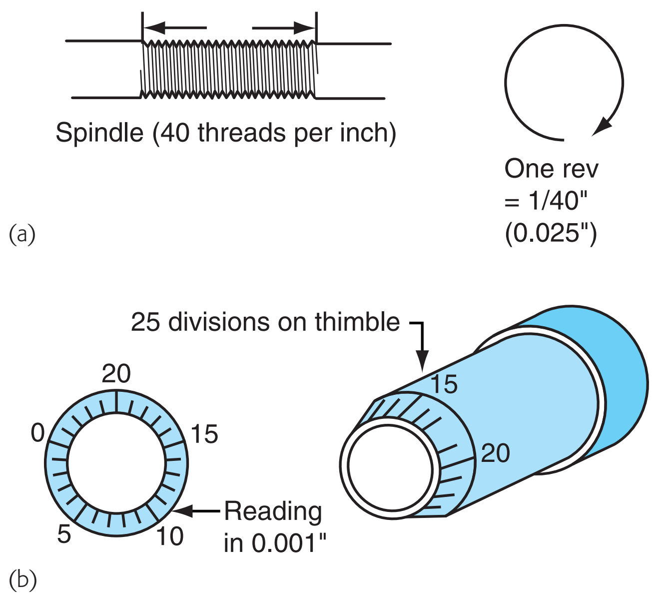


FIGURE 6.15 Relationships between (a) micrometer spindle pitch (40 threads to the inch); spindle/thimble movement (1/40", or 0.025", per revolution); and (b) graduations on the thimble of an inch-standard micrometer.

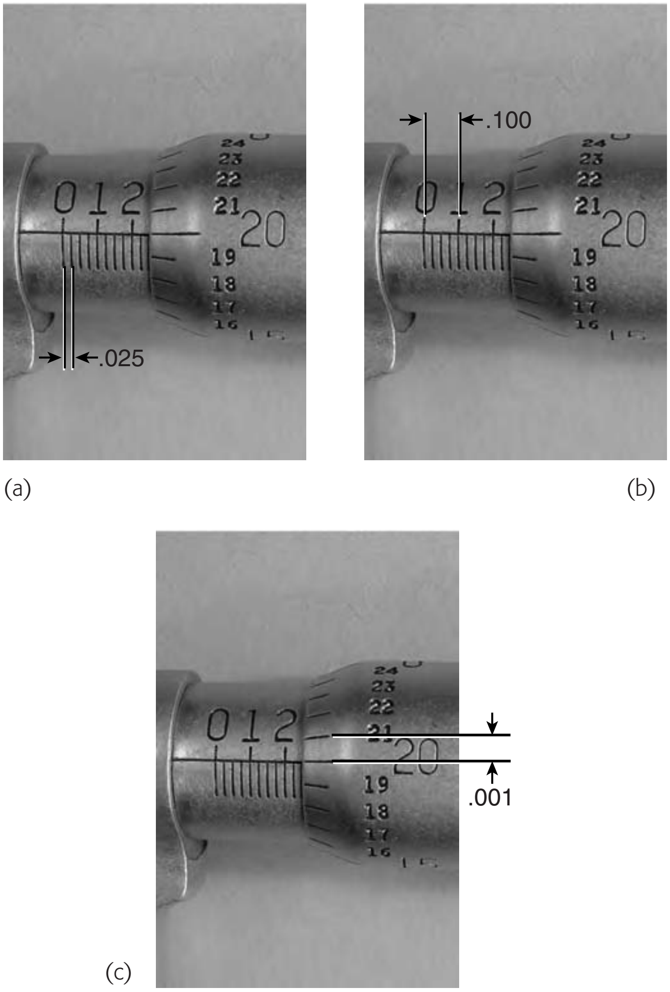


FIGURE 6.16 Micrometer measurements. (a) Each line on the barrel is 0.025″ (one revolution of the thimble). (b) Each number on the barrel is 0.100″ (four revolutions of the thimble). (c) Readings on the thimble are 0.001″ (1⁄25 of a revolution of the thimble). *(Courtesy of Tim Gilles)*

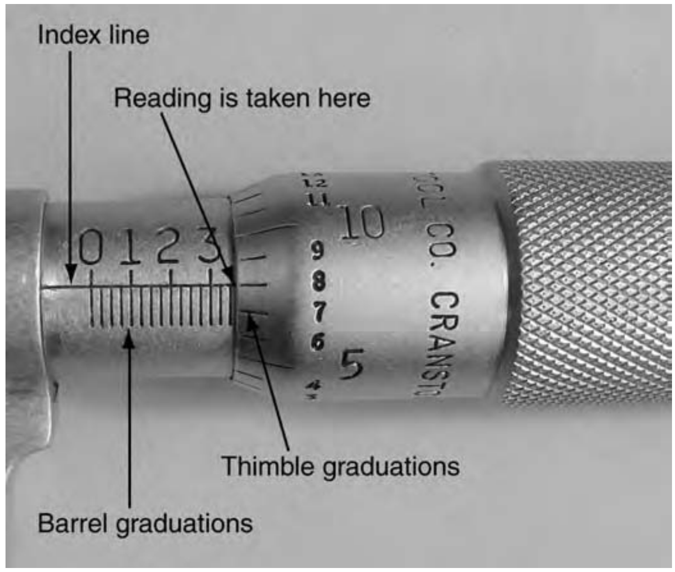


FIGURE 6.17 Reading a micrometer. *(Courtesy of Tim Gilles)*

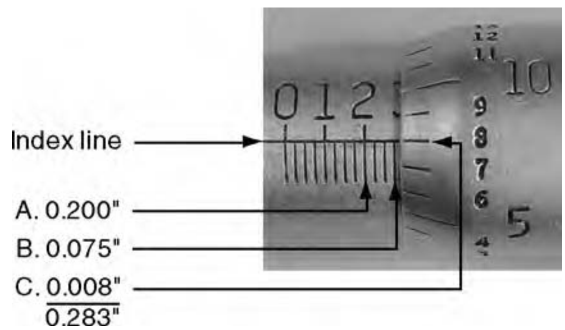


FIGURE 6.18 To read a micrometer to the nearest 0.001″, add A, B, and C together. *(Courtesy of Tim Gilles)*

on the thimble that lines up with the zero line. In **Figure 6.17**, this amount is 0.008''. If you add 0.350 to 0.008, you get 0.358'', which is the total for this reading.

In **Figure 6.18**, the reading is 0.283'' and is obtained by adding the barrel measurement to the thimble measurement. The reading is rounded off to the nearest 1⁄1000 of an inch (0.001'').

The micrometer is held as shown in **Figure 6.19**. An experienced technician will develop a feel for the micrometer. Compare your readings to those of an experienced person until you are consistent. The readings might be off by as much as 0.001''. When you have developed a consistent feel, you can set your micrometers to read at zero by using a **gauge standard** (**Figure 6.20**). Slide the micrometer over

FIGURE 6.19 How to hold a small micrometer. *(Courtesy of Tim Gilles)*

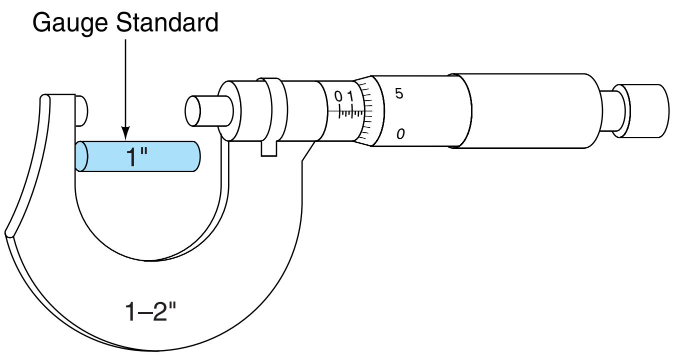


FIGURE 6.20 A gauge standard is used to calibrate a micrometer.

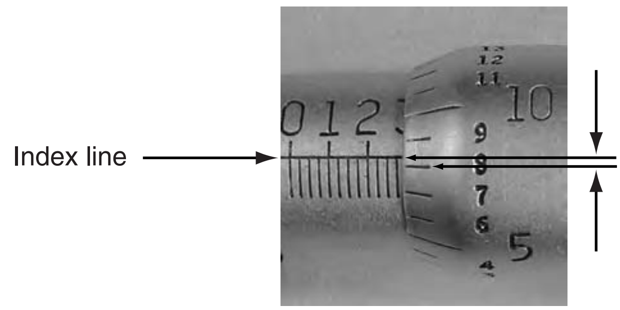


FIGURE 6.22 Make an approximate reading to four places (0.0003") by estimating the distance between the index line and the reading on the thimble. *(Courtesy of Tim Gilles)*

the part and roll it back and forth (**Figure 6.21**). It should be snug against the part but not tight. Use the ratchet until you develop a good touch.

Normally, a reading will be rounded off to the nearest 1⁄1000 of an inch (0.001"). But sometimes an estimate can be made to the nearest ten-thousandth (0.0001") (**Figure 6.22**). This estimate is made by gauging the distance between the index line and the last number passed on the thimble.

Micrometer Vernier Scale. Some micrometers also have a vernier scale for making readings to 0.0001" (called tenths). Most measurements need not be more accurate than 0.001", but in case more accuracy is needed, the vernier scale divides a thousandth of an inch into tenths of thousandths of an inch (**Figure 6.23**) . There are ten graduations on the top of the micrometer barrel that occupy the same space as nine graduations on the thimble. The difference between the width of one of the nine spaces on the thimble and one of the ten spaces on the barrel is 1⁄10 of one space.

Because each graduation on the thimble represents 0.001", the difference between graduations on the barrel and thimble is 0.0001". If the zero lines up with a line, the reading is accurate to three decimal places (**Figure 6.24**) .

If no line on the thimble lines up exactly with the zero line, the vernier scale is used. To read to tenths, simply find the line on the vernier scale that lines up with any number on the thimble, and then add this number to your reading. The example in **Figure 6.25** reads 0.3812".

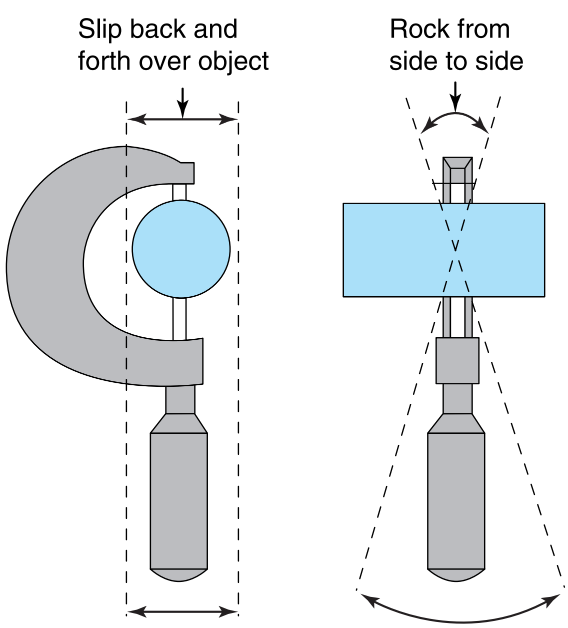


FIGURE 6.21 Adjust the fit of the micrometer to the part so that it is snug but not tight.

Metric Micrometer. Except for the graduations on the hub and thimble, metric micrometers look the same as English mikes. One turn of the thimble turns the spindle 0.5 mm, as opposed to 0.025". The hub is graduated in millimeters and half millimeters (**Figure 6.26**). The lines below the index line are the half millimeters (0.5 mm). Two revolutions of the thimble equal 1.0 mm on the hub. The thimble usually has 50 divisions. Every fifth line has a number from 0 to 45. Each graduation on the thimble is equal to 0.01 mm (1⁄100 millimeter).

The metric micrometer is read in the same manner as its English counterpart. Just add the millimeter and half millimeter readings on the barrel to 1⁄100 th (0.01) millimeter on the thimble.

The vernier scale feature gives the ability to read to two thousandths of a millimeter (0.002 mm).

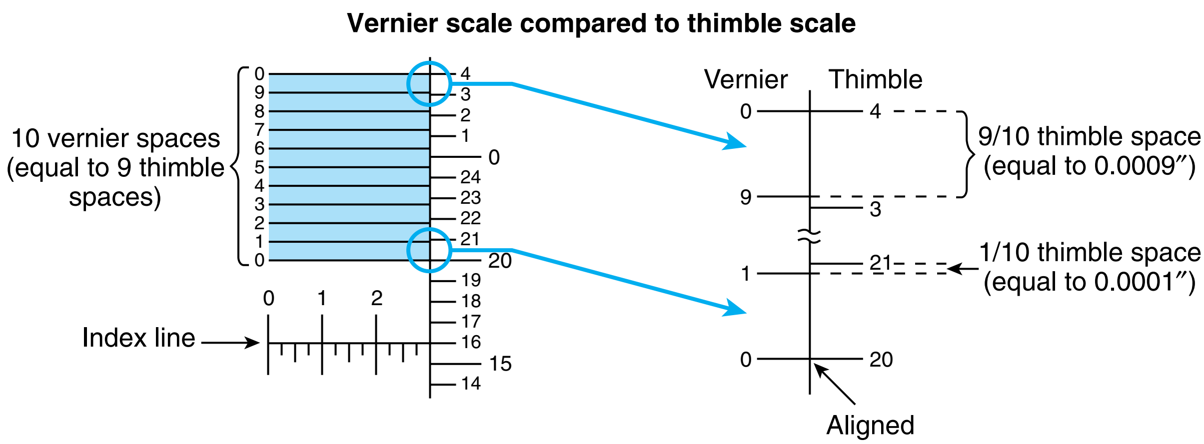


FIGURE 6.23 A micrometer vernier scale.

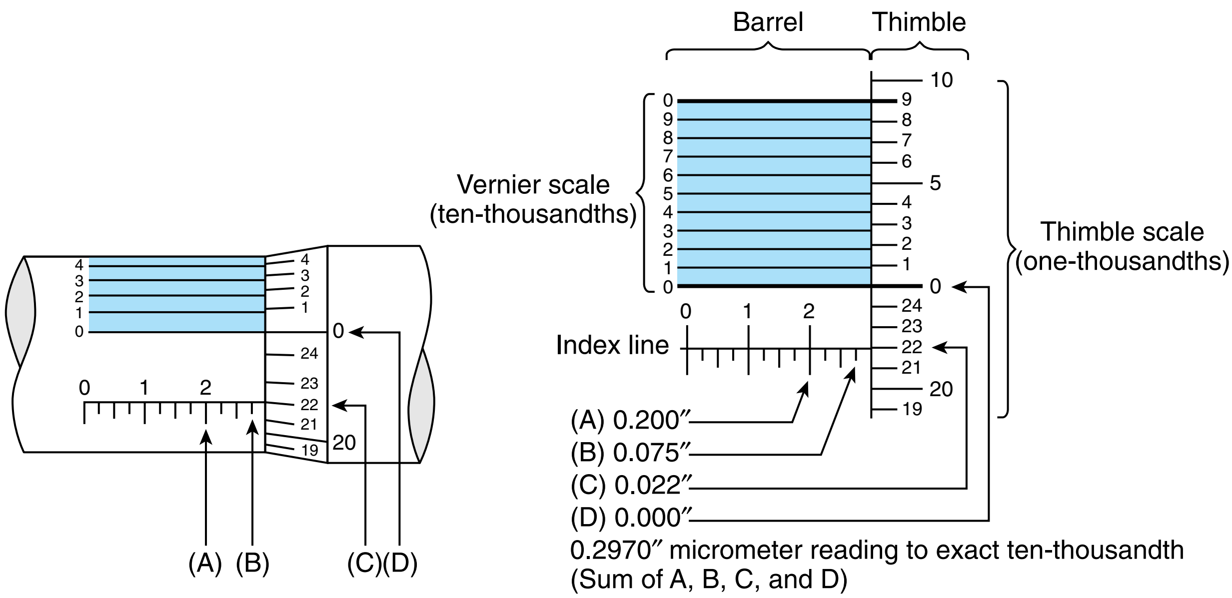


FIGURE 6.24 A reading of exactly 0.2970″. Both zero lines are aligned with the thimble lines.

There are only 5 divisions on this scale, compared to 11 on the English vernier scale. When one of the lines on the vernier scale lines up with *any* of the lines on the thimble, add that amount to the reading.

Combination Digital Mikes. Combination micrometers give both metric and English readings in a digital readout window (**Figure 6.27**), which is accurate to 0.0001. One version gives inch readings on the barrel; the other gives metric readings on the barrel.

Inside Micrometers. An inside micrometer (**Figure 6.28**) may be used to measure cylinder bores and main and rod bearing bores. The thimble of an inside micrometer does not move as freely on the barrel as the thimble of an outside micrometer. The added friction helps keep the reading from changing. Reading an inside micrometer accurately requires some practice.

Inside micrometers have extension rods to make them the proper size. They have handles for use in deep cylinders. **Figure 6.29** shows an example of an inside micrometer reading.

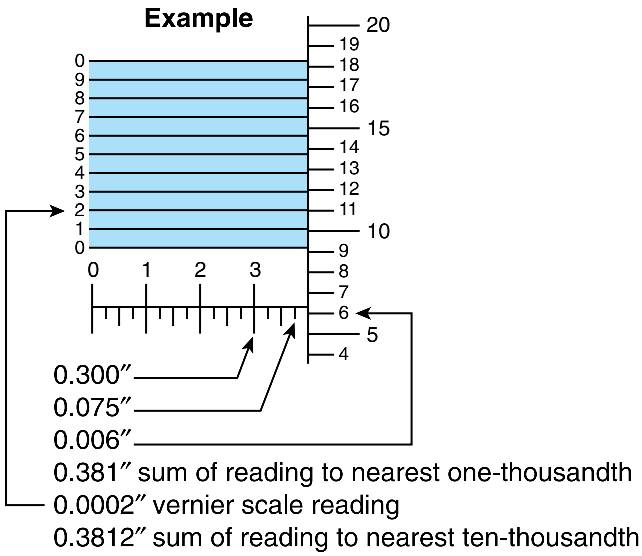


FIGURE 6.25 The vernier scale indicates 0.0002″.

SHOP TIP

Calibrating an inside micrometer is a questionable practice. Many machinists choose to use an inside mike as a transfer instrument, making the measurement and then reading the tool with a calibrated outside micrometer.

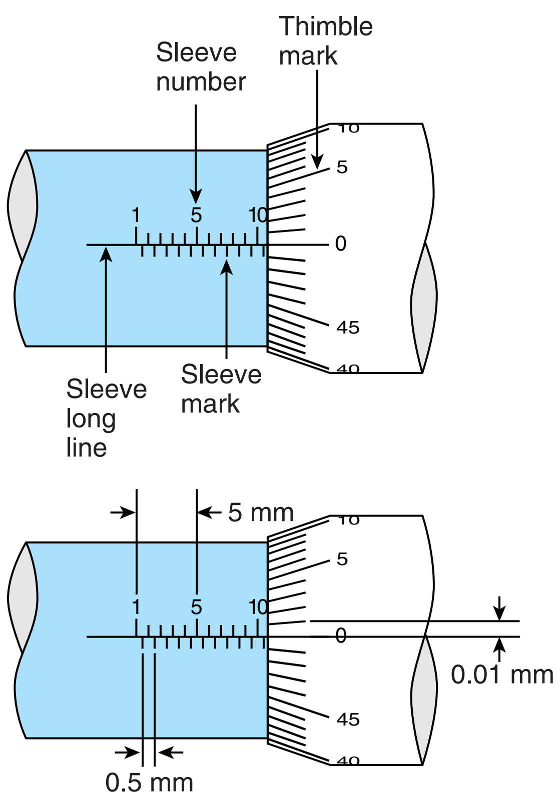


FIGURE 6.26 Metric micrometer markings and graduations.

FIGURE 6.27 A digital micrometer can be switched between inch and metric readings.

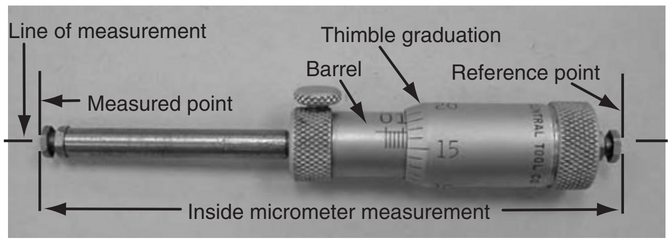


FIGURE 6.28 Inside micrometer nomenclature. *(Courtesy of Tim Gilles)*

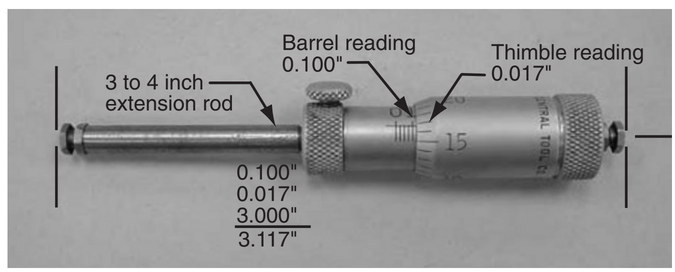


FIGURE 6.29 Taking an inside micrometer measurement. *(Courtesy of Tim Gilles)*

Telescoping and Split Ball Gauges

An inside micrometer cannot work in cylinders smaller than about 2", so telescoping or small hole (split ball) gauges are used (**Figure 6.30a**). These are known as transfer gauges, because the measurements they make are read with an outside micrometer.

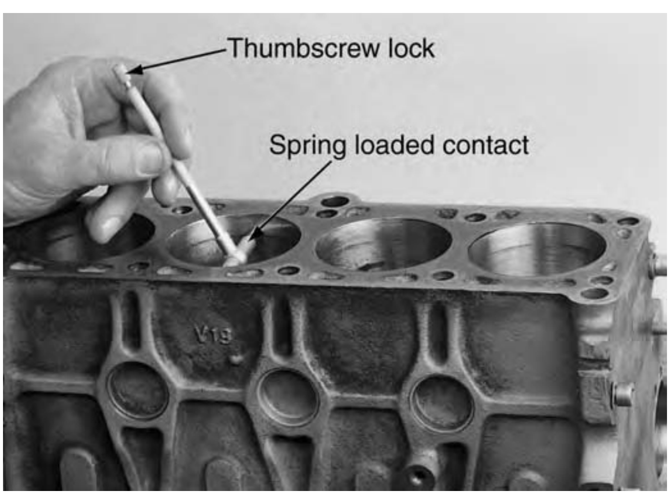
The small-hole gauge is used on small holes such as valve guides. Be sure to take your reading at 90° to the split in the ball (**Figure 6.30b**).

Telescoping gauges come in different sizes. They can be used with a micrometer to measure cylinders, bearing bores, and so on (**Figure 6.31**) .

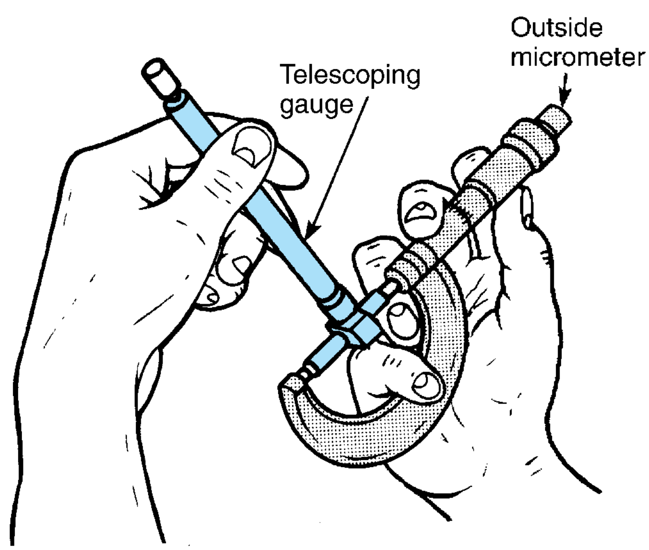
(a)

(b)

FIGURE 6.30 Small hole gauges. (a) A set of small hole gauges. *(Courtesy of L. S. Starrett Company)* (b) After setting the gauge to size, read the size with an outside micrometer at 90° to the split in the ball. *(Courtesy of Tim Gilles)*



(a)



(b)

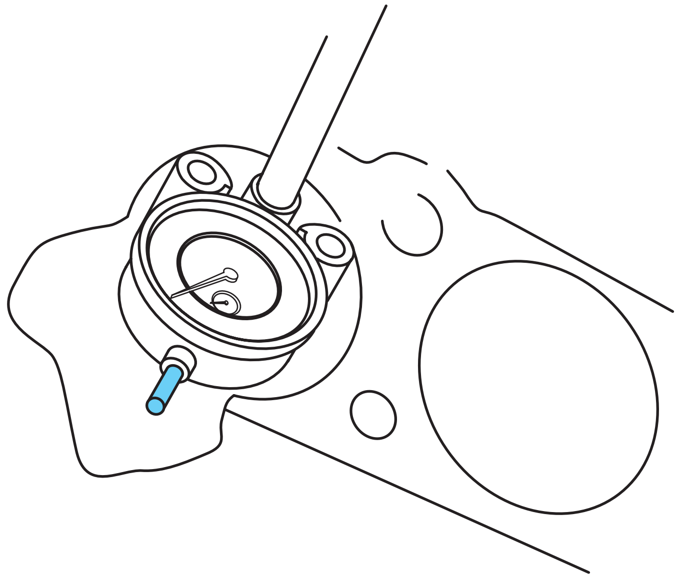
FIGURE 6.31 (a) A telescoping gauge in a cylinder bore. *(Courtesy of Tim Gilles)* (b) The gauge is read with a micrometer.

Dial Indicators

A dial indicator can measure movements, such as end play of crankshafts and valve guide wear. It can also measure valve-in-head depth and cylinder and main bearing bores. These processes are covered in subsequent chapters. Features of the indicator are shown in **Figure 6.32**.

An indicator is a very sensitive instrument consisting of small gears activated by spindle movement. Movement is transmitted through a small gear to an indicating hand on a dial. The dial can be either balanced or continuous (**Figure 6.33**). Long-range indicators are equipped with revolution or sweep counters.

Indicators are comparison instruments, because an indicator reading must be compared to a known measurement (**Figure 6.34**). When measuring thrust (forward and backward movement), no comparison is necessary.



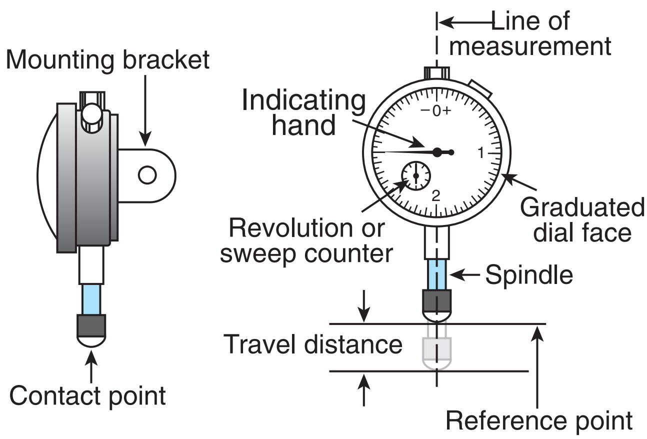


FIGURE 6.32 Dial indicator nomenclature.

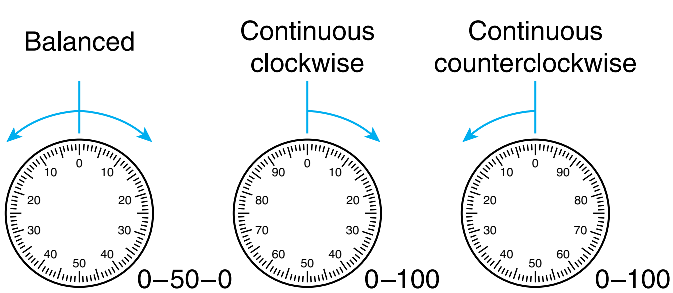


FIGURE 6.33 Types of dial indicator faces.

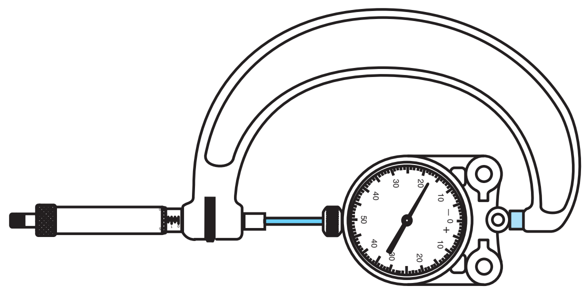


FIGURE 6.34 Measuring a dial indicator for comparison.

A special indicator and micrometer setting fixture used for measuring cylinder bores is shown in Chapter 11. The tool is a comparator gauge. It has a micrometer setting fixture. If the setting fixture is set to read a cylinder bore of 4.375", then when the gauge on the indicator reads "0" it is actually reading 4.375". Another indicator for measuring valve guides is shown in Chapter 7.

One type of indicator has a magnetic base (see Figure 7.21a). Another type has various attachments for clamping it to the workpiece (**Figure 6.35**). The most popular and versatile indicator among technicians is the vise-grip indicator shown in **Figure 6.36**. It has many uses in the specialty areas of auto repair.

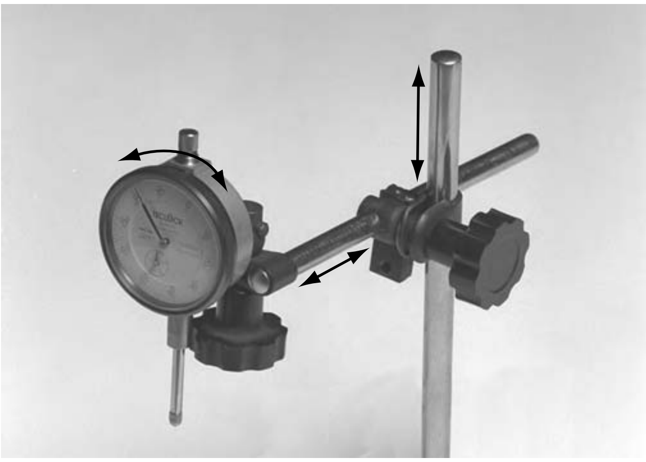


FIGURE 6.35 Various positions of a universal dial indicator set.

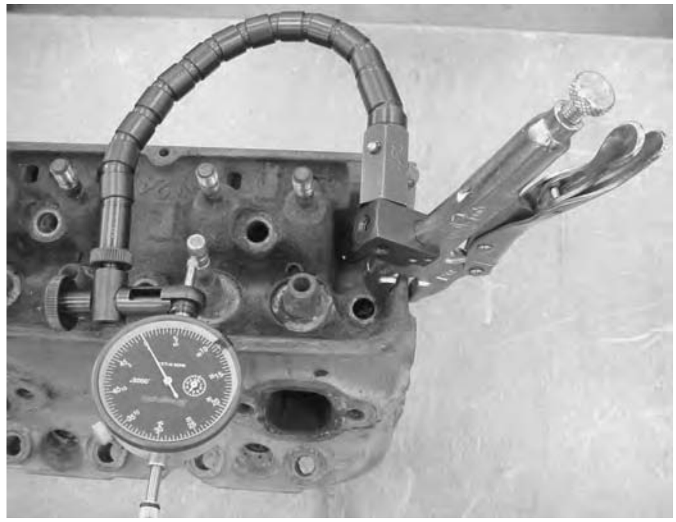


FIGURE 6.36 A vise-grip indicator in use. *(Courtesy of Tim Gilles)*

Key Terms

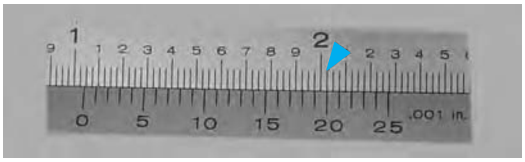
British Imperial (U.S.) system
caliper
foot-pounds/newtons
gauge standard
I.D.
LCD
metric system
O.D.
Plastigage
vernier scale

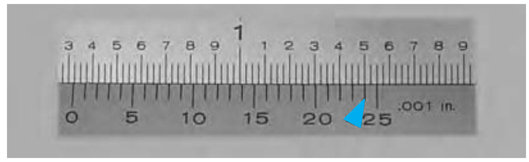
Study Questions

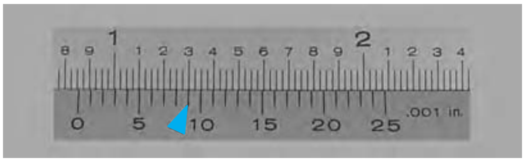
1. What system of measurement is based on the number 10?
2. Convert 5 inches to millimeters. _____
3. Convert 127 millimeters to inches. _____
4. Approximately how many cubic inches are there in 1 liter?
5. Approximately how many cubic inches equal 2.7 liters?
6. What is the most *versatile* precision measuring instrument a technician can own?
7. What measuring instrument can measure I.D., O.D., and depth from 0" to 7"?
8. On precision measuring instruments, how is 1⁄10" expressed with decimals?
9. How much movement on the scale will result from one revolution of the micrometer thimble in fractions of an inch?
10. How much movement on the scale will result from one revolution of the micrometer thimble in thousandths of an inch?
11. Name the tool used to calibrate a micrometer.
12. Which scale on the micrometer is used to measure to 0.0001"?
13. When reading a small-hole gauge, how is the micrometer reading taken in relation to the split in the ball, on the split or 90° to the split?
14. Name an instrument that would be used to measure end play of a shaft.
15. The small extra gauge found on the face of a long-range dial indicator is called a revolution _____.

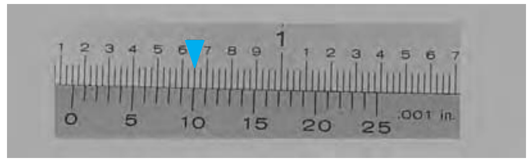
Vernier Caliper Practice

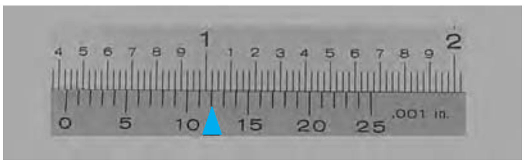
Enter the vernier caliper readings below.

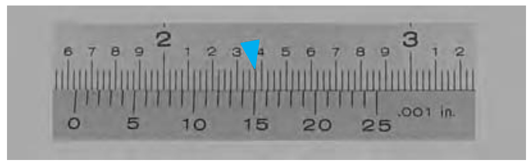
1. 

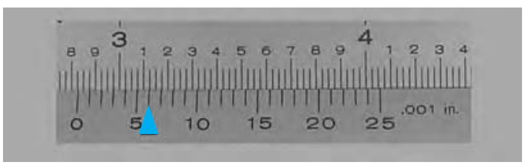
2. 

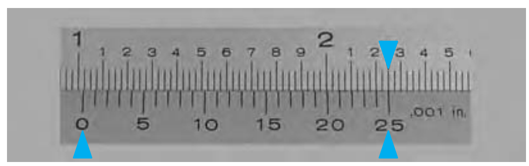
3. 

4. 

5. 

6. 

7. 

8. 

Micrometer Practice

Enter the micrometer readings below.

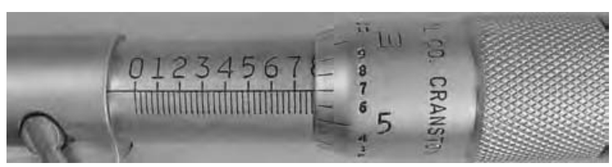
1. 

2. 

3. 

4. 

5. 

6. 

7. 

8. 

SECTION 2

The Breathing System

Overview

The focus of these chapters is on the cylinder head, valvetrain, and other parts related to engine breathing. Theory of the parts and their operation is covered in detail, with emphasis on proper diagnosis, service, and repair procedures. Cylinder head coverage in Chapters 7 and 8 includes theory and service of the head casting, valves, valve guides, valve guide seals, valve springs, and related parts. Chapters 9 and 10 include discussion of the camshaft, lifters, cam grind, and the valve timing. Intake and exhaust manifolds, superchargers, and turbochargers are also covered.

CHAPTER 7

Cylinder Head: Parts and Service

Contents

- Cylinder Head Material
- Head Disassembly
- Carbon Removal
- Crack Inspection
- Crack Repair
- Valve Guide Inspection
- Valve Guide Repair
- Reaming Valve Guides
- Valve Guides and Seals
- Resurfacing Heads

Objectives

Upon completion of this chapter, you should be able to:

- Disassemble, clean, and inspect cylinder heads.
- Analyze wear and damage to cylinder head parts.
- Understand theory related to cylinder head parts.
- Select and perform the correct repair.

Introduction

Cylinder head work is the largest engine repair specialty area. As vehicles accumulate many miles, they sometimes require valve jobs or new head gaskets. Sometimes an engine's oil consumption can be due to faulty valve guide seals and worn valve guides. Other times, piston rings can be at fault. This possibility must be pointed out to a customer who wants a valve job on a high mileage engine. The lack of carbon around the outer edge of a piston (or a "washed" appearance) can indicate leaking piston rings (see Chapter 4). Rebuilding a cylinder head on an engine with this indication will not solve the oil consumption problem.

Many of today's aluminum blocks have cast-in iron sleeves, called "captured" sleeves. There are also some all-aluminum engines without sleeves.

CYLINDER HEAD MATERIAL

Cylinder heads on today's engines are made of aluminum. Aluminum heads are an **alloy**; several materials are combined for their best attributes. Aluminum expands at about one and a half times the rate of cast iron, so that presents some problems. But aluminum also dissipates heat five times as fast as cast iron.

VINTAGE ENGINES

On vintage engines, heads were made of cast iron. As manufacturers moved toward the use of aluminum, it was used for heads or blocks, but not usually used for both the block and head. This was because iron was needed to provide rigidity.

Aluminum replacement heads are available in the aftermarket (**Figure 7.1**), often to replace original equipment cast iron heads. A pair of these heads usually weighs 40 to 50 pounds less than the iron heads they replace. Because aluminum dissipates heat faster than cast iron, a reduction in cylinder pressures results and compression ratio can be higher.

NOTE

Unless the aluminum has high silicon content, it is much easier to damage than cast iron. **Figure 7.2** shows an aluminum head with some scratches that accidentally occurred during careless handling on the workbench.

When a head is called a *stock replacement*, it will be able to be fit with all of its original parts. A *bolt-on* head will have the head bolt holes located in the same locations as the OE head, but do not always expect other pieces to fit. Bolt-on heads are designed for racing and sometimes have raised ports to improve airflow. Special manifolds, headers, and other parts are needed with raised port bolt-on heads. Be careful to get the head you are looking for. A substantial cost difference can result.

Stock replacement aluminum heads are designed to provide more power than the engine's original cast iron heads, as long as they did not have port work previously done to them. More information on high-performance heads can be found in Chapter 10.

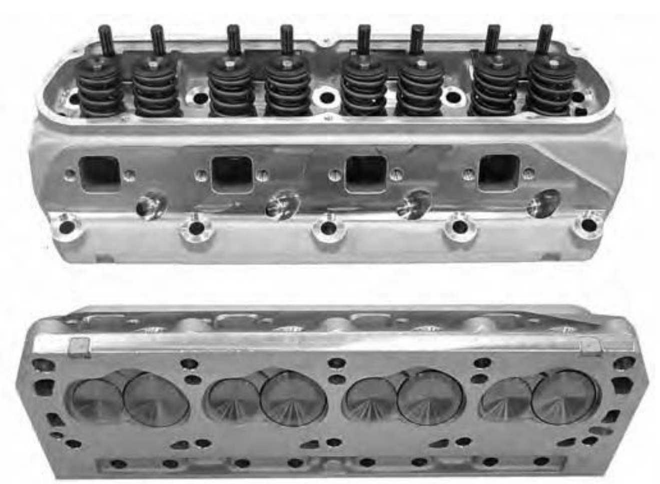


FIGURE 7.1 High-performance aluminum replacement heads. *(Courtesy of Tim Gilles)*

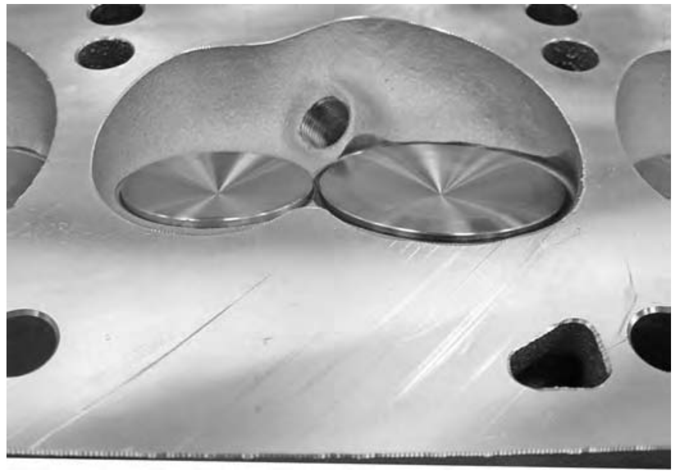


FIGURE 7.2 The surface of this head was damaged by careless handling. *(Courtesy of Tim Gilles)*

For practical performance purposes, other than high-end racing, an engine that was originally equipped with iron heads will perform very well with the OE heads. Cylinder head modifications are discussed in this chapter and Chapter 8.

HEAD DISASSEMBLY

Heads are easier to work on if they are clean. After hot-tanked heads have cooled, be sure to rinse them thoroughly with water. Following cleaning, lubricate all machined surfaces immediately to prevent rust. Be especially certain to lubricate valve springs that have been hot-tanked. Springs can lose their protective coating during hot-tanking and will rust quickly. Rusted springs should be discarded because rust creates stress raisers and changes spring tension.

CAUTION

Be careful when handling a cylinder head with an overhead cam. While the cam is still installed in the head, some of the valves will be held in their open positions. Do not set the head down on the combustion chamber side or some of the valves could be bent.

Some OHC camshafts act directly on the valve, whereas others use rocker arms (see Chapter 9). Before removing the valve and spring from some OHC heads, it is necessary to remove the rocker arms. Pry against the spring retainer and remove

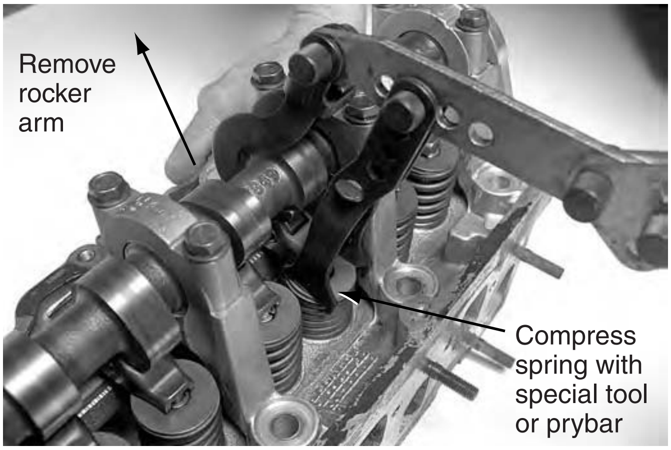


FIGURE 7.3 Remove OHC rocker arms before disassembling the valve and spring.

the rocker arm as shown in **Figure 7.3**. Then the camshaft can be removed.

Verify that camshaft caps are correctly numbered before removing them (**Figure 7.4**). On DOHC heads, number the exhaust caps E-1, E-2, and so on, and number the intake caps I-1, I-2, and so on.

Valve retainers are sometimes stuck to the valve locks (keepers) by varnish buildup. Before using a spring compressor, strike each spring retainer with a rubber dead-blow hammer and a short length of pipe, an old piston pin, or a special tool (**Figure 7.5**). If this is not done, the jaws of the spring compressor can be bent or broken.

FIGURE 7.5 Strike the retainer with a piece of pipe, an old piston pin, or a special tool. *(Courtesy of Tim Gilles)*

CAUTION

Be especially careful not to bend a valve when striking the retainer. Sometimes the retainer is so firmly stuck that it moves the valve down against the spring when struck. If the cylinder head is face down on the bench, the valve head will strike the bench, bending the valve. To prevent this problem, position the heads on the head stands (**Figure 7.6**).

Spring Removal Tools

To protect yourself from flying parts, *be sure to wear face protection* when removing valve springs. There are several types of spring removal tools. One

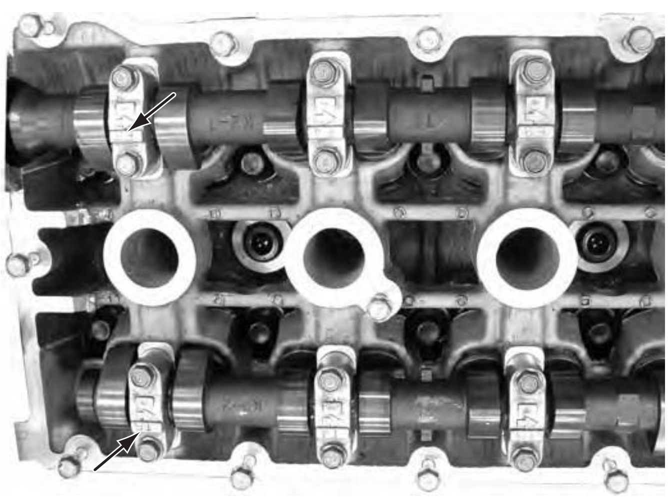


FIGURE 7.4 Verify that the cam caps are correctly numbered before removing them. *(Courtesy of Tim Gilles)*

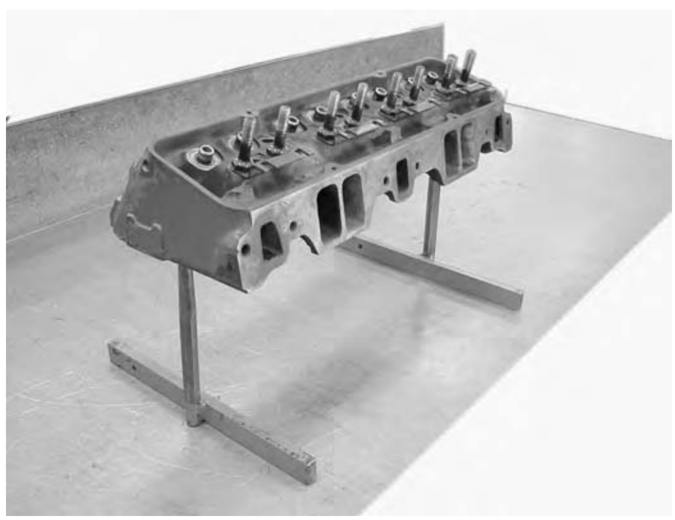


FIGURE 7.6 These head stands were made by welding a punch to a piece of steel. *(Courtesy of Tim Gilles)*

of the oldest types is the manually operated spring compressor (**Figure 7.7**). Its jaws are adjusted to fit the spring retainer (**Figure 7.8**). Also, adjust the compressor travel so that the spring will be compressed just enough to allow the keepers to be removed (**Figure 7.9**). Different offset jaw shapes are available to provide access to the various cylinder head shapes (**Figure 7.10a**). **Figure 7.10b** shows how using a compressor with the wrong jaws can result in interference between the jaws and cylinder head.

There are also spring compressors that are air operated (**Figure 7.11**). Be careful not to accidentally pinch your fingers when using this tool. The plunger moves very fast!

FIGURE 7.9 Compress the spring just enough to remove the keepers. *(Courtesy of Tim Gilles)*

FIGURE 7.7 Valve spring compressors. A common type of valve spring compressor in use. *(Courtesy of Tim Gilles)*

(a)

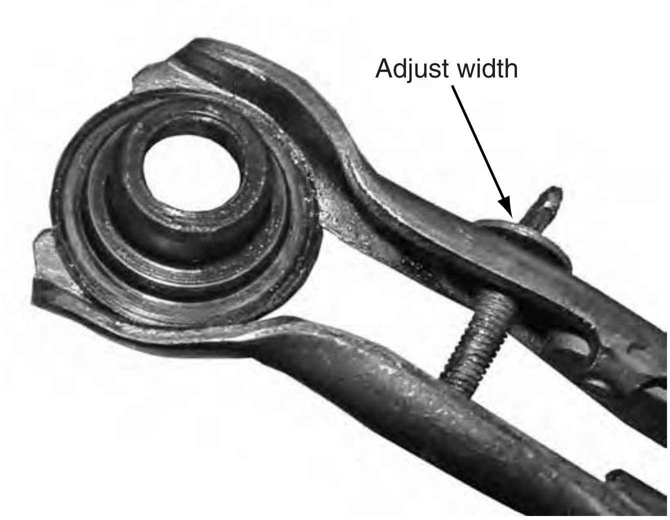
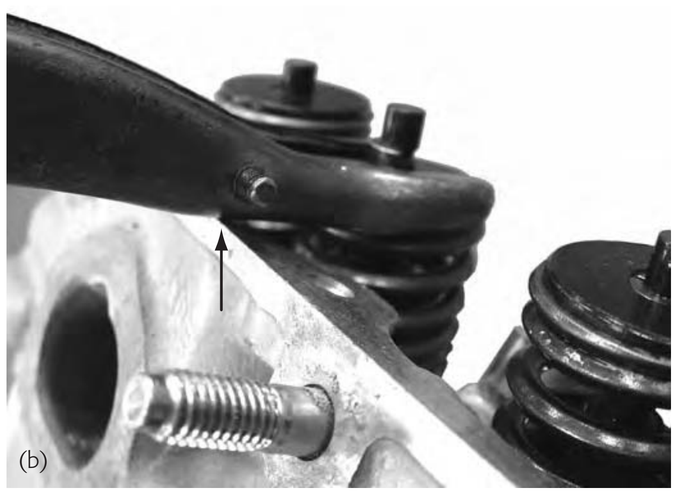


FIGURE 7.8 Adjust the jaws to fit the spring retainer. *(Courtesy of Tim Gilles)*



(b)

FIGURE 7.10 (a) Different styles of compressor jaws. (b) This valve spring compressor has the wrong jaws for this head, resulting in interference with the casting. *(Courtesy of Tim Gilles)*

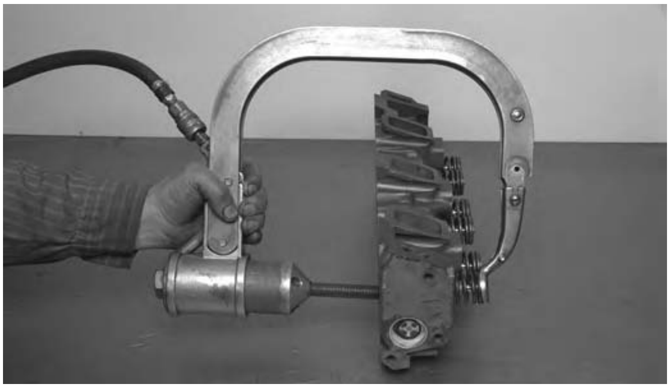


FIGURE 7.11 An air-operated spring compressor.

Heads with four valves per cylinder are popular, especially in later model high-performance engines (**Figure 7.12**). These heads typically have bucket-type cam followers (covered later). The valve and spring assembly in these heads is recessed in the head, which makes removal, and especially reinstallation, of the keepers more difficult. **Figure 7.13** shows an adapter that can be used with a standard valve spring compressor. Shops that do enough of this work to support the investment will own an air-operated bench unit that makes disassembly and reassembly of these heads much easier and less time consuming (**Figure 7.14a**). **Figure 7.14b** shows an offset adapter

FIGURE 7.12 A head with four valves per cylinder. *(Courtesy of Tim Gilles)*

FIGURE 7.13 An adapter used with a manual valve spring compressor for removing keepers on heads with bucket-type cam followers. *(Courtesy of Tim Gilles)*

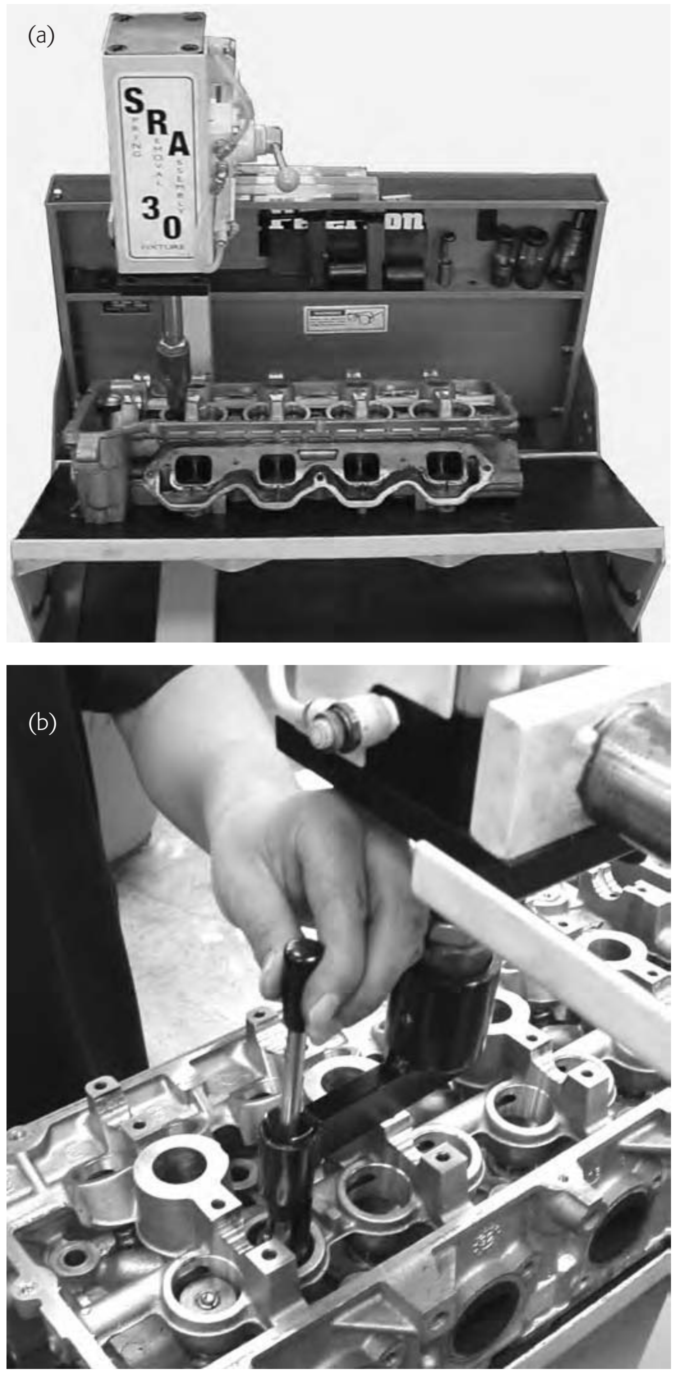


FIGURE 7.14 (a) This air-operated bench unit easily compresses valve springs on all types of heads. (b) Different sized adapters are available. They are easily installed in the press ram. This one is being used on a bucket-type OHC head. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Many engines, especially General Motors engines prior to 1992, used O-ring valve seals. These must be removed along with the keepers.

that allows easier access to the keepers when using this machine.

Some valve spring compressors can be used with the heads either on or off the engine (**Figure 7.15**). These are especially useful when removing springs to replace valve guide seals while the heads are still on the engine.

Keep Valves in Order. It is a good idea to keep all valves in the order in which they were removed (**Figure 7.16**).

- One or more oversized valve stems might have been used in a previous head repair procedure.
- If the valve guides are not serviced, the valves should be returned to their original guides.

Valves can be placed through holes in a piece of wood, metal, or cardboard. Some machinists use an electric engraver to number valves before disassembly, but this is time consuming.

Put all small valve components in a storage container. Be especially careful not to lose any keepers; they are very small and easily lost.

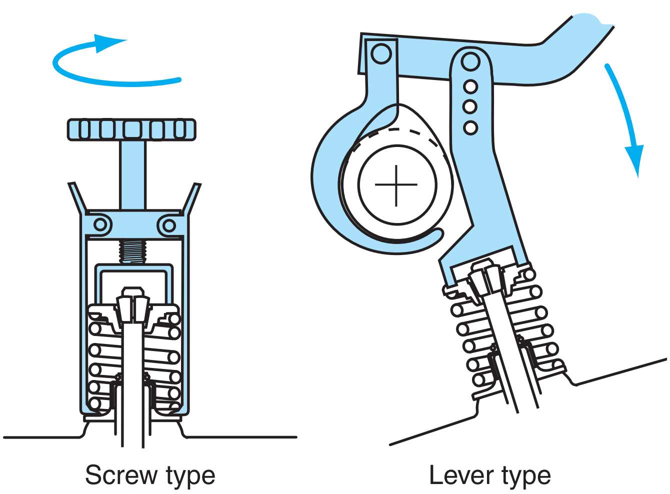


FIGURE 7.15 Valve spring compressors that can be used with the heads on or off the engine.

NOTE

Remember that aluminum heads almost always have a steel shim beneath the valve spring (**Figure 7.17**). These are very easy to lose, especially during the cleaning process.

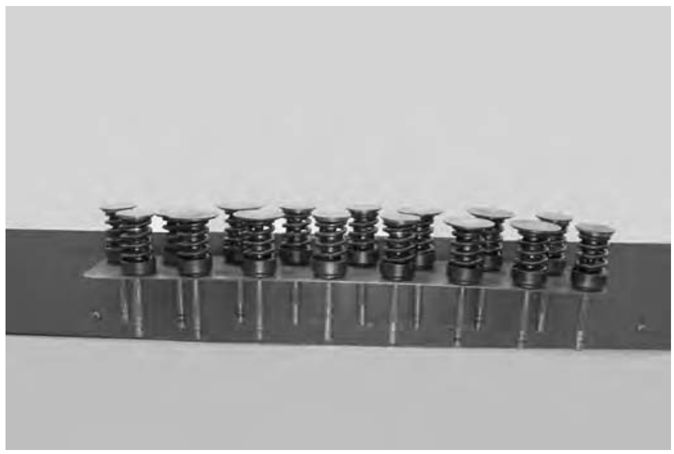


FIGURE 7.16 Keep all valves in order. *(Courtesy of Tim Gilles)*

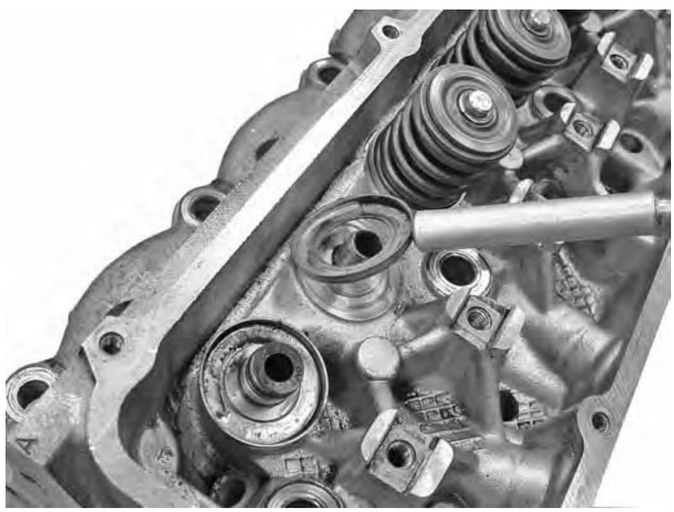


FIGURE 7.17 Aluminum heads always have a steel shim beneath the valve spring. Do not lose one during the cleaning process because replacement shims are difficult to find. *(Courtesy of Tim Gilles)*

Sometimes a valve develops a **mushroomed valve tip** due to pounding that happens when there is excessive clearance (valve lash). This mushroomed area must be dressed with a file before the valve can be removed from the guide (**Figure 7.18**).

CAUTION

Do *not* try to drive out a mushroomed valve with a punch and hammer. The valve or guide can be damaged.

SHOP TIP

A cup-type grinding wheel on an air drill can be used to deburr mushroomed valve tips.

Another reason why a valve might not easily come out of a valve guide is when a keeper groove becomes burred at the edges. A whetstone can be used to smooth the burred edges so the valve can be removed and installed without damaging the valve guide.

Measuring Valve Stem Height

After springs are removed, measure the height of the stem tip before removing the valves. Be sure to record these figures on the shop work order because this may be your only reference when reassembly time comes around. If extensive seat or valve work becomes necessary, obtaining and recording this measurement now will be an important step in the process. Factory specifications are not readily available for stem height measurements, although many of these can be found in the AERA *Cylinder Head and Block I.D. Manual* or in Prosis.

To measure **valve stem height** (**Figure 7.19**), use a vernier caliper (**Figure 7.20**) or depth micrometer. The stem height measurements should be nearly the same for all similar valve locations (intake or

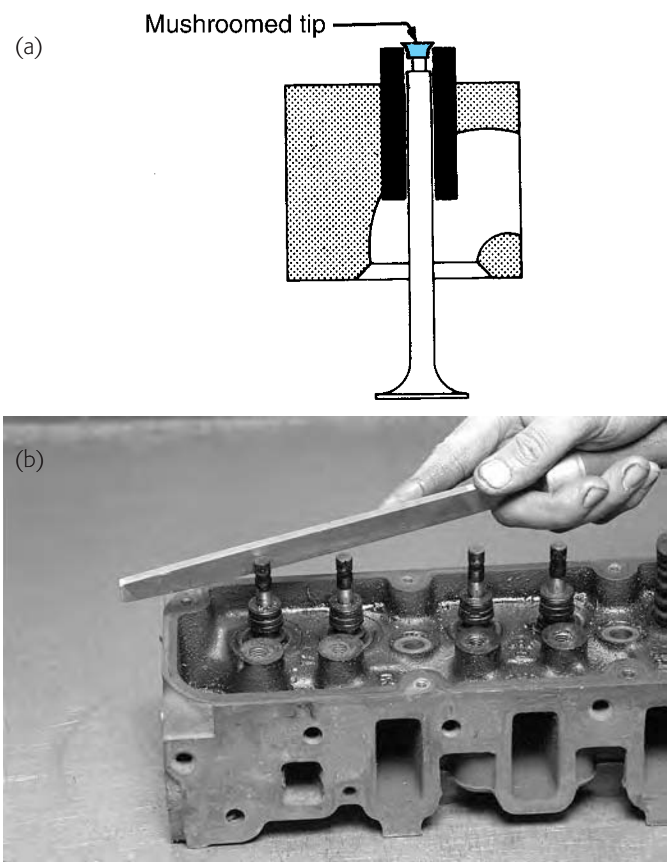


FIGURE 7.18 (a) Before removing a mushroomed valve from its guide, (b) the valve tip is filed.

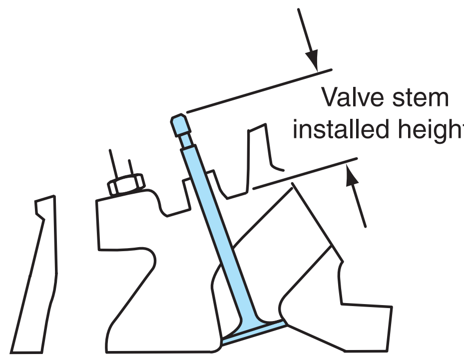


FIGURE 7.19 Valve stem height.

FIGURE 7.20 Measuring valve stem height with a dial caliper. This is an important reference, especially if any valve seats are to be replaced. *(Courtesy of Tim Gilles)*

exhaust) on one engine. Prior to disassembly, the heights of the valve springs can also be checked and recorded. This can also be a handy reference.

CARBON REMOVAL

During the life of an engine, carbon forms on combustion chamber surfaces and on the necks of the valves. The carbon is removed prior to inspecting the head for cracks.

Removing Carbon from Combustion Chambers

After disassembly, machine shops sometimes glass bead blast heads that do not have oil galleries.

CAUTION

Most OHC heads *do* have oil galleries and should **not** be glass bead blasted.

Bead blasting removes carbon very quickly and will also highlight any cracks in the combustion chambers or valve ports (see Chapter 5). It is an excellent method of removing carbon from aluminum heads but it will not work on greasy surfaces. The head must be clean. After blasting, thoroughly remove any remaining beads from the head. Some shops have a tumbling machine. Another method of removing carbon is to use a portable wire wheel with a drill motor, an air drill, or a die grinder, but this can damage an aluminum head. Remove carbon and gasket material by hand, using a gasket scraper or carbon removing tool.

- Be careful not to exert excessive pressure on the narrow head surface area between combustion chambers; damage could be done to an iron or aluminum head.
- Chemical carbon removers can be applied to aluminum heads to help soften the carbon.

Removing Carbon from Valves

Carbon can be removed from valves by glass bead blasting or with a wire wheel on a grinder (**Figure 7.21**). Clean the keeper grooves as well (**Figure 7.22**), but do not clean the guide rub/wear area of the valve stem (**Figure 7.23**). This part of the valve stem is typically chrome-plated. The wire brush will scratch the chrome, resulting in a rough surface that can cause valve guide wear.

FIGURE 7.21 Cleaning carbon from the valve neck using a wire wheel. *(Courtesy of Tim Gilles)*

FIGURE 7.22 Cleaning the keeper groove with a wire wheel.

CAUTION

Hold the valve carefully. It can be drawn into the wire wheel and thrown against the floor or wall. You can also remove a layer of skin from your fingers, resulting in a painful "burn."

When there are extremely hard carbon deposits (usually on exhaust valves), you can use an old valve to gently break off carbon before you finish cleaning the valve neck using the wire wheel (**Figure 7.24**). Be careful not to nick the good valve. Sometimes soaking carbon deposits in solvent before wire wheel cleaning will soften the deposits and shorten cleaning time.

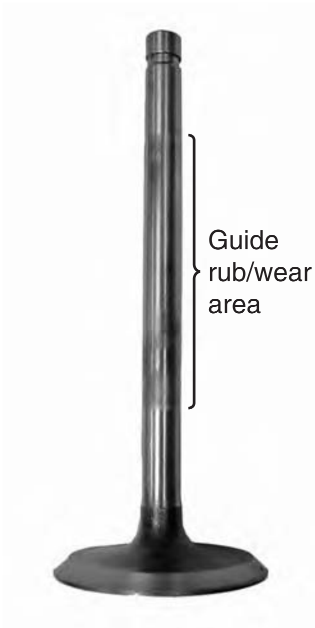


FIGURE 7.23 The worn area on this valve stem shows where it rides in the valve guide. Do not wire brush this area when cleaning. *(Courtesy of Tim Gilles)*

FIGURE 7.24 Chipping off heavy carbon deposits with an old valve.

CRACK INSPECTION

Cracks are sometimes found in combustion chambers, between combustion chambers, and also, rarely, on the valve spring side of the head (**Figure 7.25**). There are a number of ways to detect cracks. Sometimes after the head has been cleaned, cracks will be apparent to the eye. Glass bead blasting can be especially helpful in highlighting cracks.

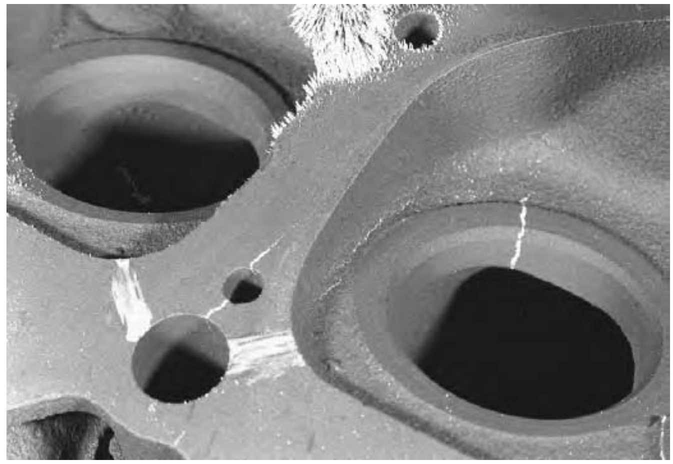


FIGURE 7.25 Examples of cracks in a cylinder head.

Magnetic Crack Inspection

Crack inspection on iron heads can be performed using a simple magnetic crack detector, which is shown in **Figure 7.26**.

- The electromagnet is turned on, which sets up a magnetic field.
- The head is dusted with iron powder and the powder lines up with the magnetic lines of force. A crack interrupts these lines of force, causing the powder to gather around the crack.
- The magnetic field must be broken for the test to work. Magnetic crack detection works best when the crack runs between the poles of the magnet. If the crack is parallel to the magnetic poles, the crack might not show up. Turn the magnet 90° after the first test; the lines of force will move, possibly revealing a crack that did not previously show up.

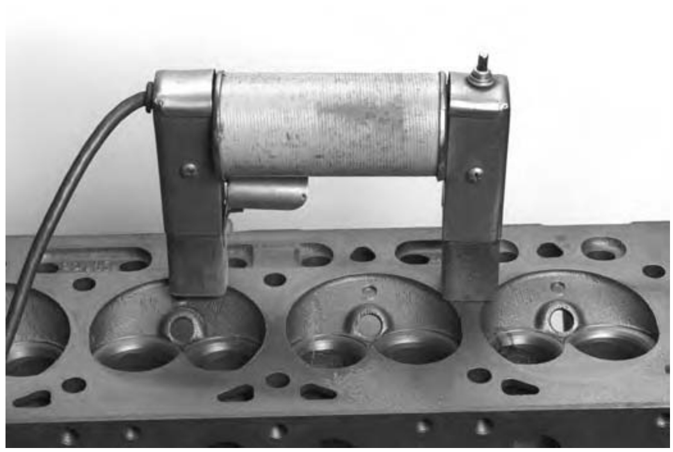


FIGURE 7.26 A magnetic crack detector.

- Put chalk on the crack so you can find it after the magnetic powder has been removed.
- Magnetic powder is available in different colors.
- Be sure to check the top side of the head for cracks, too.

Magnaflux® is the common trade name for a more sophisticated magnetic crack detection product. There are also large, bench-type magnetic crack detectors. These use a magnetic liquid and black light and are very effective in making a crack stand out in ferrous materials.

Dye Penetrant

Dye penetrant can be used to detect cracks in any metal (**Figure 7.27**). It is usually used on aluminum castings but not on iron because of its expense compared to magnetic detection. It is important that all grease and carbon be removed from the head prior to crack checking with penetrant because carbon can hide a crack.

- First, spray the surface with cleaner and allow it to dry (**Figure 7.27a**).
- Next, spray a red dye onto the cleaned surface. Allow the dye to soak in for 5–30 minutes.
- Then wipe the excess dye from the surface (**Figure 7.27b**). A shop towel moistened with the cleaning solution works well, but do not soak the surface with cleaner.
- Finally, spray a light coating of the white developer to make cracks visible to the eye (**Figure 7.27c**). Cracks show up as red or pink lines on a white background.

A black light crack detector works in a similar fashion. Shine the black light on the surface after spraying a special solution on the head.

Pressure Testing

Another popular way of testing for cracks is *pressure testing*, which is very effective. All openings in the head are plugged before filling it with water or air. The head is outfitted with a custom-fitted pressure tester (**Figure 7.28**) or a universal pressure tester, which is more time consuming.

Heated water can be used to simulate actual running conditions. Some heads require cylinder

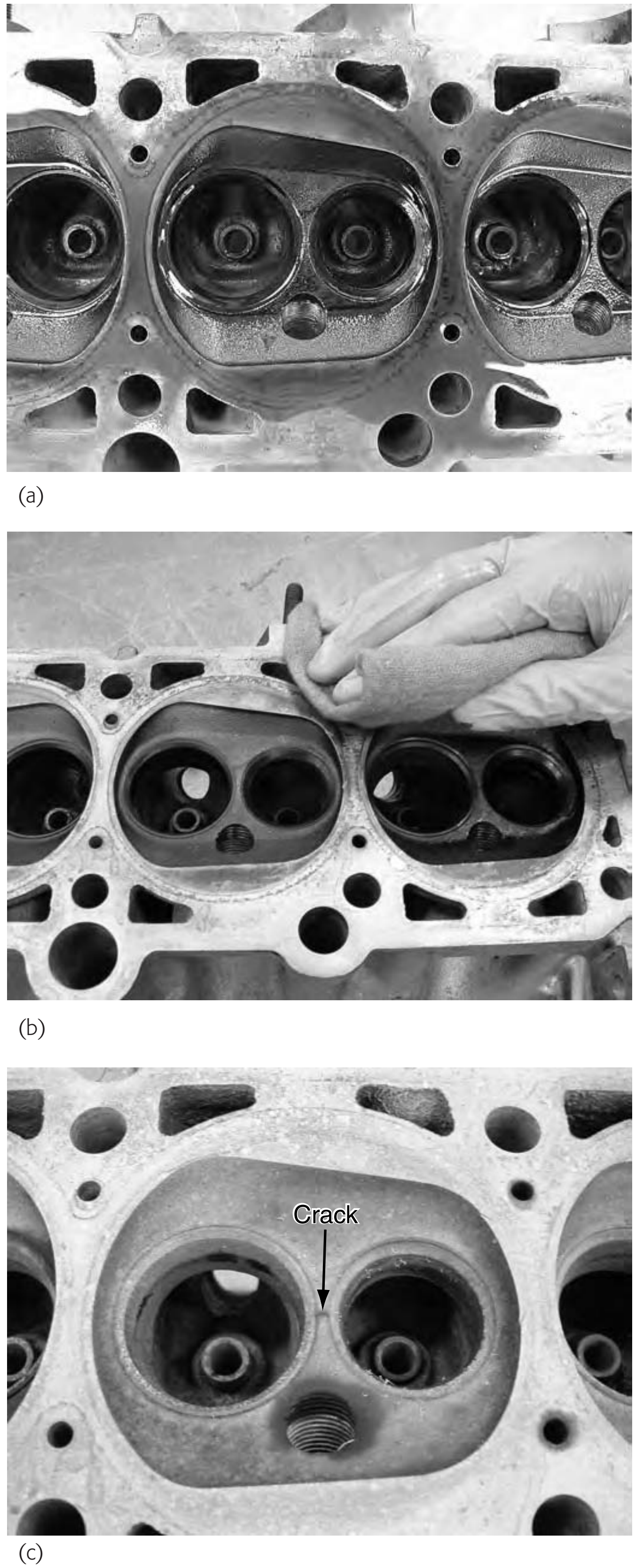


FIGURE 7.27 Checking for cracks with a dye penetrant. (a) Spray on penetrant. (b) After 5 minutes, clean the surface. (c) Spray on developer to highlight the crack. *(Courtesy of Tim Gilles)*

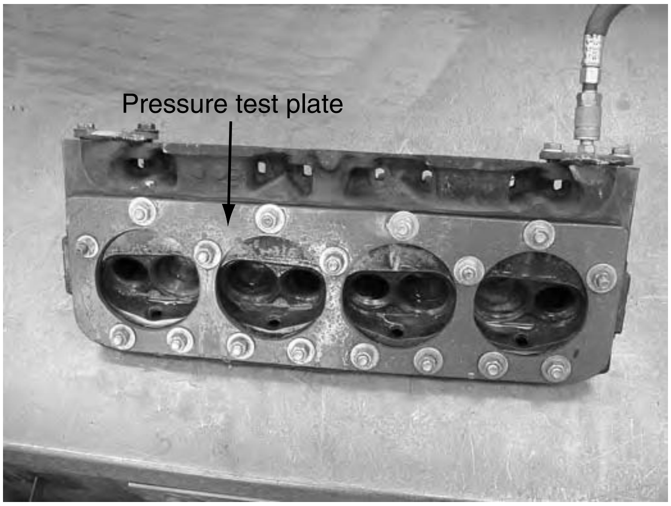


FIGURE 7.28 A custom-fitted pressure test plate installed on a cylinder head. *(Courtesy of Tim Gilles)*

head and/or cam bolt torque as well as heated water before they reveal a leak.

If air is used, soapy water is sprayed over the head surface, or the head is submerged in water to check for air bubbles.

A very small percentage of aluminum heads have porosity problems from the casting process and are vacuum-impregnated with resin to seal them during manufacturing. This process is also done in castings of brake master cylinders, power steering pumps, and automatic transmissions. Excessive temperatures in heat cleaning can cause leaks in vacuum-impregnated heads, which can be found during pressure testing.

CRACK REPAIR

Cracks are sometimes repairable, but the repair is only practical if the cost of a bare head is more than twice the cost of the crack repair. If there is any question whatsoever as to the effectiveness of a crack repair, it is not worth taking a chance. A new or used head should be obtained. Also, factory aluminum heads are heat treated. The heat treatment is lost during welding.

Tapered Plugs

Cracks in iron heads can be repaired with tapered, threaded plugs (**Figure 7.29**). This process is known in the industry as **pinning a crack** or **stitching a crack**. The plugs are usually made of iron, but sometimes brass plugs are used.

FIGURE 7.29 Threaded plugs for crack repair.

NOTE

The pin cools better when it extends into the water jacket. If it does not go into the water jacket and it overheats, it opens up the crack.

NOTE

Both ends of the crack must be drilled to prevent the crack from spreading any further (**Figure 7.30**).

- After drilling, recheck with a crack detector to be sure that the ends of the crack have been found. If both ends of the crack cannot be seen, scrap the head.
- Drill holes along the crack.

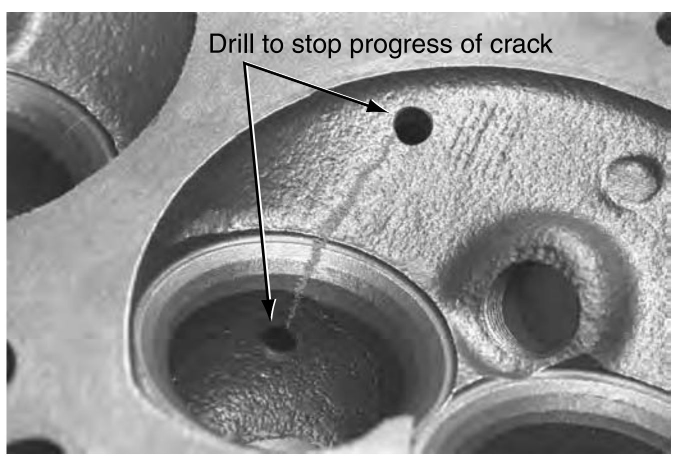


FIGURE 7.30 Pinning a crack. Drill both ends of the crack.

- Ream the holes with a tapered reamer and then tap them with a tapered tap (**Figure 7.31**).
- Dip the plugs in a ceramic sealer before installing them.
- Install and cut one plug, and then drill the overlapping hole for the next one. Each plug overlaps about one-third of the next plug all along the crack. Start at the lowest point and work your way up the crack.
- Install the plugs at different angles so that they will interlock above and below the surface. For illustration purposes, the plugs in **Figure 7.32** were *not* cut off as each one was installed.
- Cut the plugs with a jab saw to about one-quarter of their diameter (**Figure 7.33**). Use a hammer to break them off (**Figure 7.34**).
- Then peen the plugs with an air chisel.
- Last, grind and finish the surface (**Figure 7.35**).

SHOP TIP

To help close the crack, peen outward toward the casting when peening the plugs; peen inward toward the plugs when peening the casting.

FIGURE 7.31 A tapered plug is installed after drilling, reaming the hole with a tapered reamer, and then tapping the hole. *(Courtesy of Tim Gilles)*

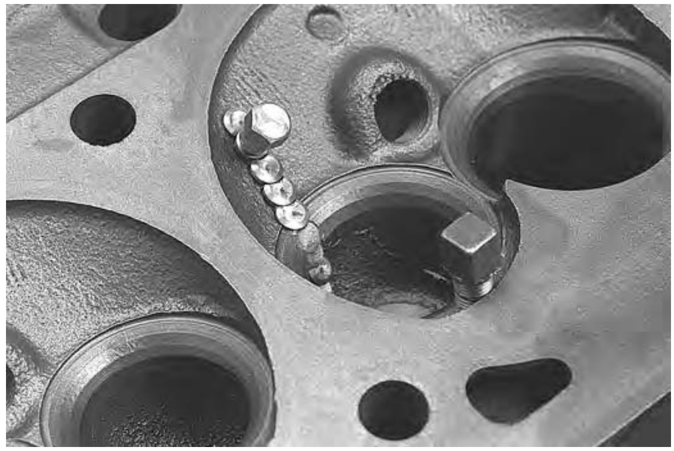


FIGURE 7.32 Install the pins one at a time and then cut them off.

FIGURE 7.33 Cut the pins to about one-fourth of their depth using a jab saw. *(Courtesy of Tim Gilles)*

FIGURE 7.34 After cutting slots in the pins, they break easily. *(Courtesy of Tim Gilles)*

FIGURE 7.35 Grind and clean the chamber. Install an insert seat.

Cracks between the seats are difficult to repair. Manufacturers often state that these kinds of cracks are acceptable, provided they do not leak coolant.

Welding a Crack

Welding is the usual method for repairing cracked aluminum heads (**Figure 7.36**). The aluminum is preheated and then welded under an inert gas shield, known in the industry as **heli-arc welding** or tungsten inert gas **(TIG) welding**.

Welding iron heads is less common; it is a very specialized job. An iron head must first be heated in an oven to about 700°F (371°C), or the head will crack as it is welded. Nickel rod is used to weld iron heads. Specialty shops usually weld iron heads using an inert gas welder. Powdered metal spray welding is another form of specialized cast welding used to repair cast iron heads.

FIGURE 7.36 This aluminum head is being repaired by TIG welding.

NOTE

Some heads and blocks have threaded core plugs that close off holes to water jackets. These plugs sometimes corrode, becoming very thin before finally causing cooling system leaks into the oil. Strike the middle of these plugs with a hammer and a center punch to see whether they are still in good condition.

VALVE GUIDE INSPECTION

Worn valve guides can cause oil consumption. A badly worn valve guide can also cause excessive valve seat wear so look for unusual seat wear during head disassembly (**Figure 7.37**).

The guide wears in a "bellmouth" shape due to fore and aft pressure (called *scrub arc*) exerted by the rocker arm (**Figure 7.38**).

Wear occurs at the bottom of the guide due to heat and lack of lubrication. Wear also occurs at the top of the guide, probably because of dirt. If the valve is worn in the area that corresponds to the top of the guide (**Figure 7.39**), the wear will be visible to the eye. Pay careful attention to the guides that are mated to these valves.

FIGURE 7.37 This exhaust seat has been severely pounded due to a worn valve guide.

FIGURE 7.38 Valve guide wear. *(Courtesy of Tim Gilles)*

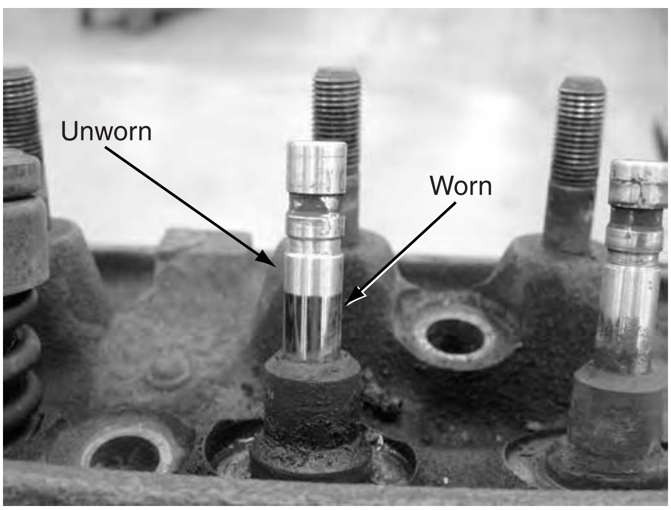


FIGURE 7.39 A valve stem worn at the top. *(Courtesy of Tim Gilles)*

NOTE

When a valve seat is remachined, it is aligned to the valve guide; a worn valve guide will not provide an accurate pilot area.

Remove Valve Guide Seals

Remove the valve guide seals and check valve stem-to-guide clearance. Many engines have positive valve guide seals (covered later in this chapter) that fit the top of the guide snugly. On OHC engines, they are sometimes difficult to remove without a special tool like the one shown in **Figure 7.40**.

Measure Valve Guide Wear

Be sure to clean the guide with a nylon bristle brush before measuring it (**Figure 7.41**). A metal brush will remove carbon, but it can also scratch the valve guide. If there is carbon buildup in the valve guide, it is probably worn excessively.

Following are different ways of measuring valve stem-to-guide clearance:

- **Ball gauge and outside micrometer** (see Figure 6.30). Measure the guide at the bottom (combustion chamber side) and the top (rocker arm side).

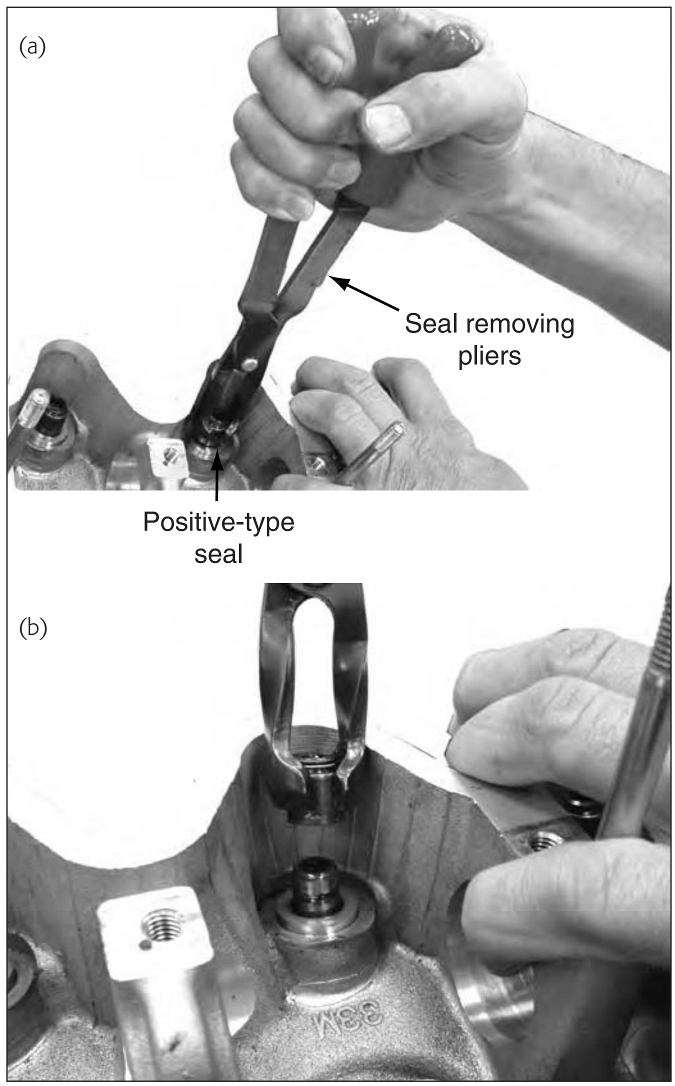


FIGURE 7.40 Removing a positive valve seal using special pliers. *(Courtesy of Tim Gilles)*

FIGURE 7.41 Clean the valve guides before measuring them for wear. *(Courtesy of Tim Gilles)*

- **Dial indicator** (**Figure 7.42a**). Hold the valve in its normal open position. Use a piece of rubber hose (**Figure 7.42b**) or an old cut-off valve guide to position the valve correctly, or simply match up the end of the guide rub area with the top of the guide during the measurement (see Figure 7.39).
- Rock the valve back and forth in the direction of rocker arm movement. Actual clearance is half that shown on the indicator dial.

Maximum allowable wear is limited to 0.005" or less. Typical specifications are 0.001"–0.003" for intake valves and 0.002"–0.004" for exhaust valves. An experienced machinist will learn to feel for guide wear without an indicator and then decide whether or not to fix it. Some machinists consistently repair or replace all guides during a valve job.

Valve guides can be measured with a split ball gauge or a precision gauge like the one shown in **Figure 7.43**. The gauge is set to zero with a special gauge that uses two valves for comparison (**Figure 7.43a**). When the tool is installed in the guide, actual valve-to-guide clearance registers on the gauge (**Figure 7.43b**).

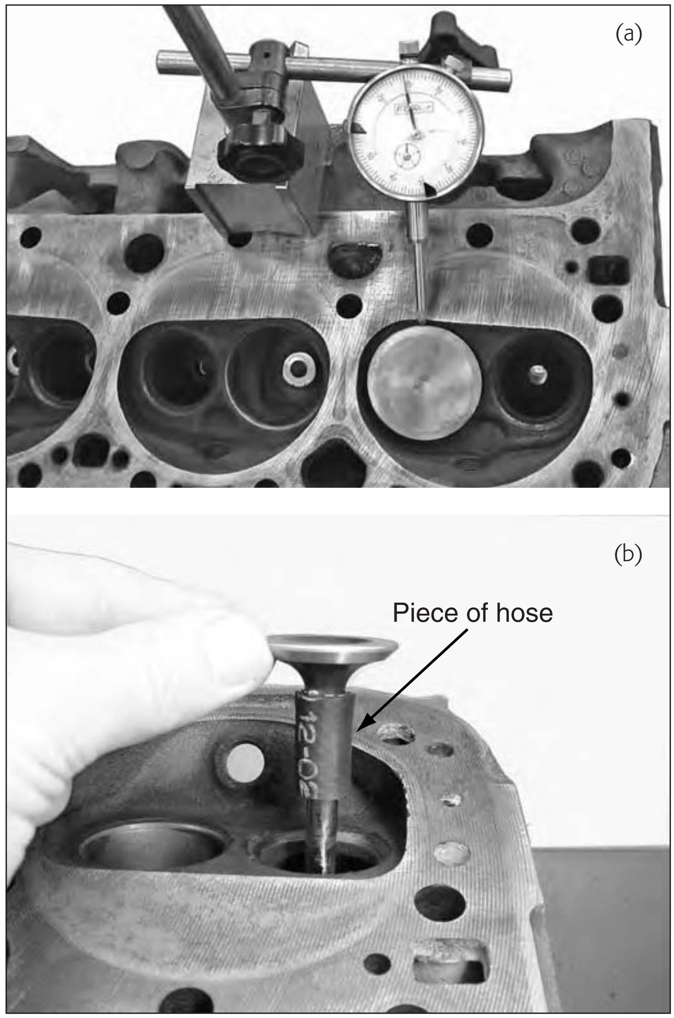


FIGURE 7.42 (a) Measuring guide wear with a dial indicator. (b) Hold the valve in its normal open position during measurement. *(Courtesy of Tim Gilles)*

NOTES

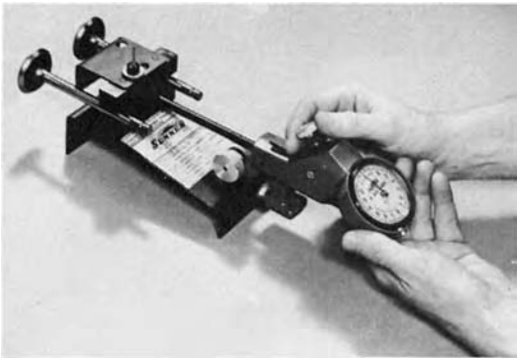
- Worn guides can also cause crankcase pressure.
- When a severely worn exhaust guide is found, the corresponding valve *spring* should be carefully inspected. Hot exhaust gas can travel up the guide and heat the spring, causing it to lose its tension permanently. It will be shorter than the other springs.
- Excessive wear is often found on the exhaust guides of cylinders located next to an EGR valve that needs service.

VALVE GUIDE REPAIR

There are a number of ways to repair valve guides, some better than others. Different guides include **integral valve guides** (part of the head) and *replaceable inserts* (**Figure 7.44**). With a replaceable guide, a superior material can be used.

Integral guides are used with iron heads because they are less expensive to manufacture and they provide better heat transfer than replaceable guides.

(a)



(b)

FIGURE 7.43 A precision guide measuring gauge. (a) Setting the gauge to the valve size. (b) Measuring stem-to-guide clearance. *(Courtesy of Sunnen Products Company)*

To prevent valves from seizing in the guide, all methods of guide repair require honing or reaming for correct stem-to-guide clearance (**Figure 7.45**).

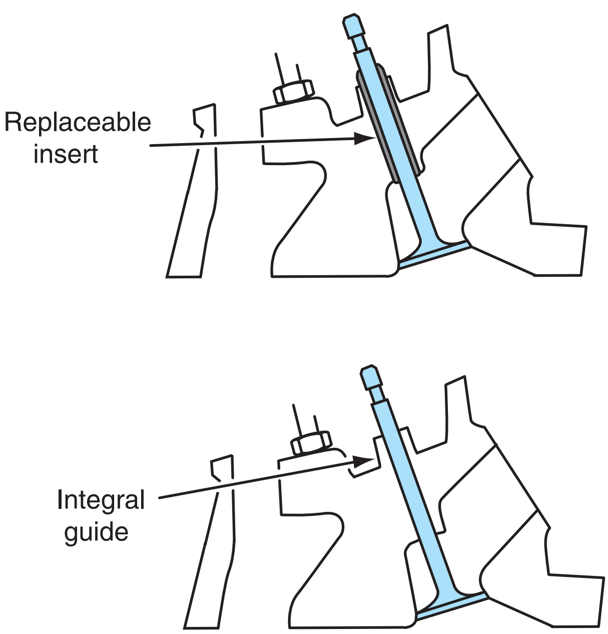


FIGURE 7.44 Valve guides: replaceable insert and integral.

FIGURE 7.45 A scuffed valve stem results when the valve stem seizes in the guide. *(Courtesy of Tim Gilles)*

SHOP TIP

The AERA recommends putting a 1⁄32" chamfer at the combustion chamber end of the inside diameter of a valve guide (**Figure 7.46**). A valve that is too tight in the valve guide will occasionally stick, resulting in a rough idle. The valve will not seat completely, the long-term result being that the valve burns because heat is not carried between the valve face and water jacket that surrounds the valve seat. **Figure 7.47** shows some valves that were tight in their valve guides. Notice the dark area at the bottom of the guide rub area. This area should be shiny all the way around the stem.

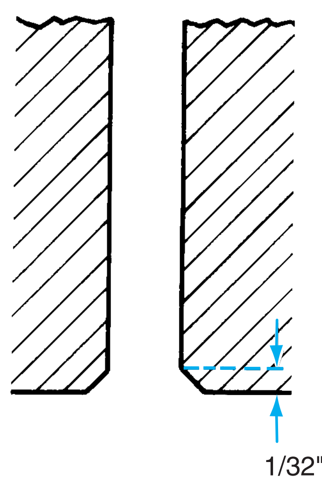


FIGURE 7.46 Chamfer the combustion chamber end of the valve guide.

FIGURE 7.47 Valves that are too tight in the bottom (hottest area) of their guides can stick instead of closing properly. This results in poor valve seating and, ultimately, a burned valve. *(Courtesy of Tim Gilles)*

SHOP TIP

To prevent valve sticking, it is better to keep to the loose side of the tolerance.

Valve Guide Knurling

Knurling is an inexpensive way of bringing valve guides back to original clearances (**Figure 7.48**). Knurling has fallen in popularity in recent years as other inexpensive methods have emerged. Some consider it to be only a temporary repair.

Knurling is a metal displacement process, not a cutting process. As metal is forced down by the teeth of the knurling tool, the area of surrounding metal is forced up. This is comparable to making a dimple on a piece of metal using a center punch, resulting in a raised area surrounding the dimple.

After a valve guide is knurled, its inside diameter is smaller than the valve stem. The correct clearance is restored when the inside diameter (I.D.) of the guide is reamed to fit. Knurling is not successful if the guide is worn more than 0.007" or if the guide has been knurled before. Although the finished I.D. provides less surface area for wear, it provides additional area to hold lubricants.

Knurling a bronze valve guide often results in a broken knurler. Some machinists report success knurling bronze using 90W gear lubricant.

- Clean the guide first with a metal guide cleaner to remove any carbon because carbon will wear out a knurling arbor.
- A speed reducer driven by a drill motor pushes the knurling arbor through the guide, forcing it to conform to the shape of the arbor.
- Check the guide before reaming it to be sure it is too small to allow the valve to fit. Try to fit a valve partway into each end of the guide after knurling. Be sure that the valve has had its stem tip chamfered on the valve grinder prior to this check. If the valve fits in partway into the guide, the guide is too worn for knurling to be effective (**Figure 7.49**).

If the knurl was effective, ream the guide to fit with a self-piloting reamer (**Figure 7.50**). Use lubrication when knurling cast iron guides but *not* when reaming the guide to size.

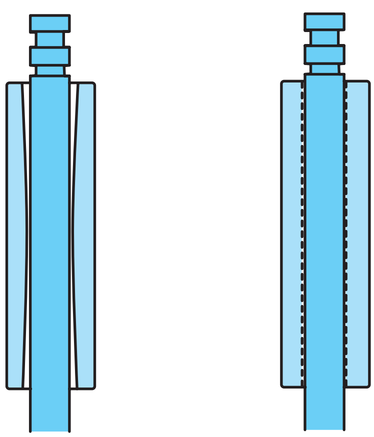


FIGURE 7.48 A valve guide before and after the knurling process.

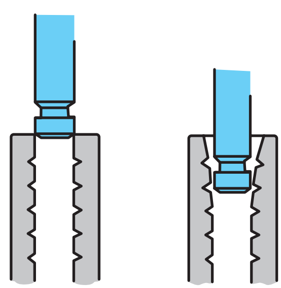


FIGURE 7.49 The guide on the right is worn too far for the knurling process to be effective.

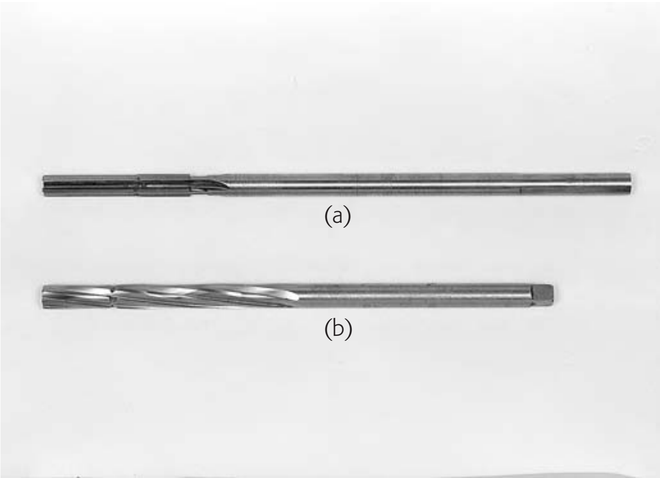


FIGURE 7.50 Guide reamers. (a) This reamer is used to enlarge a guide for an oversized valve stem; it has an aligning pilot section at the bottom. (b)This reamer is used after knurling; its bottom cutting edges are tapered.

REAMING VALVE GUIDES

Valve guides are reamed without lubricant. If lubricant is used, the flutes on the reamer plug up with iron dust, resulting in an oversized guide bore.

- Most reamers are designed to be turned clockwise only. Turning a reamer backwards will dull its cutting teeth.
- Do not stop reaming while in the guide. Go all the way through and remove the reamer from the bottom. Do not reverse the reamer to bring it out of the guide.
- Carefully clean the guide after resizing it. A nylon guide brush or an air blowgun should be used to thoroughly clean the grooves in the guide.

Reamers should be stored individually so they do not become damaged. Dull reamers can be resharpened by a specialty machine shop. The cutting edge of a reamer is at its front, just like a drill bit, so it does not become smaller with sharpening. The flutes on a reamer are tapered from 0.001" to 0.002" (larger at the bottom). Otherwise, the reamer would get stuck as it advanced through the guide.

Replaceable Guides

A replacement guide repair process is used when a completely new guide surface is desired, or when a guide becomes too worn to be repaired by knurling (0.005" to 0.007" wear),

Reaming Bronze Valve Guides. Phosphor bronze, a premium material for valve guides, is said to last up to five times as long as iron. Unlike cast iron, which is porous, bronze guides have self-lubricating qualities. Bronze is not easily machined and is combined with aluminum silicone for manufacturing purposes.

Valves can run in phosphor bronze guides with very little clearance. Although some machinists claim that as little as 0.0005" clearance is necessary, follow manufacturers' recommendations for clearance.

NOTE

It is better to err on the side of too much clearance than too little.

- Reamers used for bronze have reverse helix flutes so that chips will crawl up the guide (similar to the cutting action of a drill bit).
- Lubricant is very important. Use a bronze cutting lubricant or SAE 90 gear oil.
- Because of the heat generated when machining bronze, the reamer should be cooled in lubricant after each guide is reamed. If two reamers are available, one can be cooling while the other is being used.

NOTE

Dull bronze reamers will usually work satisfactorily on cast iron, but once a reamer has been used on iron, it will no longer work on bronze.

Reaming Guides Oversize. When disassembling heads, be sure to keep valves in order in case some of them have oversized valve stems, which are sometimes available from different manufacturers. The old guides are reamed to fit the oversized stems. General Motors uses oversizes of 0.003", 0.005", 0.006", 0.010", and 0.013". Recently, a 0.015" oversized "rebuilders" valve has become more popular, with a 0.030" larger head diameter to help maintain valve and spring height.

Reamers are designed to provide a finished fit but not to significantly enlarge a hole (less than 5%). A good rule of thumb for reaming is to cut a

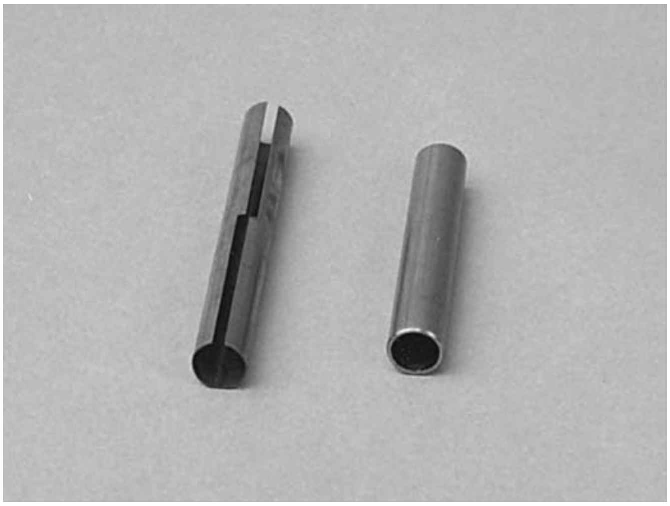


FIGURE 7.51 A thinwall bronze guide liner (left) and a solid guide liner (right).

maximum of 0.005" in one pass. For simplicity, a rebuilder might keep an inventory of 0.005 oversized stems for a particular engine. Then only one size of reamer is required to service all heads.

Thinwall Guide Liners. Thin bronze valve guides are available in two styles, solid and split (**Figure 7.51**). The split style is called a *thinwall* guide liner. The split in the liner helps prevent misalignment during installation. The offset in the split prevents oil from running down into the cylinder.

A newer style thinwall guide, called a Bronze Bullet™ liner, is produced with a spiral on its inside diameter.

Thinwall guide liners are available in 0.030" and 0.060" oversizes. The 0.030" is more popular because there is less likelihood of cracking the original valve guide during installation. Because of the smaller amount of material removed from the guide, the guide-to-seat accuracy is more closely maintained than with replaceable guides (covered later).

A 0.030" guide liner can be used on a guide that has been previously knurled or on guides worn up to 0.015" (wear can be all on one side).

A universal length liner is long enough to use in most applications and is cut to length after installation in the guide. Guide liners also come in different lengths. High production shops buy liners of specific lengths for each head they work on.

The photo sequence shown in **Figure 7.52** describes the thinwall process.

- The guide is bored 0.030" oversize (**Figure 7.52a**).
- The guide bore is cleaned (**Figure 7.52b**).
- An insert is lubricated and driven into the hole with a 0.002" to 0.003" pressed fit (**Figure 7.52c–e**).
- The guide is trimmed to length (**Figure 7.52f**).
- The guide liner must be *burnished* to seat it against the guide bore. This eliminates air pockets that would prevent proper heat transfer. The manufacturer recommends this process, especially if a valve is to be run with very little clearance. Burnishing can be accomplished in two ways. The earlier style thinwall liners can be spiraled on their inside diameter using a burnishing tool and a speed reducer (**Figure 7.52g**). Most speed reducers provide about 5:1 reduction and when used with a drill motor produce a cutting speed of from 150 to 200 rpm.
- The inside of the guide liner (which is 0.003" smaller than stock) is finished to its final size with a reamer (**Figure 7.52h**) or a ball broach.

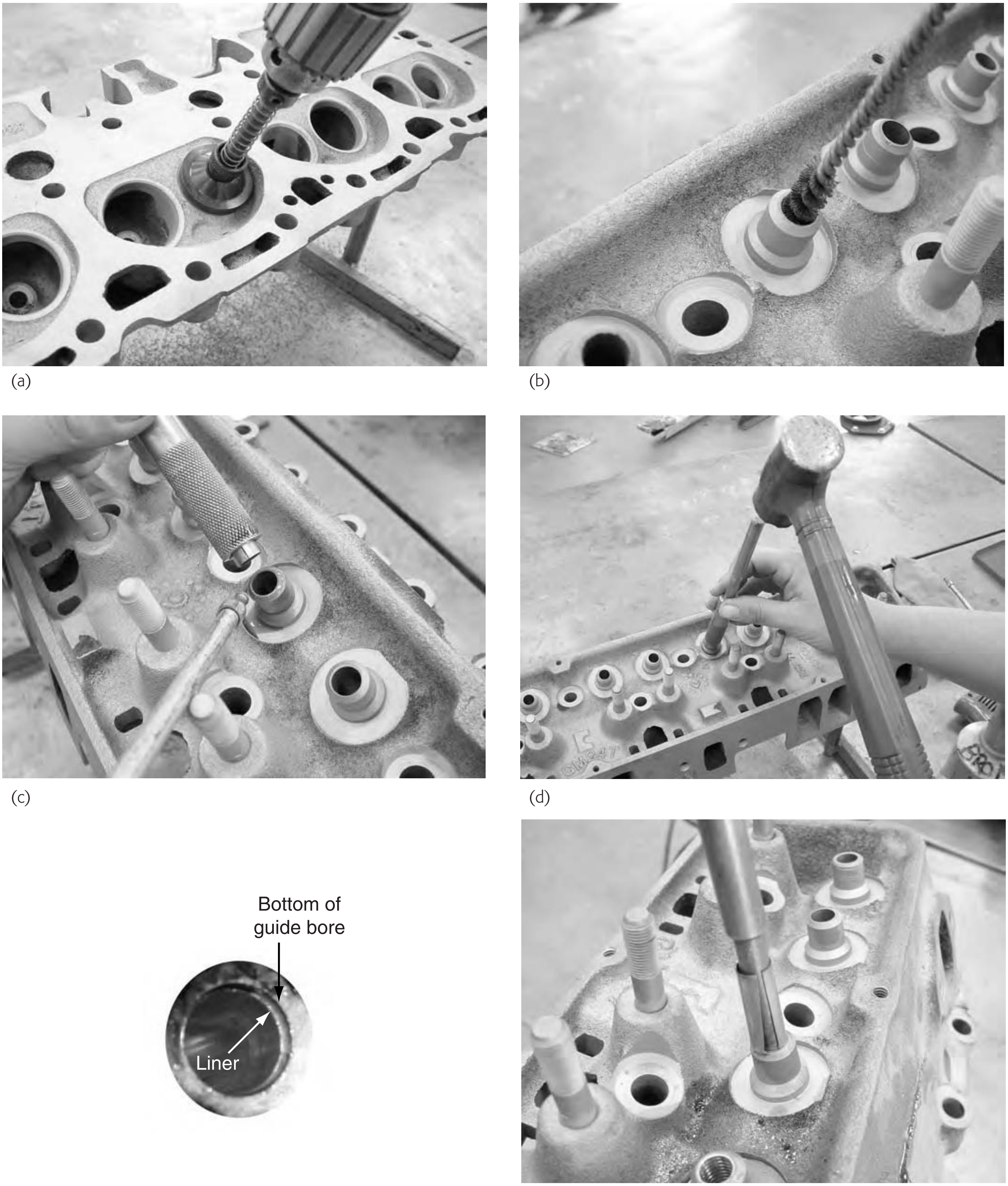
NOTE

Be sure to use lots of bronze lubricant (**Figure 7.52i**). Bronze is especially hard on cutting tools.

A ball broach (**Figure 7.52j**) is used with an air chisel. This process is faster than reaming, because it burnishes the liner to the guide at the same time it finishes the inside diameter to size. The broach, which is really a burnishing tool, extrudes the guide, pushing the metal through it. This results in a longer valve guide. Install the liner only to within 1⁄32 of the bottom of the guide so that the extra metal need not be trimmed off. During the broaching process, the guide will grow to fill this remaining 1⁄32.

Because of the extrusion process, a ball broach of 0.001" to 0.002" larger than the desired finished size is usually necessary. Start with a smaller size and work up 0.001" at a time until the desired fit is obtained. An advantage to a ball broach is that it does not become dull like a reamer does. As ball broaches become smaller, they can be relabeled with an engraver and used with smaller size valve stems.

Many shops use a hard carbide ball bearing called a roller burnisher, which is another popular tool that works the same way as a ball broach. When the ball is driven through the guide, it seats the



(a) (b) (c) (d) (e) (f)

FIGURE 7.52 Installing a thinwall guide liner. (a) Bore out the old guide. (b) Clean the guide. (c) Install the thinwall in the holder and lubricate the guide bore. (d) Use a brass hammer to pound the thinwall into the guide bore. (e) Stop pounding when the bottom of the liner is about $\frac{1}{32}''$ from the bottom of the guide bore. (f) Trim the top of the guide liner to length. *(All photos courtesy of Tim Gilles)*


(g)


(h)


(i)


(j)

FIGURE 7.52 (continued) (g) The spiral appearance of a guide liner. (h) Ream or broach the inside of the liner to finished size. (i) Use plenty of the correct cutting lubricant when reaming bronze. (j) A ball broach. (*All photographs courtesy of Tim Gilles*)

guide to the guide bore and finishes the guide I.D. to size. Because the ball rolls, it wears evenly, remaining true to size.

To cut the original bore oversize, a carbide cutter is usually used in high production shops. A special guide fixture used to align the cutter to the valve seat ensures a more exact hole. When a ball broach is used, this is especially important for providing good heat transfer between the guide bore and the bronze insert. If the inside of the guide is spiraled (a slower process), the alignment fixture is not as important.

Large rebuilders can grind all their valve stems undersize with a special machine, and then use guide liners that have been finished undersize to fit the stems. Shops that cannot afford the machine can send their stems in to be reground. This can be especially practical when dealing with the very expensive sodium-filled valves.

Bronzewall

Bronzewall uses a bronze piece similar to a long helicoil (**Figure 7.53**). It is turned into the guide after the guide has been threaded with a special power tap. It is especially important to clean the threads in the guide before installing the insert.

FIGURE 7.53 The coil is installed on a special tool and turned into the threaded guide.

The top of the coiled insert is clamped to the top of the guide with a special clamp to prevent it from threading out of the guide as it is reamed to size. Then the coil is seated tightly into the guide by driving a special tool through the guide.

The job is finished by reaming the insert with a reverse direction reamer and special bronze cutting oil and trimming the top of the insert. If a worn bronzewall guide is found, it can be removed and a new one installed and reamed.

Replaceable Insert Valve Guides

The most common valve guide repair done in the engine rebuilding industry is the replaceable insert guide. Insert guides, sometimes called thick-wall, are either bronze or iron and come in a variety of shapes. The inside surface can be spiral-grooved or smooth, and some come with a bronzewall-type insert already installed (**Figure 7.54**).

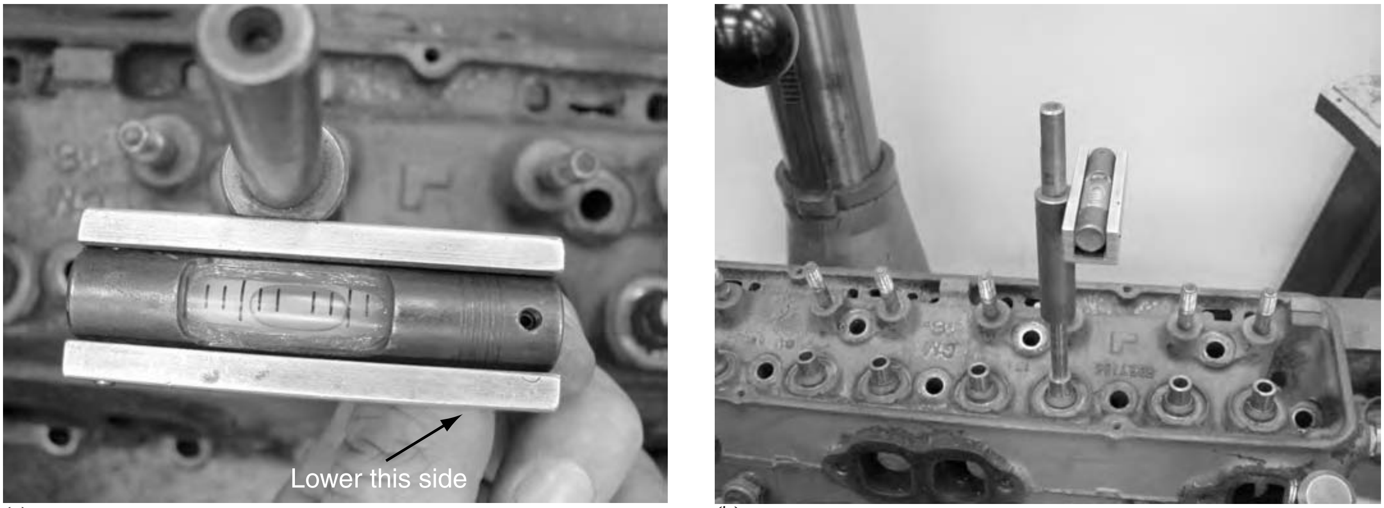
FIGURE 7.54 One type of replaceable valve guide.

Guide inserts are most accurately installed with a milling machine or a guide and seat machine (**Figure 7.55**). There are also portable machines on the market for this purpose. All of the machines use the same basic procedure.

First, an accurate setup is required. If the guide is to be bored, the hole must be aligned to the existing guide or to the valve seat. When the guide and seat machine was installed in the shop, its table was leveled by the installer. When the cylinder head is fixed to the machine's mounting surface, its side-to-side level will remain constant. This becomes the reference point for completion of the leveling procedure. Once the head is secured to the machine, an adjustable level is positioned on a valve guide pilot and adjusted until its bubble is centered in its vial (**Figure 7.56a**). The horizontal surface of the head must now be adjusted to be level, 90° to the table's horizontal surface (**Figure 7.56b**).

The cutting tool that enlarges the existing valve guide to fit the replacement insert has a small pilot

FIGURE 7.55 A valve guide and seat machine.



(a) (b)

FIGURE 7.56 Insert guide installation. (a) Adjust the level horizontally (to correspond to the work surface). (b) Adjust the head until the bubble is centered. *(Courtesy of Tim Gilles)*

area at its end for alignment in the guide (**Figure 7.57**). Often, the amount of required metal removal is too much for one pass of the cutter. A second oversized reamer is used to finish the guide to the correct interference size (**Figure 7.58**). There are also combination core drill and finish reamers that can be used to finish the guide in one pass.

Guides can be pressed or driven in with an air chisel or hammer (**Figure 7.59a**). *Be sure to wear eye protection when working with an air chisel.* Valve guides are either precut or the universal type, which must be cut to length (**Figure 7.59b**). Cutting the top of the guide to length is done with a special tool called a spot facer (**Figure 7.59c**). Measure the height of the guide following machining (**Figure 7.59d**). Engineers determine valve guide length requirements. One engineering formula states that the length of the valve guide should be seven times that of the valve stem diameter.

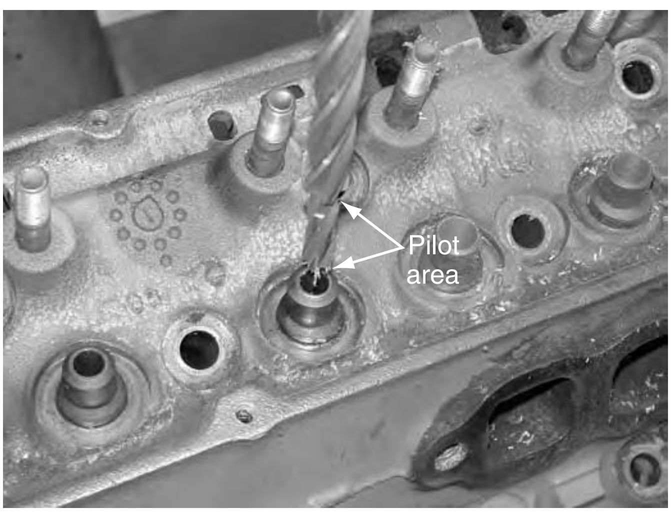


FIGURE 7.57 Ream the worn guide to accept a new insert guide. Notice the pilot area at the bottom of the reamer. *(Courtesy of Tim Gilles)*

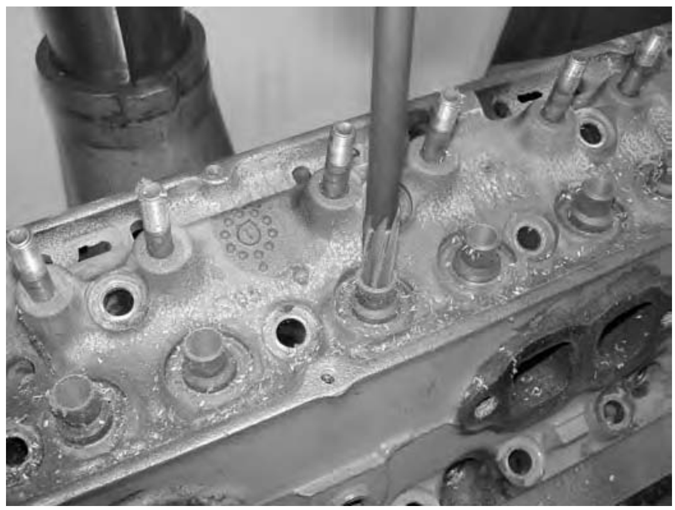


FIGURE 7.58 Finish reaming the guide to the correct interference fit for the new insert. *(Courtesy of Tim Gilles)*

After the guide has been cut to length, the I.D. is reamed to the correct size for proper valve clearance (**Figure 7.60**).

When removing guides from aluminum heads, it is advisable to tap a thread into the bottom of the guide and install a screw that the driver can pound

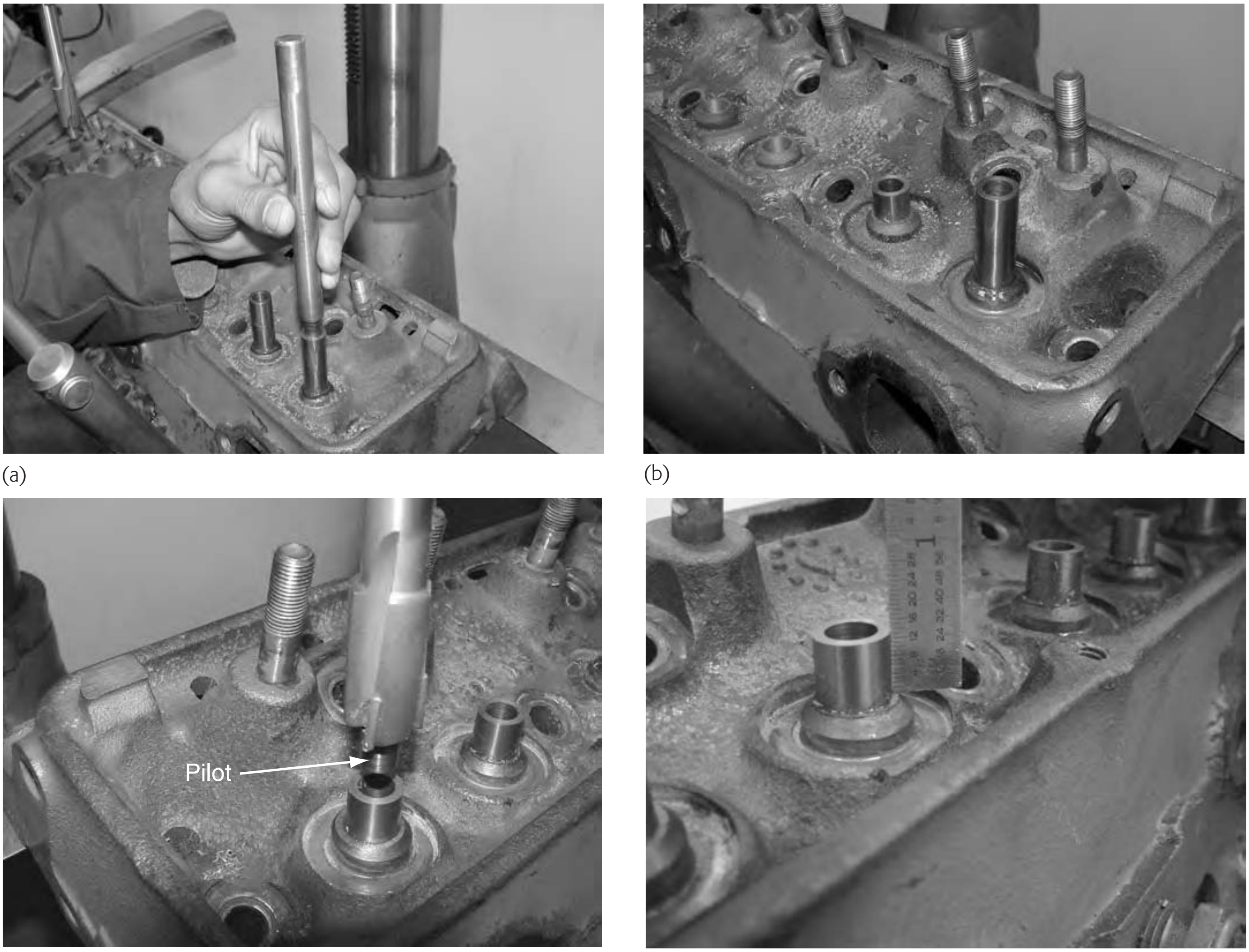


FIGURE 7.59 Installing press-fit guides. (a) Drive the guide into the guide bore until it is flush with the bottom of the valve guide. (b) Some guides are precut, but machine shops often use universal guides that require cutting to length. (c) A piloted carbide cutter is used to cut the guide to length. (d) Measure the height of the guide. *(Courtesy of Tim Gilles)*

against (**Figure 7.61**). Otherwise, a brass guide can mushroom at the top, making its outside diameter larger; the guide bore will be ruined and the new guide will be loose.

SAFETY NOTE

Be sure to wear eye protection when driving out guides against a bolt. Cast iron guides can fly apart.

Guides should be driven out from the rocker arm side when possible. Carbon builds up around the outside of the guide on its combustion chamber end. If the guide must be driven out from the bottom, the carbon must be removed first.

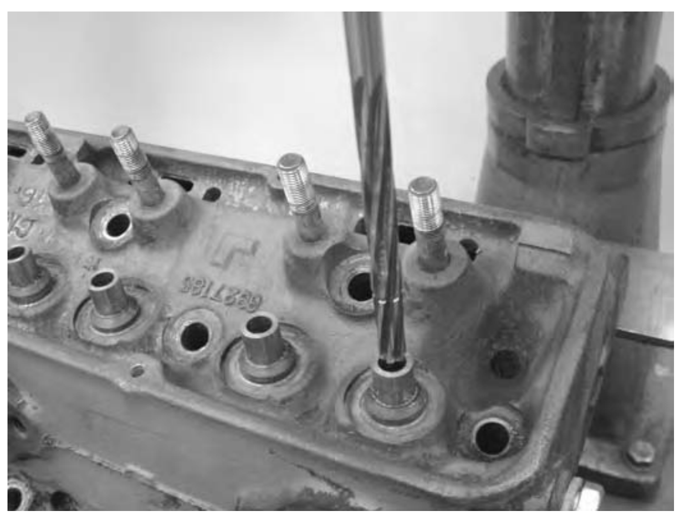


FIGURE 7.60 Finish-ream the guide following installation. *(Courtesy of Tim Gilles)*

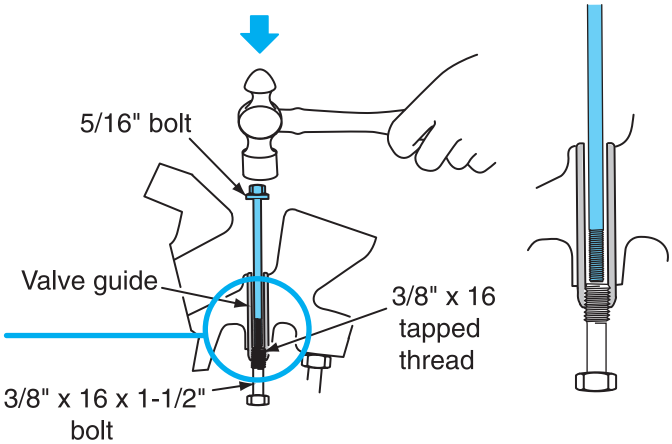


FIGURE 7.61 Removing a guide from an aluminum head.

Some guides are "wet" guides; they are cooled by a water jacket. Scoring the guide bore during guide removal can result in a coolant leak.

Valve guides are interference fit in the head. Heating an aluminum head in an oven to 200°F (93°C) before removing guides can be helpful. A propane barbecue with a thermostat control can also be used.

NOTE

Be careful not to overheat a cylinder head. Aluminum heads are not usually heated to more than 450°F (232°C); aluminum anneals at 460°F (238°C). Valve seats are interference fit also and may fall out as guides are being hammered out.

Guides that are very tight can be partly drilled out to make removal easier. Bore from the combustion chamber side and leave about 0.0015''–0.020'' wall thickness to press. This is especially helpful when removing guides from aluminum heads.

It is important that replaceable guides be installed properly. Aluminum heads should be heated or the guide chilled for easy installation. Install the guide immediately, before temperatures equalize. Guides should hang into the valve port only to a specific depth, so check the old ones before removing them.

NOTE

Lubricating valve guides before pressing them into the head will prevent galling (friction welding). Sometimes guides will break or become stuck if they are not pre-lubed.

Guides are available in oversizes to compensate for looseness in the guide bore. Be sure to ream the I.D. of new insert guides to correct any distortion that might have occurred during installation.

Off-Center Guides

Some engines have removable guides that were bored at the factory *after* they were installed. The holes appear off-center to the eye (**Figure 7.62**). Replacement of these guides often requires valve seat replacement also. Some of these guides are also larger in diameter at the valve spring end and must be driven out in that direction. Instead of replacing these guides, it is a good idea to repair them by using one of the methods covered earlier in this chapter or to use a guide repair process that centers on the guide hole prior to boring the guide oversize.

Some guides have a groove on the outside of the top for holding a positive-type valve stem seal. Knurling, reaming, or tapping for bronzewall installation will weaken or break this type of guide.

Honing Valve Guides

Honing guides is a useful technique, especially when the right size reamer is not available. Guides can be honed to size with the tool shown in **Figure 7.63** mounted on a hand drill. Use honing oil. The hone size is adjustable.

FIGURE 7.62 The I.D. of this insert guide was bored *after* it was installed at the factory. Notice how far off-center the hole is. *(Courtesy of Tim Gilles)*

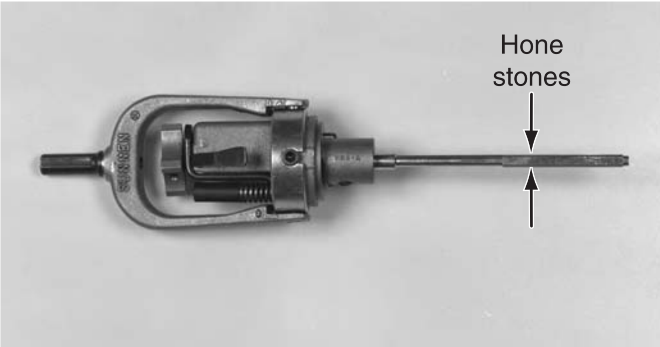


FIGURE 7.63 A valve guide hone.

NOTE

All guide repairs must be finished before refinishing or replacing the seat.

VALVE GUIDES AND SEALS

Faulty valve guides or valve guide seals are often the cause of oil consumption in an engine with low odometer mileage. The valve guide must be in good condition to prevent oil consumption. On many engines, the valve guide is the primary seal, whereas the valve guide seal is secondary. If the valve guide is bad, the engine will burn oil even if new seals are installed.

It was previously thought that oil leakage occurred through intake valve guides only. However, overhead valve (OHV) V8 test engines were run with intake and exhaust seals. When the exhaust seals were removed, oil consumption was found to increase (**Figure 7.64**). A vacuum is created at the bottom of the exhaust valve guide when the exhaust gas passes by. This is known as the "atomizer effect" (**Figure 7.65**).

Oil leaks past a faulty intake seal during the intake stroke. Smoke from intake leakage is often most noticeable during deceleration when there is less fuel and higher engine vacuum. Leakage from an exhaust guide can also cause smoke from the exhaust pipe, although exhaust guide leakage is often invisible because the oil vaporizes in the hot exhaust stream (1000–1600°F [538°C–871°C]).

Valve guide tops are often cut to a slant or taper to deflect oil. Worn guides are more susceptible to oil leakage than unworn guides. Cylinder heads with rocker arms are especially prone to *bellmouth wear*,

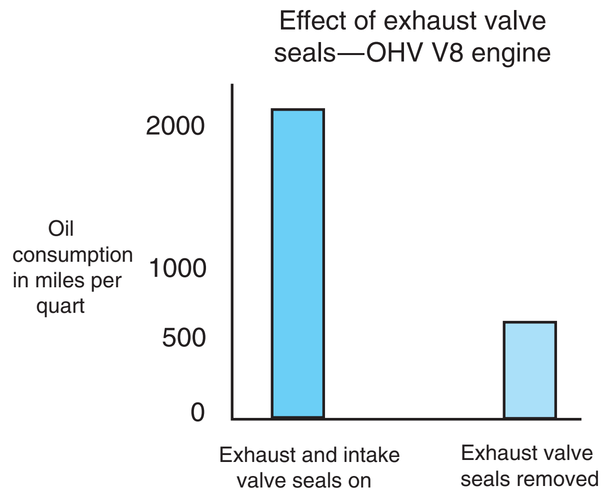


FIGURE 7.64 Oil consumption with and without exhaust valve seals.

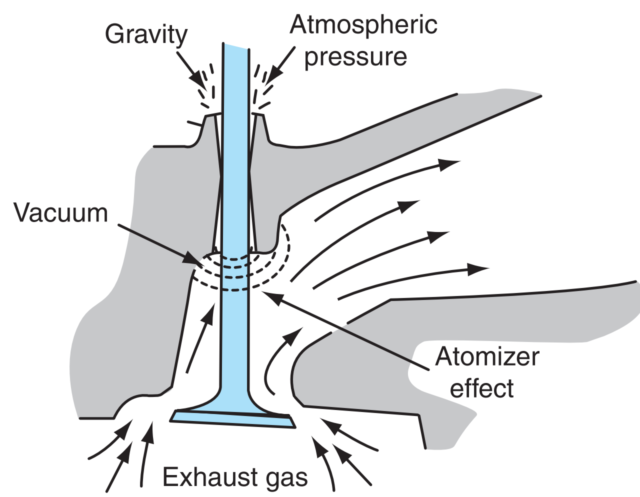


FIGURE 7.65 The "atomizer effect" pulls oil down the exhaust guide.

which acts like a funnel (**Figure 7.66**). Valve guide seals sometimes become brittle with age and begin to leak. Because guide-to-stem clearance is so small, guides will wear more quickly once seals start to leak. Contaminants carried in the oil that leaks into the guide often cause the valve stem to wear excessively. Oil consumption from bad guide seals is often much more severe with worn guides.

Types of Valve Guide Seals

Original equipment valve stem seals are recommended because design engineers have allowed for sufficient valve guide lubrication in their design. Although the best protection against valve guide oil consumption is to maintain correct stem-to-guide clearance, seals are installed as extra insurance.

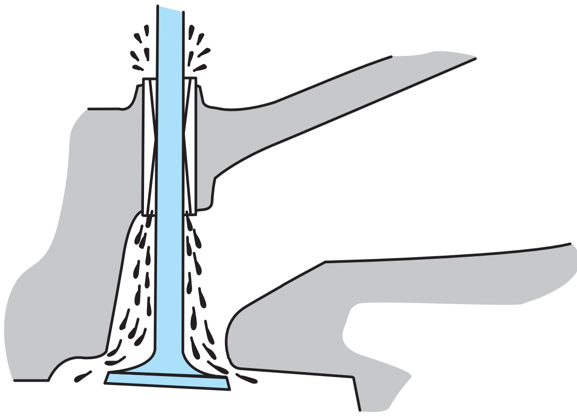


FIGURE 7.66 Bellmouth wear of the guide causes oil consumption.

There are three principal types of valve guide seals (**Figure 7.67**).

FIGURE 7.67 Three types of valve stem seals.

Positive Valve Guide Seals

A positive-type seal (Type III) is attached to the top of the guide. It fits the guide tightly and does not move with the valve like an umbrella seal (**Figure 7.70**). Positive seals were available as an aftermarket improvement on vintage engines and have been supplied as original equipment for overhead cam and higher rpm engines for many years. Today, nearly all engines use positive valve guide seals. Most of them have a coil spring around the outside edge of the seal. Oversized and undersized valve stems can be used with these seals (from 0.005" under to 0.015" over).

For a positive seal to work properly, the I.D. of the valve guide must be concentric with the outside (O.D.).

Positive-type seals are often provided with a special plastic cover to protect the surface from being cut during installation by the grooves in the valve stem (**Figure 7.72**).

SHOP TIP

When installing positive valve stem seals, soaking them in hot water first makes installation easier. Ford recommends soaking its positive seals in boiling water for 20 minutes or in room temperature water for 24 hours. This softens the seals so they will not crack during installation. The warm water procedure works well on installation of other brands of positive seals also.

VINTAGE ENGINES

O-ring and umbrella seal installations were used on older pushrod engines (**Figure 7.68**). Umbrella seals fit the stem snugly and travel up and down with the valve. Most older General Motors engines used a square-cut O-ring seal that fit into an extra groove in the valve stem. This is called a Type I seal. An O-ring seal uses a metal umbrella under the valve retainer (**Figure 7.69**) to prevent oil from running around the retainer and down the valve stem.

Umbrella-type seals were used by other manufacturers and as a universal replacement seal by repair shops. The umbrella seal is called a Type II seal. It is more effective in preventing oil from entering the guide once the guide is worn. Some of the premium umbrella seals have a small coil spring on the outside of the seal to tension the lip against the valve stem.

VINTAGE ENGINES

For a positive seal to work correctly, the I.D. of the valve guide must be concentric with the outside. When the guide was not cut to the proper size and concentricity at the factory, it had to be cut with a special tool before installing a positive-type seal. A relatively inexpensive carbide cutter driven by a drill motor was used to machine the top of the guide (**Figure 7.71**). The guide was machined until the specified height was achieved. There are different sizes of seals available, using a cutter that machines the guides to match the size of the seal.

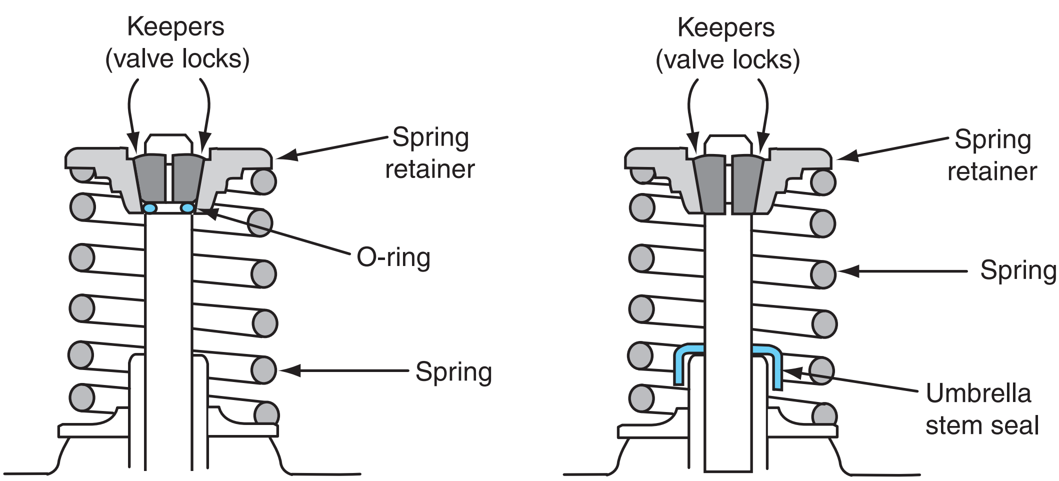


FIGURE 7.68 An O-ring and an umbrella seal.

FIGURE 7.69 On most vintage GM engines, this metal umbrella is used with O-ring type valve guide seals. Oil from the pushrod bathes the rocker arm and flows onto the top of the retainer. *(Courtesy of Tim Gilles)*

NOTE

Be careful not to cock or misalign the seal during installation. It is important that the seal be perpendicular to the valve stem.

Seal Quality

Because seals deteriorate with age and excessive heat, a premium quality seal is desirable. The least expensive seal is effective in temperatures up to 250°F (121°C). The most expensive is good to 440°F (227°C). The different materials all feel and look the same. Typical O-ring seals are made of polyacrylate rubber (ACM). Some manufacturers use nitrile (NBR), which is rated for 250°F (121°C) continuous operation with intermittent operation to 300°F (149°C).

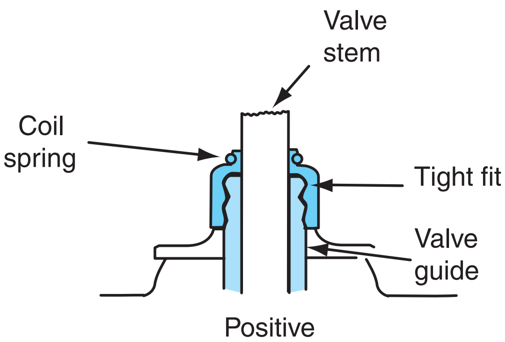


FIGURE 7.70 A positive valve guide seal fits tightly on the valve guide.

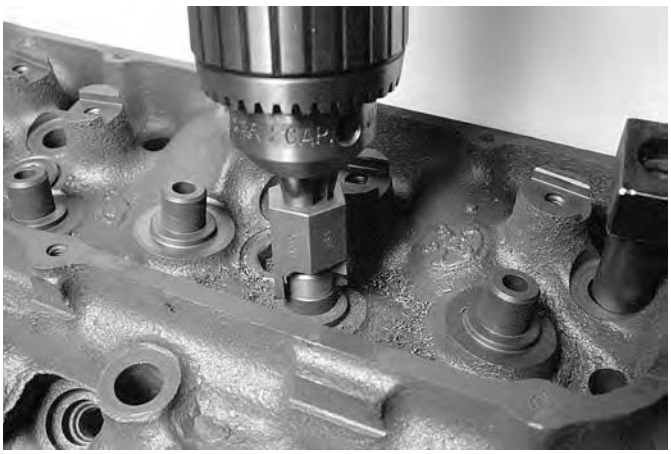


FIGURE 7.71 Positive seal installation on a vintage head. Machining the valve guide to accept a positive seal.

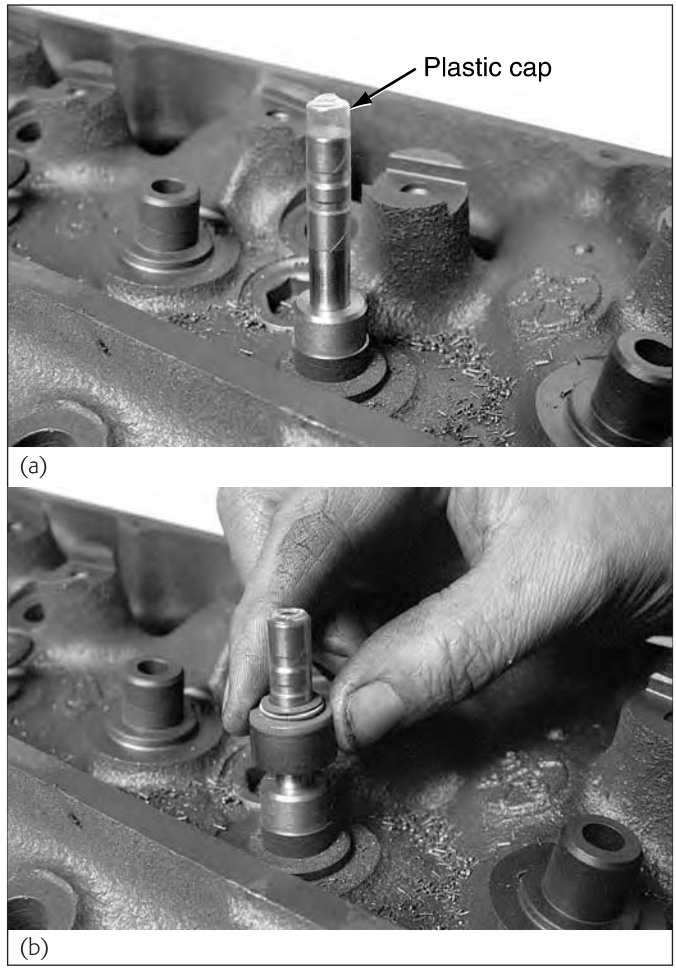


FIGURE 7.72 (a) A plastic cap is installed over the keeper grooves before (b) the seal is installed on the valve stem tip.

Umbrella seals are made of many different materials. They are colored differently for identification but could be made in any color. Enginetech, Inc., a parts manufacturer, uses the following color codes for their umbrella seals:

- Polyacrylate seals are black.
- Nitrile seals are blue or green.
- Silicone seals are red.
- Teflon® (PTFE) seals are white.

Some manufacturers use different materials and shapes for intake and exhaust seals. These may be color coded (**Figure 7.73**). For instance, General Motors uses red for exhaust and blue for intake in these applications. Honda has a white spring on intakes and a black spring on exhausts.

FIGURE 7.73 Valve guide seals are sometimes different colors. Check the instructions with your gasket set to determine which seal goes on which valve. *(Courtesy of Tim Gilles)*

Umbrella seals are usually made of nitrile or silicone. Nitrile seals should be used only on the intake side because they are not rated high enough for exhaust valve heat. Silicone (MVQ) seals are rated for 330°F (166°C) continuous use and 400°F (204°C) intermittent use. They are suitable for intake and exhaust valves.

Positive seals are made of the same materials as umbrella seals and also of Viton® (FPM) or fluoroelastomer. Viton's operating range is 440°F (227°C) continuous and 480°F (249°C) intermittent. Teflon seals used by some manufacturers are good for slightly higher temperatures but are harder, so it is more difficult for them to seal as effectively.

Replacing Valve Springs or Valve Guide Seals (Heads on Engine)

On some engines, valve seals can be checked for brittleness while the heads are on the engine. The seals nearest a heat source like the EGR valve often become brittle before the others. If bad guide seals are found, they can be replaced without removing the cylinder head from the engine (**Figure 7.74**).

- Put compressed air into the cylinder using a hose adapter installed in place of the spark plug.
- Both of the cylinder's rocker arms are removed so this will ensure that both valves are closed when the cylinder is pressurized.
- A special spring compressor is used to compress and remove the valve spring. See Figure 7.15 for other valve spring compressors that can be used with the heads on the car.
- Look out for an excessively worn valve guide; a successful repair may require valve guide replacement.

FIGURE 7.74 This tool is being used to compress the valve spring on a pushrod engine while compressed air is pumped into the spark plug hole to hold the valves closed. *(Courtesy of Tim Gilles)*

When compressed air is not available to hold the valve against its seat, a good trick is to put a piece of rope into the cylinder while the piston is below TDC. Turning the crank by hand will force the rope between the piston and the head of the valve, wedging the valve against its seat. The rope is easily removed when the job is completed.

Bad guide seals will be obvious. They will be brittle and will no longer seal. Be sure to remove all pieces of the guide seal that break off. Broken guide seals are often the cause of oil pump failure (see Chapter 14).

RESURFACING HEADS

Heads that are excessively warped must be surfaced to ensure proper head gasket sealing.

Checking Flatness

Clean the head surface before checking for flatness. Use a straightedge and feeler gauge (**Figure 7.75a**) diagonally, vertically, and horizontally on the head (**Figure 7.75b**). When checking for warp on the ends of a head, be sure to rock the straightedge to the opposite side of the head. If you do not do this, you will only get half of the warp reading. A round straight bar is also available for checking straightness (**Figure 7.76a**). The round bar is more suited for checking the alignment of bearing bores (**Figure 7.76b**).

NOTE

Warp readings on the top and bottom sides of an OHC head are often not equal to one another. When checking the valve cover rail for straightness, the spark plug side of the valve cover rail is often warped more than the other side. Maximum warp on the cam side of the head is 0.002". If the camshaft side of the head is straight, but the combustion chamber side is warped, resurfacing should correct the problem. But if the cam side is warped, the head will need to be straightened. Head straightening is covered later in this chapter.

Why Do Head Gaskets Start to Leak?

Cylinder heads sometimes warp, causing head gaskets to fail. Have you ever wondered why the top surface of a warped head remains relatively flat, whereas the bottom of the head is considerably more distorted?

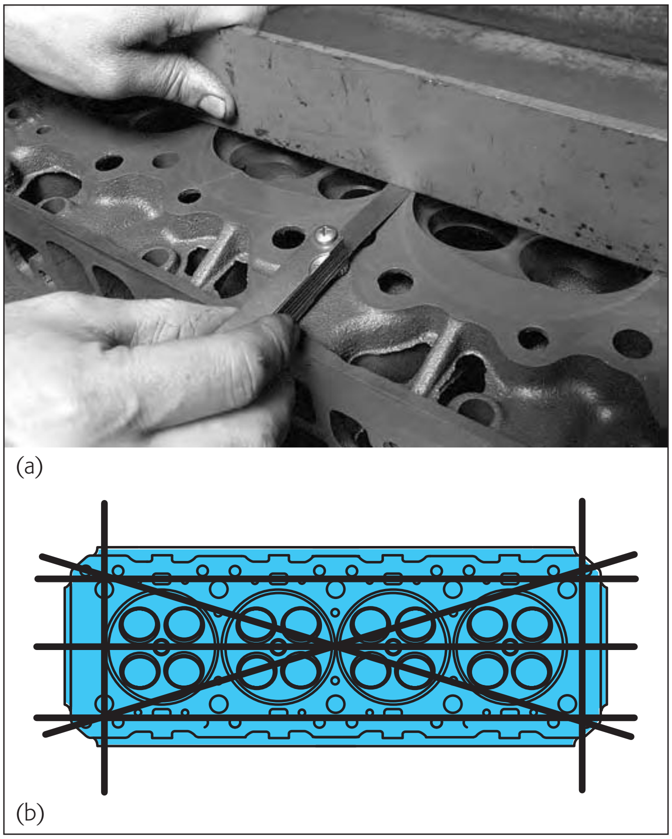


FIGURE 7.75 Check for excessive warpage. (a) Use a feeler gauge and straightedge. (b) Check diagonally, vertically and horizontally.

One theory is that the metal of the cylinder head has been "crushed" at the combustion chambers. During combustion, flash heat in the combustion chamber is great (2500°F [1371°C]). As the head expands, it moves from end to end, sliding against the head gasket as designed. The head bolts stretch, allowing the head to expand vertically. Coolant keeps the head relatively cool, but the *skin* of the combustion chamber is exposed to flash heat, especially during abnormal combustion or engine overheating. The skin expands but it cannot go anywhere, so it is compressed and crushed. When the head cools, the skin area now occupies less space.

Cast Iron Heads Warpage

When checking cast iron heads, as a general rule:

- Heads warped more than 0.006" on in-line sixes, and more than 0.004" on four or eight cylinders, need to be resurfaced.
- Heads should not be warped more than 0.002" in any 6" length or 0.0015" within a 3" diameter.
- Flatness across the width of a head should not vary by more than 0.002".

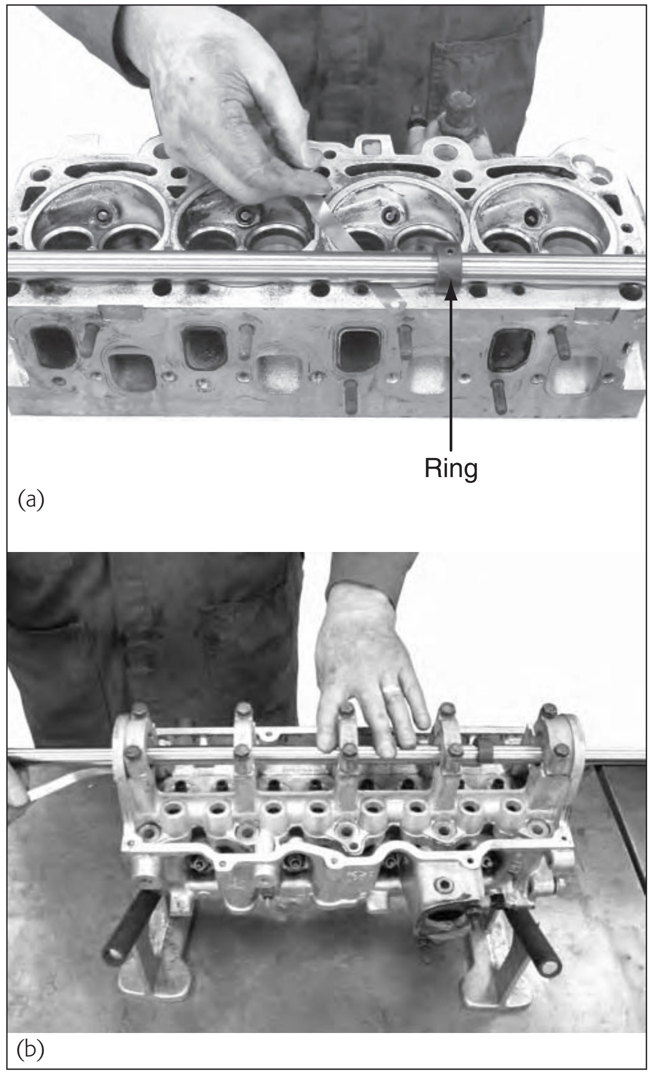


FIGURE 7.76 (a) A round bar for checking flatness. The ring has a machined flat surface to prevent the bar from rolling. (b) Using a round bar to check cam bore misalignment *(Courtesy of Tim Gilles)*

When checking head flatness on a four cylinder, try to fit a 0.004" feeler gauge under the straightedge. If it fits, but a 0.005" does not, then it is okay. Also, aluminum heads with corrosion around water passages must be resurfaced. Some may require welding first if more than 0.010" material removal is anticipated.

> **REMEMBER:**
> **Surface flatness is the sum of the warpage of the head and block combined. Blocks rarely warp, but be sure to check to avoid exceeding recommendations.**

Aluminum Head Warpage

Aluminum heads can have no more than 0.002" of warp in any direction.

Resurfacing by Grinding or Cutting

Resurfacing is accomplished either by "fly cutting" the head on a milling machine or grinding the head on a head grinder. Factory broach marks usually run from end to end on the head. A head may have been surfaced previously. Heads that have been milled or ground in a machine shop will have a circular (**Figure 7.77**) or crosshatch surface pattern.

NOTE

Multilayered steel (MLS) gaskets are used on many newer engines (see Chapter 16). These gaskets require a very *smooth* surface finish. Be sure to follow the manufacturer's recommendations. An AERA bulletin (TB1671) describes this and lists many of the engines that use this type of head gasket.

Head resurfacing can increase compression, so remove as little metal as possible.

- Grinding is slower than cutting because more passes must be made with the grinding wheel.
- Grinding is better than cutting for removing hard spots in the metal.

NOTE

CBN, or cubic boron nitride, is a material used for cutting tools and grinding wheels. It removes material 3 or 4 times faster than an ordinary stone wheel and its life span is 10 times as long.

- When cutting a head surface with a multiple cutter head, the carbide cutters must be within ±0.0005" of each other (one-half of one-thousandth of an inch). If one cutter is adjusted improperly and is higher than the others by only 0.001", it will be doing all the work and a rough cut will be the result.
- If a head was milled or ground, check the head after resurfacing for twist that might have occurred when clamping the head in the surfacer.

FIGURE 7.77 A circular pattern left on the head during machining. This pattern is too rough. Speeding up the cutter rotation and/or slowing down the advance rate will provide a smooth finish.

Many surfacers use water for coolant. Water-soluble oil is added to the water. This keeps rust from accumulating and also acts as a lubricant when surfacing aluminum heads. Kerosene or a spray lube can also be applied to aluminum heads before surfacing.

Aluminum is not all the same and it can machine differently, depending on the manufacturer and country of origin. To do a satisfactory job, carbide cutters must be sharper for aluminum than for cast iron. Overheating can harden aluminum.

After Machining

When a head is resurfaced, some shops stamp the amount of metal removed on a head boss with a number stamp to alert the next machinist who works on it. When measuring head thickness, measure at all four corners if possible. Deburr any sharp edges left on the combustion chamber by machining. Sharp edges can cause preignition. Holes in the head for the head bolts can be deburred with a tapered reamer.

Resurfacing V-Type Heads

Heads used on V-type engines should not have more than 0.024" removed from their surfaces to prevent the intake manifold ports from not aligning correctly with the ports in the head (**Figure 7.78**). Misaligned ports can result in oil consumption due to oil kicked up by the lifters, or air leakage into the intake manifold. Excessive metal removal can also cause hydraulic lifters to bottom out, resulting in interference between the valves and pistons.

Sometimes more metal is removed from the head surface than is desirable. To compensate, some gasket manufacturers make a thicker head gasket or a 0.020" metal shim that is installed under the head gasket (see Figure 16.80). Check for availability

VINTAGE ENGINES

When nearly all heads were cast iron, *belt sanders* were popular. They were fast but had many disadvantages and some people did not like the cosmetic appearance of a belt sanded finish. The biggest drawback to belt sanding is that unless the belt is extremely fine, it does not leave an unacceptable finish for the MLS gaskets used on most new bimetal engines. Belt sanding also spreads abrasive material around the shop from dust thrown off the end of the belt, and it is difficult to gauge the amount of metal removed from the head. Also, the finished surface is always level to the original surface.

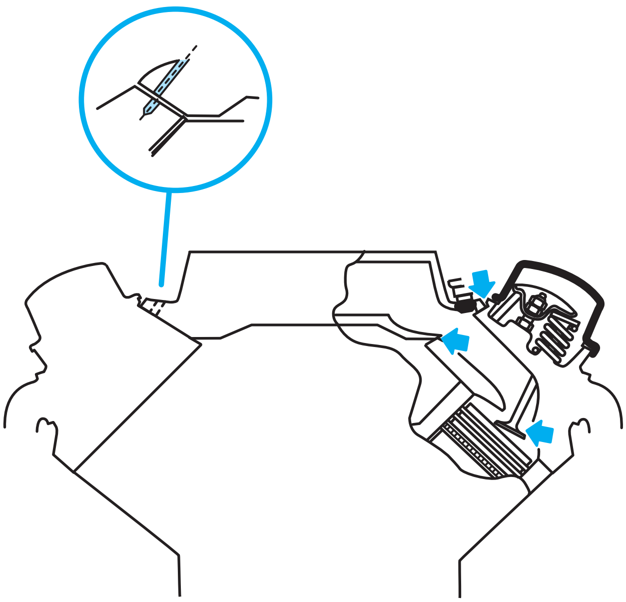
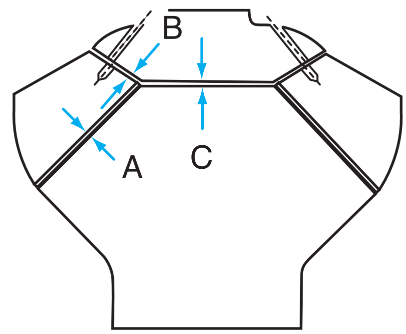


FIGURE 7.78 Results of excessive metal removal on a V-type engine.



HEAD ANGLE IN DEGREES

5° . . . Amount removed at A x 1.1 = Amount to be removed at B
10° . . . Amount removed at A x 1.2 = Amount to be removed at B
15° . . . Amount removed at A x 1.4 = Amount to be removed at B
20° . . . Amount removed at A x 1.7 = Amount to be removed at B
25° . . . Amount removed at A x 2.0 = Amount to be removed at B
30° . . . Amount removed at A x 3.0 = Amount to be removed at B
35° . . . Amount removed at A x 4.0 = Amount to be removed at B
40° . . . Amount removed at A x 8.0 = Amount to be removed at B
Amount removed from surface A x 1.17 (Multiplier for top manifold surface C)

FIGURE 7.79 A formula for intake manifold resurfacing.

before machining. The shim, or a thicker head gasket, can be used to compensate for excessive head surface removal on V-type engine heads, or the intake manifold can be resurfaced using the formula shown in **Figure 7.79**. Shorter pushrods will probably have to be used also. Once a manifold and heads are surfaced in this manner, all the parts are mated. It will not work to just replace one of the pieces without special machining of the new part.

When heads are milled to increase compression for competition engines, they are usually angle ground (considerably more metal is removed from the exhaust side of the heads) so that the ports remain aligned. As a part of the angle grinding process, the inside of the intake port in the head is also machined to match the angle of the port in the intake manifold.

Straightening Cylinder Heads

Aluminum OHC heads are sometimes straightened. Quickly verify that the camshaft turns easily before you check the top surface of the head for flatness. Remember, maximum allowable warpage on the cam side of the head is 0.002".

NOTE

If the camshaft does not turn easily and the machinist only surfaces the bottom side of the head, a broken camshaft can result.

Here is one head straightening method:

- Clamp the head to a heavy plate or an old engine block with shims under the lower portion of the head. Some machinists like to put pressure on the head with a hydraulic press and then clamp it in place.
- Heat the center two-thirds of the back side of the head to about 450°F (232°C) with a propane torch. Use a tempilstick to monitor temperature (see Chapter 4).

NOTE

Be careful not to melt the aluminum. It does not change color as it gets hot. Aluminum melts at 1225°F (663°C).

- Allow the head to cool on a flat surface.
- Check the head after it is cooled to see if the cam turns easily.

Heads can also be straightened using a heating oven (**Figure 7.80**). This method is effective, but more time consuming than the torch method. Some machinists say that metallurgically this is the best way to straighten because the metal is thoroughly heated and then cooled slowly so small stress cracks are prevented.

FIGURE 7.80 A head can be straightened using an oven.

- Shims are positioned under the outside edges of the head. A rule of thumb is to add about 40% to the shim pack from the amount to be straightened. In other words, overstraighten. If the head is warped by 0.010", shim it by 0.014".
- When clamping, exert pressure on head bolt bosses or use a special fixture rather than clamping on the valve cover rail.
- Heat the head for 5 to 6 hours.
- Allow it to cool slowly. It will usually be an hour before the head can be handled.
- If the head is overstraightened, reverse the process.

An added advantage to straightening the head prior to surfacing is that combustion chamber volumes will remain equal. Normally during surfacing of a warped head, the outer cylinders' combustion chambers will end up with reduced volume.

NOTE

Removal of 0.020" from OHC head surfaces results in about 1° of retard in valve timing. These engines have chain tensioners, but they only control slack on one side of the chain (see Chapter 6). Slack on the drive side of the chain is taken up by rotation of the crank, so valve timing will be retarded after surfacing or chain stretch (**Figure 7.81**).

Resurfacing OHC Heads

Warped OHC heads with removable cam journals (**Figure 7.82**) should be checked to see that the cam still turns easily after the cylinder head is removed from the block. If not, straighten the head or remove the cam towers and surface the top side of the head. Install shims under the cam towers to take up the extra timing chain slack caused by both surfacing operations. Oversize cam bearings are available if the cam bearing bores need to be align-bored on engines without removable cam towers.

Measuring Combustion Chamber Volume

Some manufacturers make different heads for the same engine make and size, with different

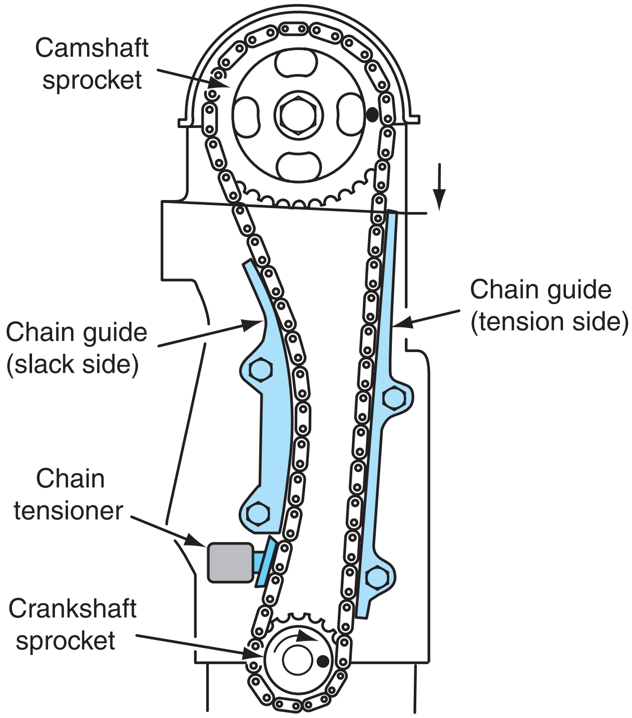


FIGURE 7.81 When an OHC head is surfaced, the camshaft sprocket moves closer to the crankshaft sprocket and the camshaft timing retards in relation to the crankshaft.

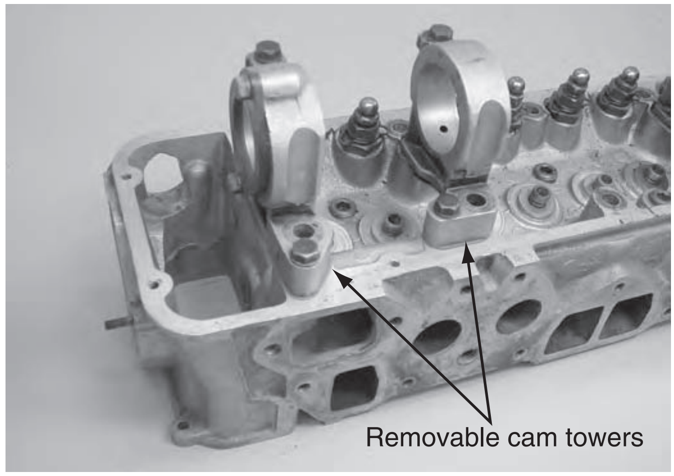


FIGURE 7.82 This vintage OHC head has removable cam towers. *(Courtesy of Tim Gilles)*

combustion chamber volumes. The combustion chamber volume is the volume in the head, head gasket, and cylinder with the piston at TDC. Measuring this volume is called "CC-ing" the chambers.

To CC the combustion chamber of the head, install all valves and spark plugs. Level the head with the combustion chambers facing up. A plate with a hole in it is positioned over the combustion chamber. A burette (a container with an on/off valve and graduations on its side) is used to meter oil into the combustion chamber (**Figure 7.83**). The amount of oil needed to fill the chamber is its CC, or volume.

Surfacing the head reduces combustion chamber CCs. The volume is increased by grinding metal from the surface of the combustion chamber or by excessive grinding on valve seats. The goal is to have all the combustion chambers with identical volumes.

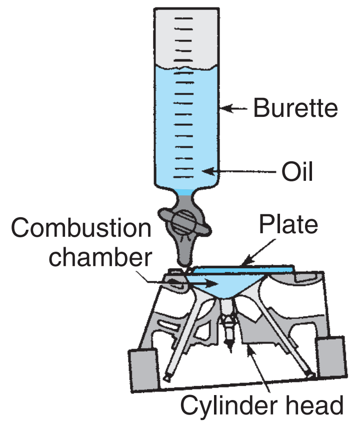


FIGURE 7.83 Measuring combustion chamber volume.

NOTE

A very probable cause of a blown head gasket is engine overheating. When the engine has been hot, it is advisable to regrind the valves and seats while the head is being serviced. The stress from the severe temperatures can result in warped valves as well as a warped head gasket surface.

Key Terms

alloy
heli-arc/TIG welding
integral valve guides
knurling
mushroomed valve tip
pinning a crack
valve stem height

Study Questions

1. What caution is necessary when setting an OHC head on a bench?
2. Before using a valve spring compressor, what part of the valve and spring assembly should be struck with a short piece of pipe and a hammer?
3. When performing procedure 2, care should be taken so as not to bend what part?
4. As valves are removed during disassembly, should they be kept in order?
5. Which cylinder heads should *not* be cleaned by glass beading?
6. Name four methods of crack detection.
   a.
   b.
   c.
   d.
7. When cracks are repaired using tapered, threaded plugs, what is this called?
8. When repairing a crack, what should be done to both ends of the crack to prevent it from growing larger?
9. What name describes the shape in which valve guides wear?
10. Describe two ways of measuring valve stem-to-guide clearance.
    a.
    b.
11. What is the name given to an inexpensive metal displacement method of resizing a valve guide?
12. Would smoke during deceleration most likely be traced to the seal for the intake or exhaust guide?
13. Name three types of valve guide seals.
    a.
    b.
    c.
14. What is the maximum amount of warpage allowed on a cast iron four cylinder head before it must be resurfaced?
15. List two methods of head resurfacing.
    a.
    b.

ASE-Style Review Questions

1. An engine has excessively worn exhaust guides. Technician A says to look for weak or short exhaust valve springs. Technician B says that this can cause excessive crankcase pressure. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. An engine has excessive valve guide wear. Technician A says to ream the guide and install a new valve with an oversized stem. Technician B says to knurl the valve stem and reinstall it in the guide. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. A valve guide has 0.015" bellmouth wear. Technician A says to knurl and then ream the guide to size. Technician B says to repair the guide with a replaceable guide insert. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. Technician A says that on some engines, guide seals have to be installed on exhaust valves only. Technician B says that even though two valve guide seals might look alike, one could be made of a rubber that will survive longer under higher temperature. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. Technician A says that OHC cylinder heads often have oil galleries in them. Technician B says that pushrod engine cylinder heads often have oil galleries in them. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. A cylinder head has required substantial metal removal to make it flat. Technician A says that a shim can be installed under the head gasket to compensate. Technician B says that on OHC engines, the valve timing will be retarded. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that Magnaflux is a crack detection method that is commonly used on aluminum heads. Technician B says that bead blasting is the preferred method for cleaning OHC heads. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says that if a camshaft does not turn easily, the head probably requires straightening. Technician B says that if the cam side of an OHC head is warped excessively, the head can be straightened. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. An engine has a warped cylinder head. Technician A says that this could be caused by running the engine with a faulty thermostat. Technician B says that this could be because the engine was overheated. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Technician A says that valve stem-to-guide clearance can be measured using a dial indicator. Technician B says that valve stem-to-guide clearance can be measured using a feeler gauge. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 8

Cylinder Head: Springs, Valves, and Valve Seats

CONTENTS

OBJECTIVES

Upon completion of this chapter, you should be able to:

- Analyze wear and damage to valves, springs, and seats.
- Understand theory related to valves, seats, springs, and other related parts.
- Select and perform the correct repair.
- Reassemble the cylinder head.

INTRODUCTION

During a valve job, the valves and valve seats are refinished to as-new condition. This chapter deals with valve and seat grinding as well as the theory and service to parts of the valve operating mechanism.

When the faces of the valve and the valve seat are machined, this causes a change in the installed height of the valve and valve spring. It is important that the valve and spring height be restored to their original measurements. Valve spring theory and service are covered in this chapter. Other parts of the valve job, including inspection and repairs to the cylinder head casting, are covered in Chapter 7.

Sometimes a rough idling engine can be traced to one or more burned or leaking valves, but this can also be due to a problem with piston rings or a leaking head gasket. Performing a professional repair on a cylinder head would solve the problem of the leaking valve or head gasket but would not correct a problem related to the engine's lower end.

VALVE SPRINGS

The purpose of the valve spring is to return the mechanism back to rest again.

Pressure on the valve comes from three sources (**Figure 8.1**):

- The spring
- The pressure of combustion
- The seat angle

There are several types of valve springs (**Figure 8.2**). A simple spring has a uniform pitch (rate).

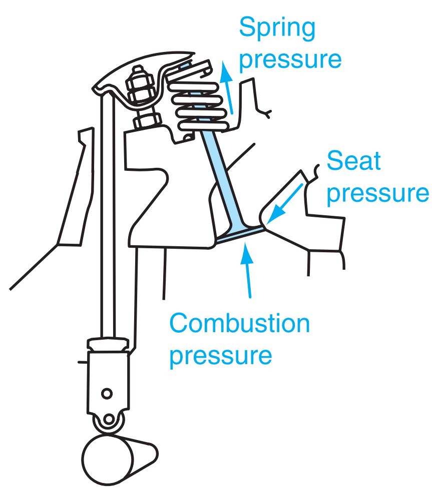


FIGURE 8.1 Valve seat pressure comes from three sources.

VINTAGE ENGINES

Larger, slow turning engines do not require as massive a valve spring. Early four stroke engines, like Ford's early racing engine, had an atmospheric intake valve consisting of a light valve spring and no cam lobe.

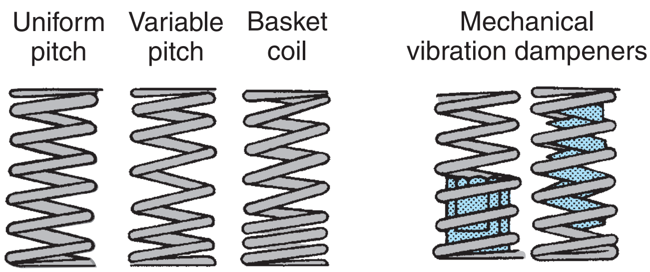


FIGURE 8.2 Several types of valve springs.

Other springs have a *variable pitch* that changes as the spring is compressed. Variable rate (basket coil) springs should be installed with the tightly coiled end of the spring toward the head (**Figure 8.3**).

Sometimes springs have multiple coils or flat-wound spring dampers (see Figure 8.2). These fit inside the spring and are wound opposite to the spring direction to help eliminate binding when the spring bends as it is compressed. Spring dampers serve to deaden undesirable harmonics or vibrations. Spring vibrations can be compared to those of a tuning fork and can result in spring breakage.

Valve Spring Inspection

It is somewhat unusual for a valve spring to break. Occasionally during head disassembly, a broken valve spring is found, although it may not have caused an obvious problem.

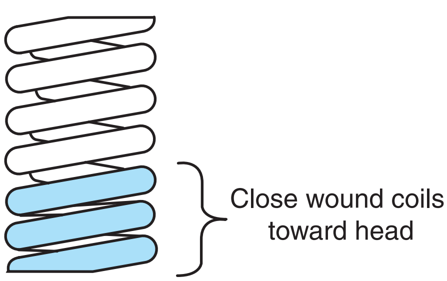


FIGURE 8.3 Correct basket coil spring installation.

Test springs for squareness, tension, and height.

- *Spring Squareness and Free Length*. Test springs for squareness (**Figure 8.4**). Most automotive springs are close to 2" in length. Discard springs that are out of square more than 5⁄64" in 2" of length. Out-of-square springs can cause excessive, uneven valve guide wear (**Figure 8.5**). A severely

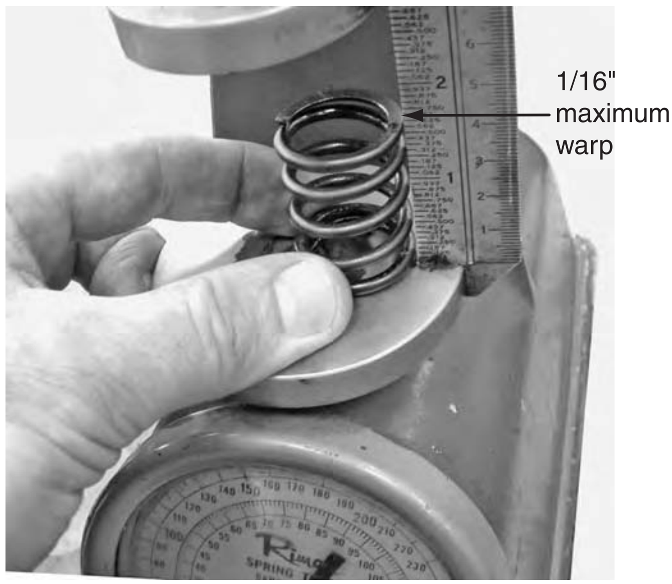


FIGURE 8.4 While rotating the spring, there should be no more than 1⁄16" of variance between the spring and straightedge. (*Courtesy of Tim Gilles*)

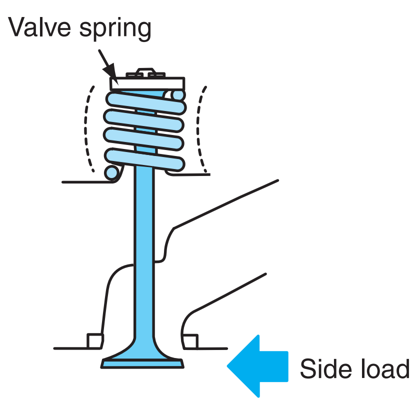


FIGURE 8.5 Out-of-square springs can cause guide wear.

out-of-square spring can also cause a valve keeper to become dislodged. Many flat rate technicians simply line up all the springs from a head and throw away any that vary in height from the rest. Springs that have been overheated will usually be shorter.

- *Spring Tension*. Spring tension should be within 5–10% of the manufacturer's specifications, with no more than a 10 lb difference among springs. It is a good idea to test new springs, too. Installing the wrong valve springs with too much spring tension can cause necked (stretched) valves (**Figure 8.6**), cupped valves (**Figure 8.7**), and worn valvetrain parts. An oversprung valvetrain can also consume power.

It is more common to find springs with too little tension because springs fatigue in use. Insufficient spring tension can result in valve float when the valve stays open at high speed instead of following the cam lobe. Valve float can result in bent or broken valves or cause pistons to crack as they strike open valves.

Weak valve springs can impede heat transfer between the valve faces and seats, which can result in valve face damage and valve burning. Too little tension results in accelerated valve seat wear when the valve spring "jelly rolls" at higher engine rpm. This causes the valve to bounce against the valve seat, creating a peening action while the seat becomes overheated. A spring often shows wear on its end when it has been used with too little tension (**Figure 8.8**). Any spring that feels loose when installed on the head should be discarded.

Check spring tension (**Figure 8.9**) in both the valve-open and the valve-closed positions with a tension tester. Compare the readings obtained with the engine manufacturer's specifications. When specifications are not supplied, compare test pressures with a new spring.

FIGURE 8.6 A "necked" valve (excessive tension). (*Courtesy of Federal-Mogul Corporation)*

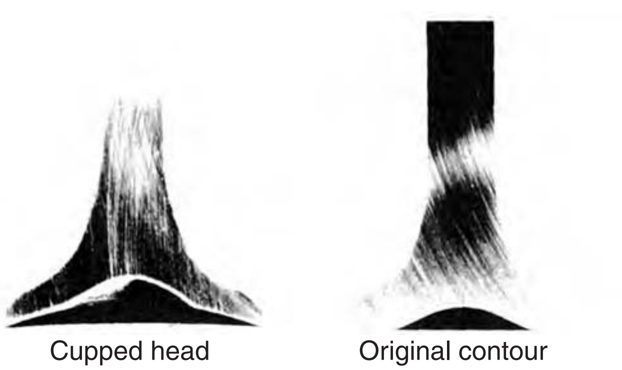


FIGURE 8.7 A cupped valve head (excessive tension). (*Courtesy of Federal-Mogul Corporation)*

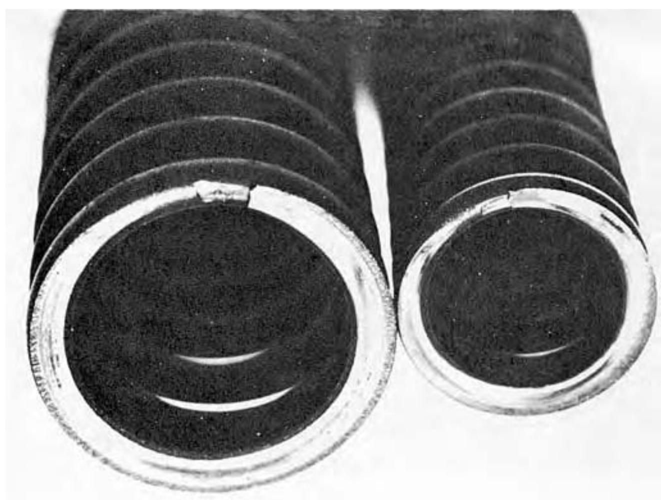


FIGURE 8.8 Wear on the ends of the spring (too little tension). (*Courtesy of Federal-Mogul Corporation)*

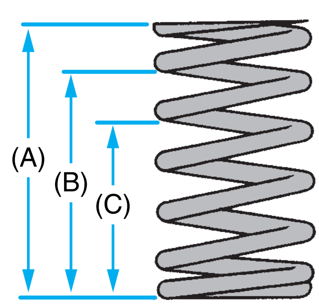


FIGURE 8.9 Spring height: (A) free length; (B) valve closed; and (C) valve open.

There are different types of tension testers (**Figure 8.10**). The most expensive one has a dial (**Figure 8.10a**). Install a spring in the tester and compress it to the specified height. An adjustable stop on the top of the tester is set so that all springs can be very quickly compared.

Another type of spring tension tester is less expensive because it uses a torque wrench to make measurements. Set the gauge by turning a threaded knob. Then compress the spring until a click is heard. To find the spring tension, double the torque wrench reading at the click (**Figure 8.10b**).

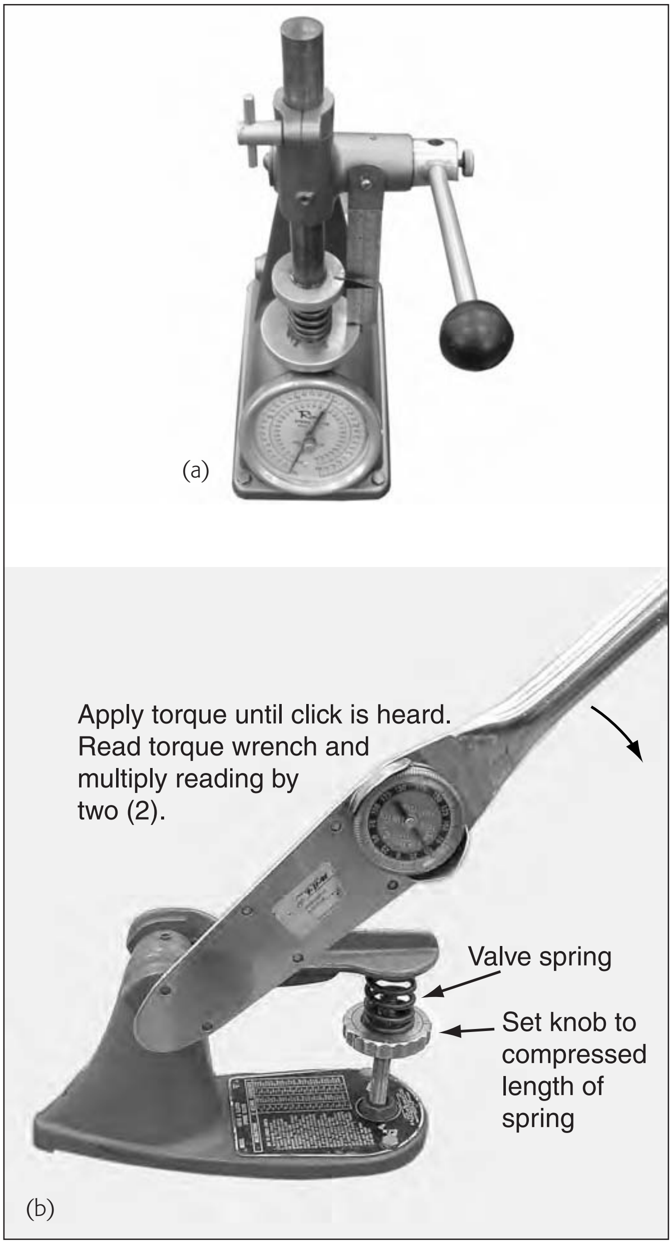


FIGURE 8.10 Spring testers. (a) A scale-type spring tension tester. (b) A spring tester used with a torque wrench. (*Courtesy of Tim Gilles*)

Racing Valve Springs

Automobile manufacturers are heavily involved in auto racing because it provides a very good opportunity for advertising. Companies that supply the engines used in race cars need to do whatever they can to provide an edge in competition. *Restrictor plate racing* has a specified opening in the air intake. Small changes in efficiency and endurance can mean the difference between winning and losing.

Opening a valve spring uses energy that is recovered when the valve closes. But excessive spring tension is hard on parts and can affect endurance. Racing engine builders use a special machine that tests valve springs to determine the engine rpm at which they will float. For this example, let us assume that the highest engine speed during a race will be 9000 rpm. If a valve spring that will not float until 12,000 rpm is substituted for a spring that will not float u ntil 9500 rpm, a measurable amount of extra power will be realized. See Chapter 10 for more information on racing valve springs and valve spring resonance.

Checking Installed Height of Spring

When the valve face and valve seat are ground, the valve moves deeper into the cylinder head. The result is less spring tension because the spring retainer moves away from the spring seat surface (spring pad) on the head (**Figure 8.11a**).

Valve shims, called **valve spring inserts** (VSI), are installed under valve springs for two reasons:

1. Aluminum heads use a thin shim to protect the soft spring seat from damage from spring action.
2. Installed spring height can be corrected by shims available in 0.015", 0.030", and 0.060" thicknesses.
   - Check the installed height measurement before reassembling the head (**Figure 8.11b**).
   - Set the spring tension tester to the installed height of the spring (**Figure 8.12a**).
   - Compare the reading obtained with the specifications. Then install a shim with the valve spring and see if the reading falls within the specified range.

Be careful. A shim too thick can result in a bind in the coil spring, especially with a high-performance camshaft.

Spring inserts usually have a serrated side to prevent heat transfer from the head to the spring.

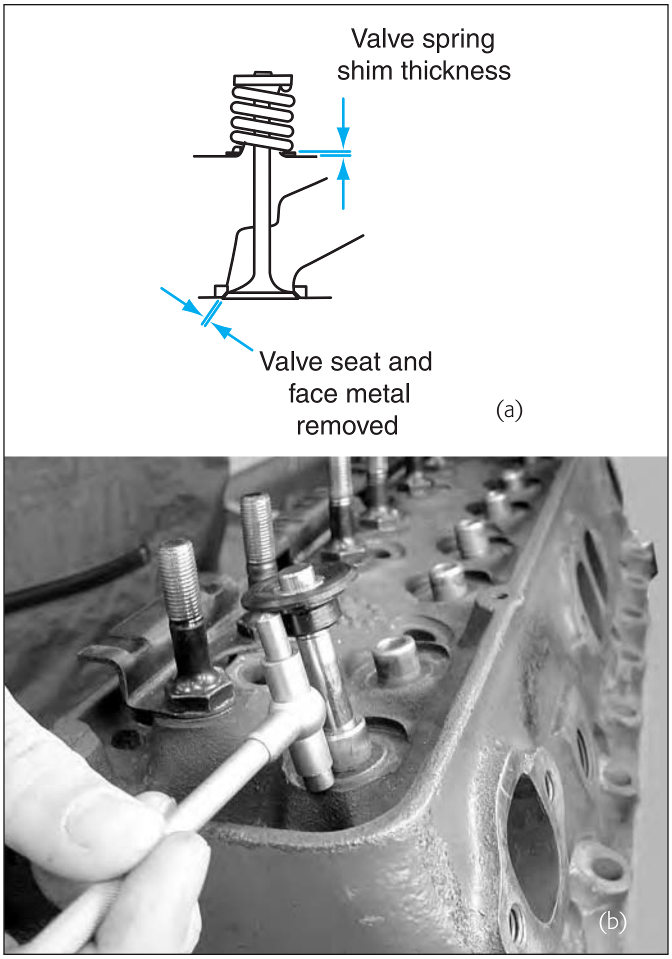


FIGURE 8.11 Correcting improper spring height. (a) The installed height of the spring changes due to wear or metal removal during machining. (b) Checking the installed spring height before head reassembly. *([b] Courtesy of Tim Gilles)*

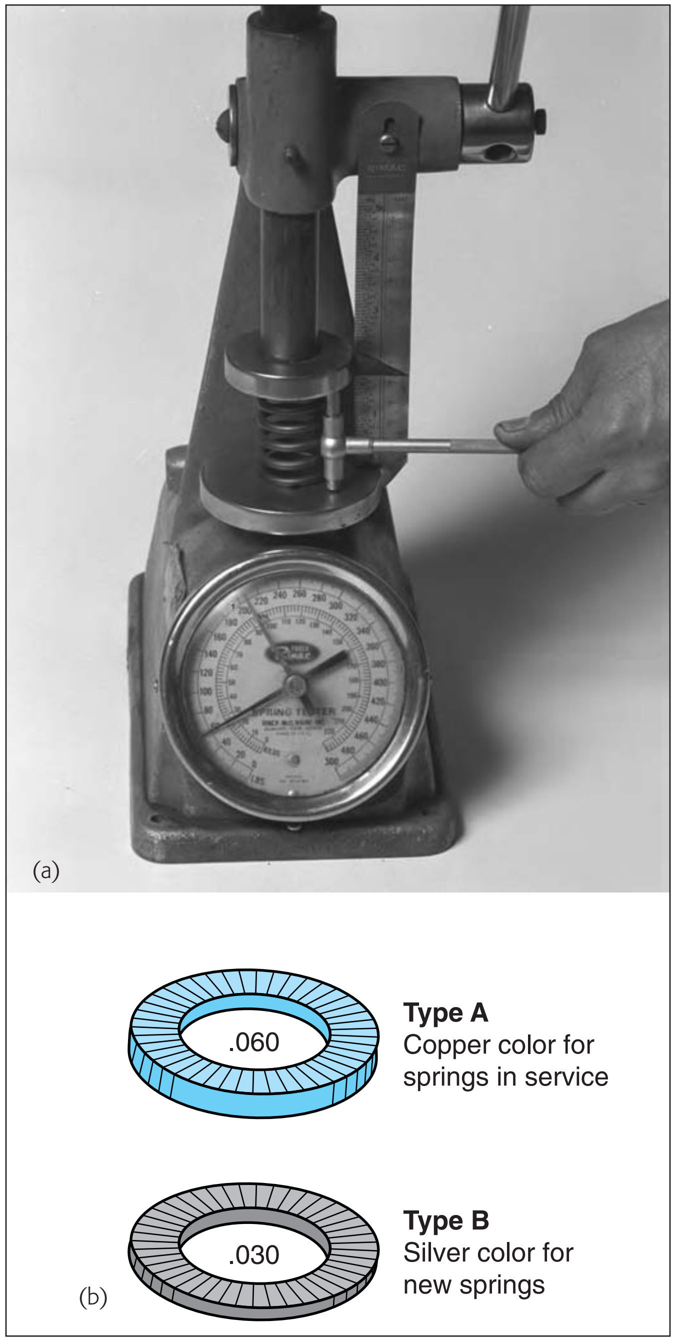


FIGURE 8.12 (a) Set the tension gauge to the installed height of the spring to see what the actual tension will be. (b) A shim corrects spring height.

- The serrated side is installed toward the head.
- Use only one shim at a time. Do not stack shims up.

Valve Retainers

Valve retainers, called keepers, are found at the stem tip end of the valve (**Figure 8.13**). The design of keepers varies among manufacturers. **Figure 8.14** shows the keeper grooves on three different styles of valves.

PUSHRODS

Cam-in-block engines use pushrods to transmit motion from the lifters to the rocker arms (**Figure 8.15**). Most pushrods are hollow to provide lubrication from the lifters to the rocker arms and valves.

Some engines use a guide plate to limit side movement of the pushrods (**Figure 8.16**). Other engines have small holes in the cylinder head or manifold that act as guides. Some performance engines have moly pushrods. These must be used with special guide plates or the pushrods will experience extreme wear against the guide plate or cylinder head.

VINTAGE ENGINES

On vintage engines, shimming valve springs to restore tension was fairly common among auto mechanics. One manufacturer of VSIs provided the following recommendations for shim use when a valve spring height measurement was not part of a flat rate repair:

- The 0.030" shim was used with a new valve or valve spring.
- The 0.060" shim was the most common and could help compensate for slight losses of original spring tension (**Figure 8.12b**). If a shim thicker than 0.060" was needed, installation of a new valve seat or a taller spring was required.

FIGURE 8.13 Valve locks (keepers). (*Courtesy of Tim Gilles*)

FIGURE 8.14 Keeper grooves of different styles used by engine manufacturers. (*Courtesy of Tim Gilles*)

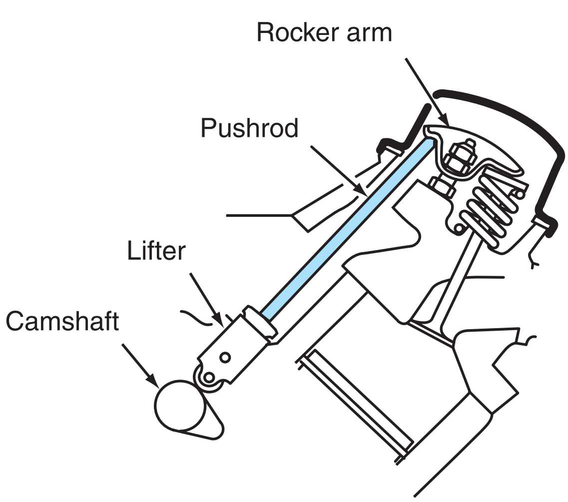


FIGURE 8.15 Pushrods transmit motion from the lifters to the rocker arms.

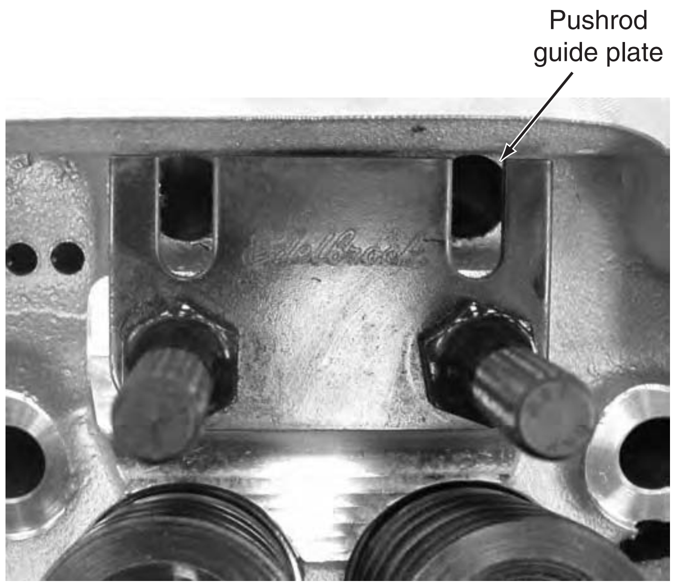


FIGURE 8.16 A pushrod guide plate. (*Courtesy of Tim Gilles*)

FIGURE 8.17 Inspect both ends of each pushrod for excessive wear. The rocker arm used with this pushrod was also replaced. (*Courtesy of Tim Gilles*)

NOTE

Excessive heat in a baking oven can cause guide plates to soften. Then they wear quickly. Check hardness with a file. If the file easily cuts the guide plate, it is not hard.

Pushrod ends are different shapes, including concave and convex. Inspect the pushrod end and rocker arm surfaces for pitting or other unusual wear (**Figure 8.17**). Roll each pushrod on a flat surface to see if it is bent (**Figure 8.18**).

When using aftermarket cylinder heads or a high lift camshaft, custom pushrods are sometimes needed so the rocker arm can be centered on the valve stem tip when the valve is half open (**Figure 8.19**). To find out the size of pushrod required, a tool set consisting of adjustable checking pushrods is available. **Figure 8.20** shows one in use. After installing the tool and taking a measurement, pushrods of the correct length are ordered. Pushrods that can be cut to length are also available. After determining the desired length, the tube section of the pushrod is cut (**Figure 8.21**) and a pushrod end is pressed onto the tube (**Figure 8.22**).

FIGURE 8.18 Roll pushrods on a flat surface to check for straightness. (*Courtesy of Tim Gilles*)

FIGURE 8.19 Custom-made pushrods are shortened until the rocker arm is centered on the valve stem tip when the valve is half open. (*Courtesy of Tim Gilles*)

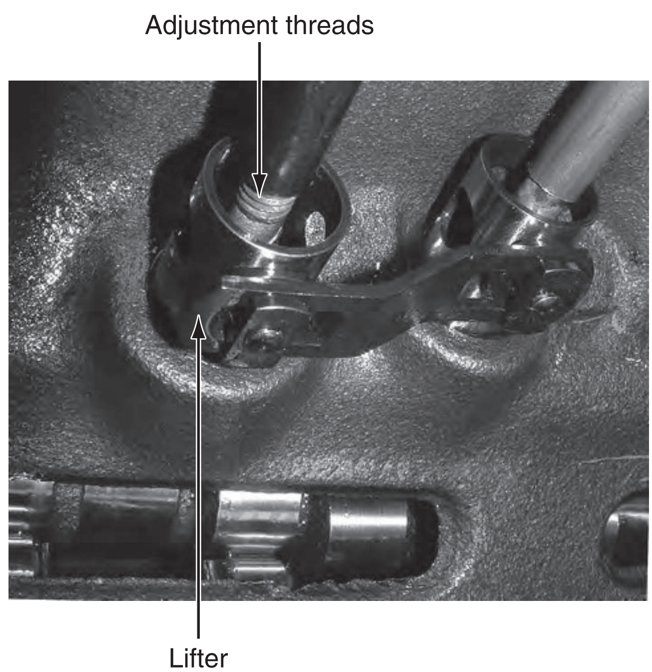


FIGURE 8.20 A temporary adjustable pushrod. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Some older Ford engines were originally equipped with different length pushrods. Most lengths are available from aftermarket suppliers. Chapter 9 discusses how to check for the correct length using a special tool to collapse lifters (see Figure 9.28).

VINTAGE ENGINES

It was common for older engines with shaft-mounted rocker arms and solid valve lifters to experience wear between the rocker and valve stem tip (**Figure 8.23**). This would make it difficult to get a proper valve clearance adjustment. Valve grinding machines have a special attachment that is used for resurfacing cast iron rocker arms at the valve tip contact point. Shaft-mounted rocker arms sometimes have replaceable bushings and are oiled through an oil passage to the inside of the shaft. If the passage becomes plugged, wear will accelerate. If the shaft becomes worn, it is replaced. New bushings in the rocker arms are honed to fit. Entire rebuilt rocker assemblies are still available for some of the more common engines.

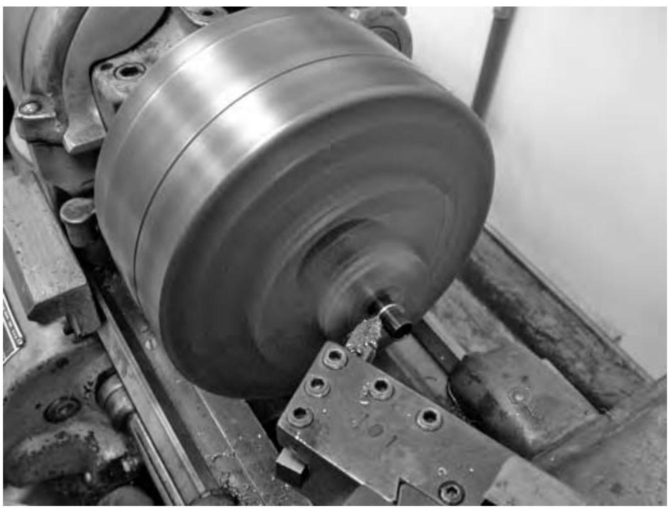


FIGURE 8.21 Cutting an aftermarket pushrod to length on a lathe. *(Courtesy of Tim Gilles)*

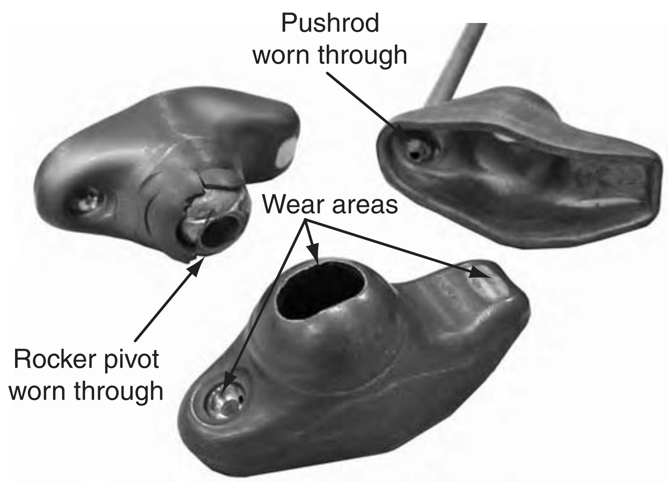


FIGURE 8.23 Worn rocker arms. *(Courtesy of Tim Gilles)*

FIGURE 8.22 This aftermarket pushrod was cut to the correct length before inserting the end. *(Courtesy of Tim Gilles)*

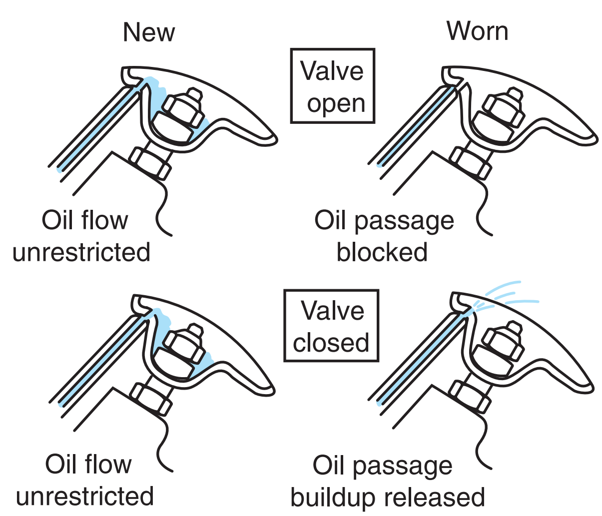


FIGURE 8.24 A worn rocker arm can cause an oil pressure buildup. This results in a spray of oil as the pressure is released.

ROCKER ARMS

Rocker arms are either shaft-mounted or stud-mounted. Older engines used more expensive cast iron rocker arms. Most modern engines use less expensive stamped steel rocker arms. Shaft-mounted rockers are usually made of iron.

Stud-mounted rockers are oiled through hollow pushrods. When the pushrod/rocker arm seat wears, oil pressure builds and is suddenly released, spraying oil all around the inside of the valve cover (**Figure 8.24**). This can result in extra oil consumption through the valve guide.

Stud-mounted rockers are made of steel stamped in a "canoe" shape (**Figure 8.25**). This type of rocker arm is less expensive than the shaft-mounted type and they are replaced when worn. The rocker arm has a ball pivot and a self-locking adjusting nut threaded to a pressed-fit stud. Sometimes pressed-in rocker studs pull out of the head, or the rocker wears against the rocker stud. The stud is pulled, the guide is reamed, and an oversized stud (0.002" larger than the reamer) is pressed into place (**Figure 8.26**). Installation of a pressed-fit stud is made easier if it is chilled before pressing it into place.

Threaded replacement studs, called screw-in studs, can also be used (**Figure 8.27**). A locknut, called a jamb nut, is used with some types of threaded studs. To provide enough clearance to keep the rocker from binding against the jamb nut, the head surface below the new stud must be cut by an amount equal to the thickness of the jamb nut.

Rocker arms sometimes have different rocker arm ratios (see Chapter 9). Increasing the ratio can cause movement of the lifter at the cam lobe to be *increased* at the valve, making it possible to have smaller cam lobes.

Some late-model OHC engines have roller rocker arms (**Figure 8.28**). Rollers provide a substantial reduction in friction, thereby increasing fuel economy. Chapter 10 includes information on high-performance roller rocker arms for cam-in-block engines.

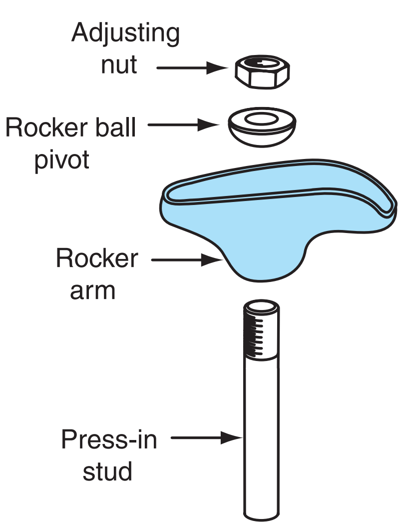


FIGURE 8.25 A stamped-steel, stud-mounted rocker arm.

VALVES AND VALVE SERVICE

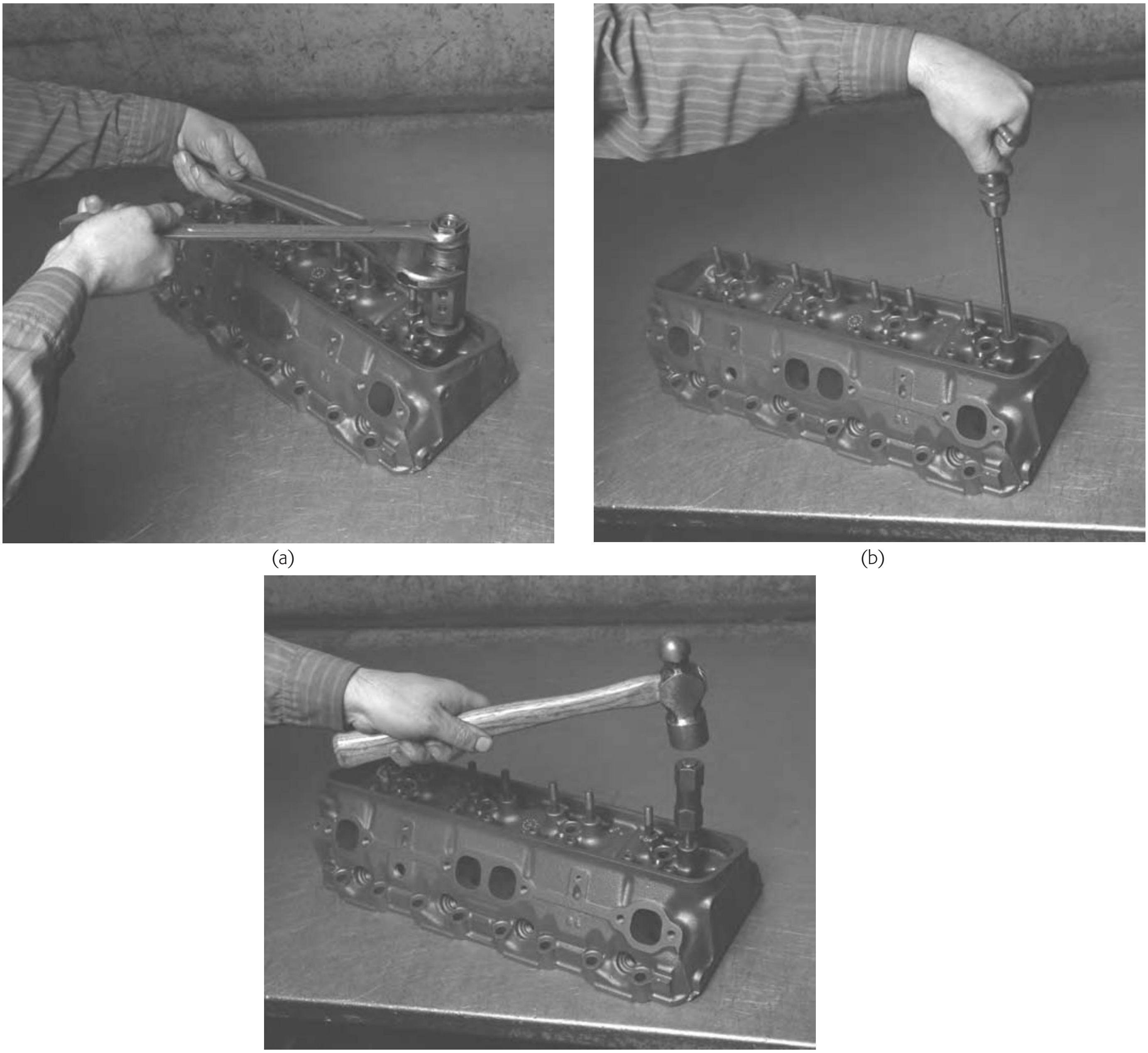
The valves used in automotive engines are *poppet valves*, which were first used in steam engines. They were designed to require little or no lubrication and they operate well in high temperatures. The combustion chamber is subjected to severe conditions during engine operation. The valve runs at high temperatures, opening and closing at half engine speed (**Figure 8.29**). Exhaust valve seats run at about 800°F (427°C), and the neck area of the exhaust valve sometimes runs at temperatures in excess of 1300°F (704°C). This is above the melting temperature of aluminum, and it is red hot for these steel valves. Valves depend on proper guide clearance and seat contact for proper cooling (**Figure 8.30**).

Effect of Valve Lash on Cooling

Valve lash (clearance) must be sufficient to allow heat to dissipate from the valve to the valve seat. If the lash is adjusted too tight, the valve will not be able to lose sufficient heat and will become overheated. Lash decreases a small amount over time due to wear between the valve face and seat (**Figure 8.31**). The valve shown in **Figure 8.32** shows evidence of even valve seating but insufficient valve lash.

Valve Damage

Wear sometimes occurs on valve stems when the engine has dirty oil, but heat is usually the cause of damage to the valve head. If a valve does not cool properly, it will quickly overheat and burn. An excessively lean air-fuel ratio will cause the valve to run at a higher temperature. This can result in the type of valve burning shown in **Figure 8.33**, which



(a) (b) (c)

FIGURE 8.26 Installing an oversized press-fit rocker stud. (a) The stud is pulled. (b) The hole is reamed to accept the oversized stud. (c) The new stud is driven in.

appears as if the valve had been cut with an oxyacetylene cutting torch.

NOTE

A valve burns from the margin toward the inside, rather than from the neck to the outside.

There are several reasons why a valve can crack and burn (**Figure 8.34**). Imperfections can raise stress, resulting in a crack. Also, uneven valve cooling can cause the valve to expand unevenly, resulting in thermal stress (**Figure 8.35**). When an overheated valve cools, it does so unevenly from the outside to the inside. This results in a condition called hoop stretching, which cracks the valve.

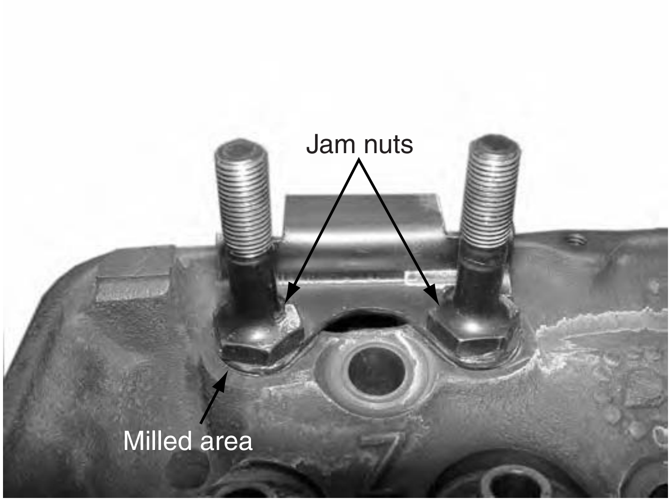


FIGURE 8.27 A threaded screw-in stud. *(Courtesy of Tim Gilles)*

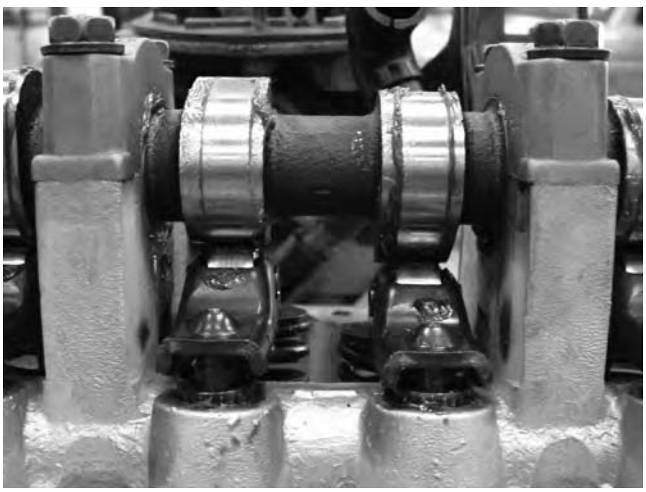


FIGURE 8.28 Roller rocker arms used on some OHC heads substantially reduce friction and increase fuel economy. *(Courtesy of Tim Gilles)*

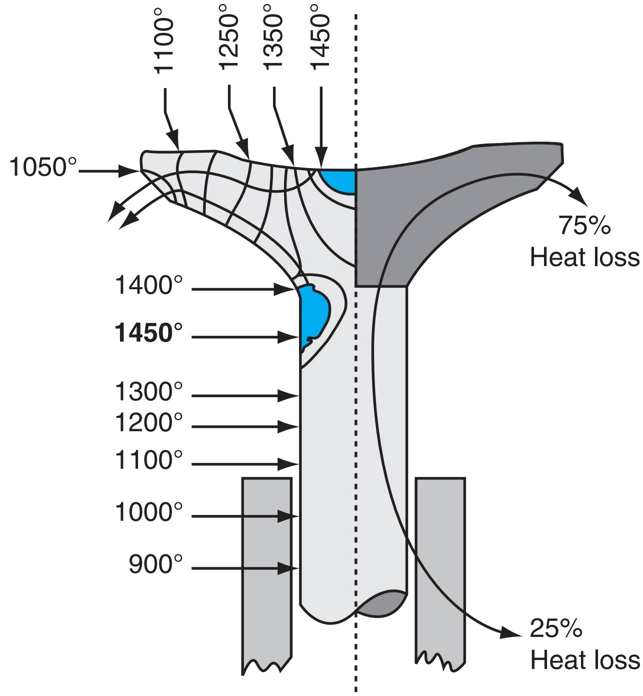


FIGURE 8.29 Typical temperatures of an automotive exhaust valve.

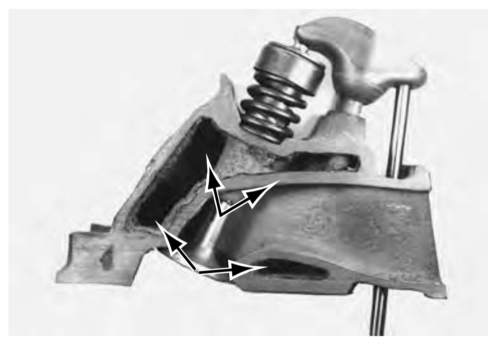


FIGURE 8.30 Valves are cooled through contact with the seat and guide. *(Courtesy of Tim Gilles)*

NOTE

What causes valves to burn? A major cause of exhaust valve burning is thermal shock. Have you ever noticed what the truckers do after they climb a long grade? They sit at the top and idle for a few minutes to let the temperatures even out before going downhill so the shock of cold coolant does not stress the overly hot exhaust valves.

Anything that causes a stress raiser in the neck of the valve is cause for replacement of the valve. **Figure 8.36** shows valves that failed in the neck area. This is the hottest part of the valve and, therefore, is most prone to failure.

Valve oxidation, usually resulting from coolant leakage, causes a valve to become rusted or corroded in the area of the neck (**Figure 8.37**). This weakens a valve and it should not be reused. The necks of some valves are aluminized to prevent corrosion to this area. Aluminizing is when aluminum oxide is combined with the base metal of the valve stem during manufacture.

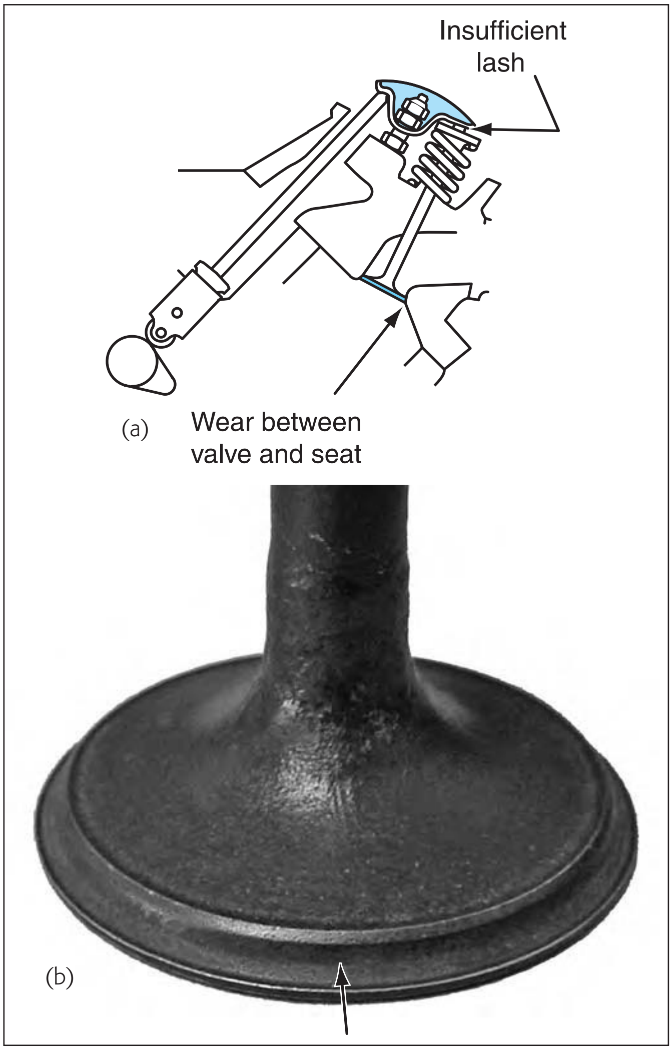


FIGURE 8.31 Problems related to valve lash. (a) Lash decreases because of head expansion or valve and seat wear. (b) The wear on this valve would result in decreased lash. *(Courtesy of Tim Gilles)*

FIGURE 8.32 This valve was not closing solidly against its seat. Continued operation would have resulted in a burned valve. *(Courtesy of Tim Gilles)*

FIGURE 8.33 An excessively lean air-fuel mixture can cause valve burning that looks like this. *(Courtesy of Tim Gilles)*

Valve Seat Wear

Valve seats operate in very severe environment. Older engines were more susceptible to valve seat wear than today's engines, which use aluminum cylinder heads with very high-quality stainless steel valve seat inserts. Valve seat recession was a common problem on older engines, but valve seats in modern engines wear very little.

Manufacturers and machine shops ultimately solved the problem of valve seat recession by installing high-quality hard valve seats in conjunction with premium exhaust-type valves for both intake and exhaust.

Temperature Protection/Valve Rotation

Some heavy-duty engines use positive-type valve rotators to ensure equal temperatures on all sides of the valve (**Figure 8.39**). The rotator can be located above or below the valve spring (**Figure 8.40**). It is often placed under the spring on high-speed engines to lessen the weight of the spring assembly.

VINTAGE ENGINES

Since the early 1970s, vehicles have used catalytic converters to control air pollution. Catalytic converters are made ineffective by the tetraethyl lead that was formerly used to raise the octane in gasoline. Another benefit of lead in gas was that it protected the nonhardened valve seats in older engines. Today's unleaded gas used in pre-1970 cars can cause wear to exhaust valves and seats when the engine is under severe operating conditions (especially maximum rpm) for long periods. Racing and marine engines fit this description.

Seat recession in older vehicles happens for other reasons as well. Soft valve seats recess when microscopic iron oxide particles form on the edge of the valve face and become superheated during valve opening. When the valve closes, these heated particles fuse to the seat. When the valve opens again, the fragment is torn away. This happens thousands of times a minute, slowly eroding the valve seat. Seat recession becomes more severe with engine speed and increased loads. Highway speeds cause faster seat recession.

Spring dampers (**Figure 8.38**) reduced "chattering," which was another cause of wear between the valve face and seat. According to TRW, this reduced seat recession by 80–95%.

Intake seats did not suffer the same wear as exhaust seats. During the days following the elimination of unleaded gas, when valve seats were routinely replaced, some engine builders experienced success in replacing only exhaust seats.

NOTE

Positive valve rotators often cause excessive valve face wear, especially when used with natural gas.

On a pushrod engine, operation of a rotator can be checked using a timing light. Make a chalk or crayon mark on the edge of the rotator. With the valve cover removed, run the engine and aim the strobe at the rotator while watching for rotation. Replace the rotator if a valve tip shows signs of a groove wearing in it (**Figure 8.41**).

Some engines use passive valve rotation in which multigrooved valve stems allow vibration to cause the valve to rotate when the valve is opened. This is much like a nut on a vibrating bolt. The two halves of the keepers butt together, allowing the valve to be free to rotate. This type of rotation is often called *roto-groove*.

NOTE

Inspect the keeper grooves to see if the grooves in the stem have worn to a sharp edge (**Figure 8.42**). If they have, both the valve and the keepers must be replaced.

Hard Faced Valves. Some valves are manufactured with hard faces for severe service conditions or when corrosion resistance is required. Cobalt hard facing is the most popular type of hard facing and is not susceptible to lead damage.

Sodium-Filled Valves. Sodium-filled valves are sometimes used in extreme operating conditions and can reduce maximum valve temperatures by about 350°F (177°C). Sodium-filled valves have thicker valve stems than standard valves (**Figure 8.43**). They have hollow stems filled with sodium

FIGURE 8.34 Cracked valves will cool unevenly and eventually burn. *(Courtesy of Tim Gilles)*

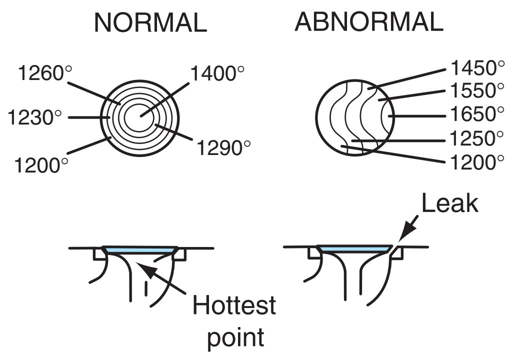


FIGURE 8.35 Exhaust valve temperatures with proper and improper seating. *(Courtesy of Federal-Mogul Corporation)*

FIGURE 8.36 The exhaust valves that are imbedded in these pistons failed in the neck area. *(Courtesy of Tim Gilles)*

(**Figure 8.44**) with the weld near the stem tip. Metallic sodium is a solid powder in the valve stem until it reaches 208°F (98°C); it is a liquid at engine operating temperature. The hollow cavity in the valve is only about half full of sodium. The liquid sodium moves heat from the hottest area of the valve, at the valve neck, to the valve guide, where the heat is dissipated into the water jacket located behind it.

FIGURE 8.37 This valve has been ruined by corrosion in the neck area. *(Courtesy of Tim Gilles)*

FIGURE 8.38 This spring has a dampener to reduce vibration. If you look closely, you can see evidence of pitting from rust on this spring. It must be replaced. *(Courtesy of Tim Gilles)*

CAUTION

Metallic sodium will burst into flame if it comes into contact with moisture, so it is dangerous to grind or break these valves. Sodium is safe so long as it is contained in the valve.

Sodium-filled valves can fail if valve stem-to-guide clearance becomes excessive because the heat cannot dissipate from the valve stem.

Exhaust and Intake Valves

Intake valves are larger than exhaust valves (**Figure 8.45**). Expanding exhaust gases are under a

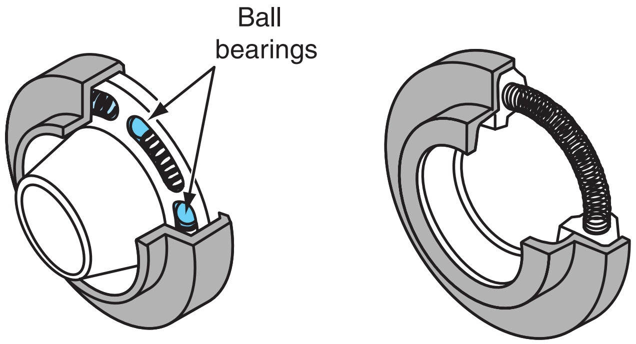


FIGURE 8.39 Valve rotators.

FIGURE 8.40 This valve rotator is located above the valve spring. *(Courtesy of Tim Gilles)*

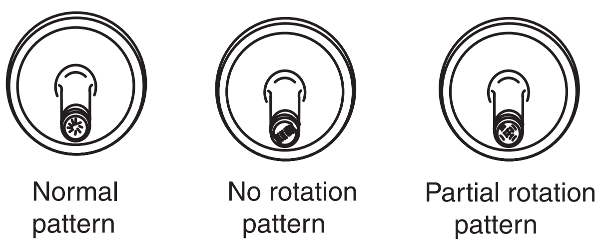


FIGURE 8.41 Wear patterns on the stem tip caused by defective rotators.

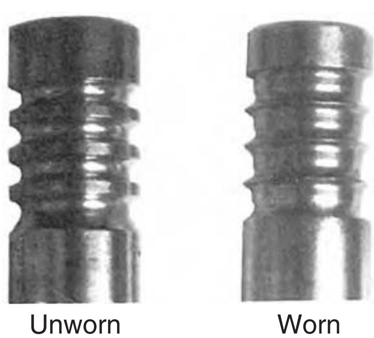


FIGURE 8.42 Worn keeper grooves. *(Courtesy of Tim Gilles)*

FIGURE 8.43 Sodium-filled valves have thicker stems. The valve stems on the right have the same size keeper grooves and retainers. *(Courtesy of Tim Gilles)*

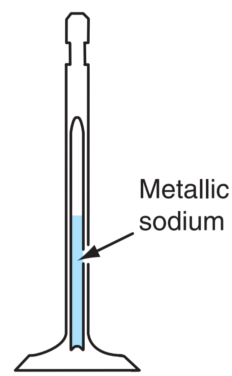


FIGURE 8.44 A cutaway of a sodium-filled valve.

great deal of pressure so they can be forced through smaller exhaust ports. The exhaust valve is forced open against this high cylinder pressure so exhaust valve stems sometimes have a hard tip welded in place (**Figure 8.46**). Sometimes a gap is visible at the point where the tip is welded to the valve stem. According to TRW, a 0.008" maximum gap is acceptable and the welds are ultrasonically inspected for continuity.

A typical intake valve is made of high carbon steel, hardened and tempered to resist corrosion, which is a leading cause of valve failure. Because they suffer such tremendous punishment, exhaust valves are usually made of higher-quality stainless steel. Two-piece welded valves have

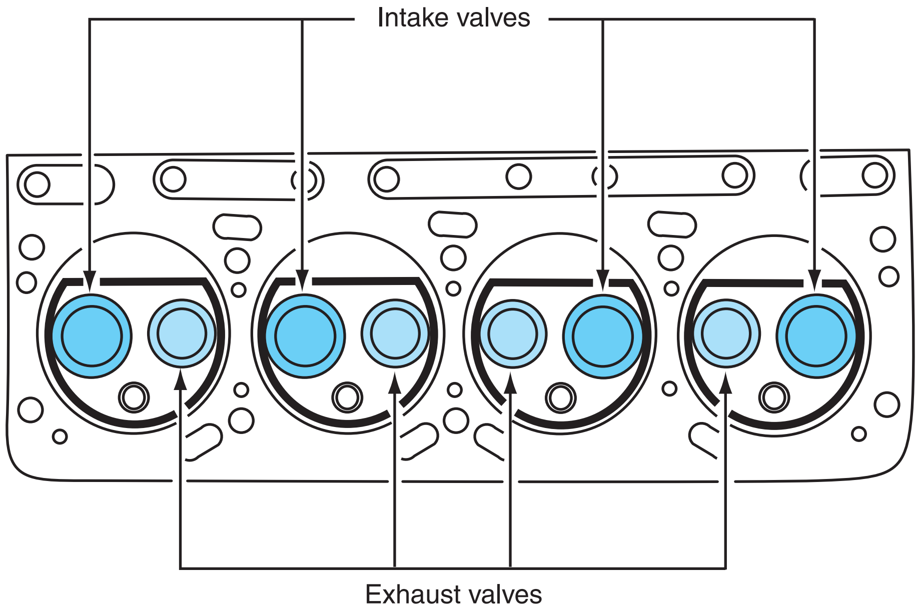


FIGURE 8.45 Intake valves are almost always larger than exhaust valves.

FIGURE 8.46 An exhaust valve stem with a hardened tip. *(Courtesy of Tim Gilles)*

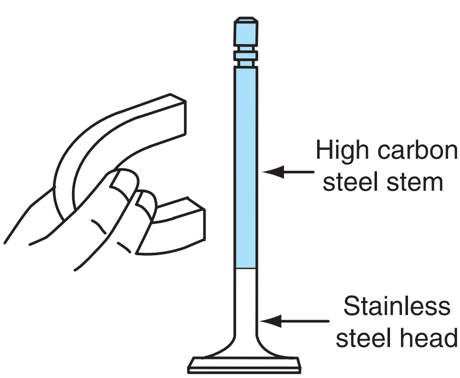


FIGURE 8.47 Two-piece valve magnetic test.

a forged stainless steel head welded to a high carbon steel stem about two-thirds of the way down from the stem tip. Valve stems are often chrome-plated, so the weld is not visible. The weld is very strong and failure of valves usually occurs at the neck area of the valve, not at the weld.

NOTE

The stainless steel part of the valve is usually nonmagnetic. Check with a magnet to see if the valve is one or two piece (**Figure 8.47**).

Intake valves fail most often due to breakage or warpage; exhaust valves can break or burn. Many rebuilders replace all valves as a regular practice.

Valve Stem Coating. Valve stems use one of two protective coatings to prevent stem wear. Chrome plating, which reduces stem wear by up to 80% over 50,000 miles, is commonly done in North America. In Europe, the popular stem coating is bath nitriding, which leaves a black finish that is as effective as chrome.

Measuring the Valve Stem

The valve stem is checked for wear with a micrometer (**Figure 8.48**). Measure the unworn

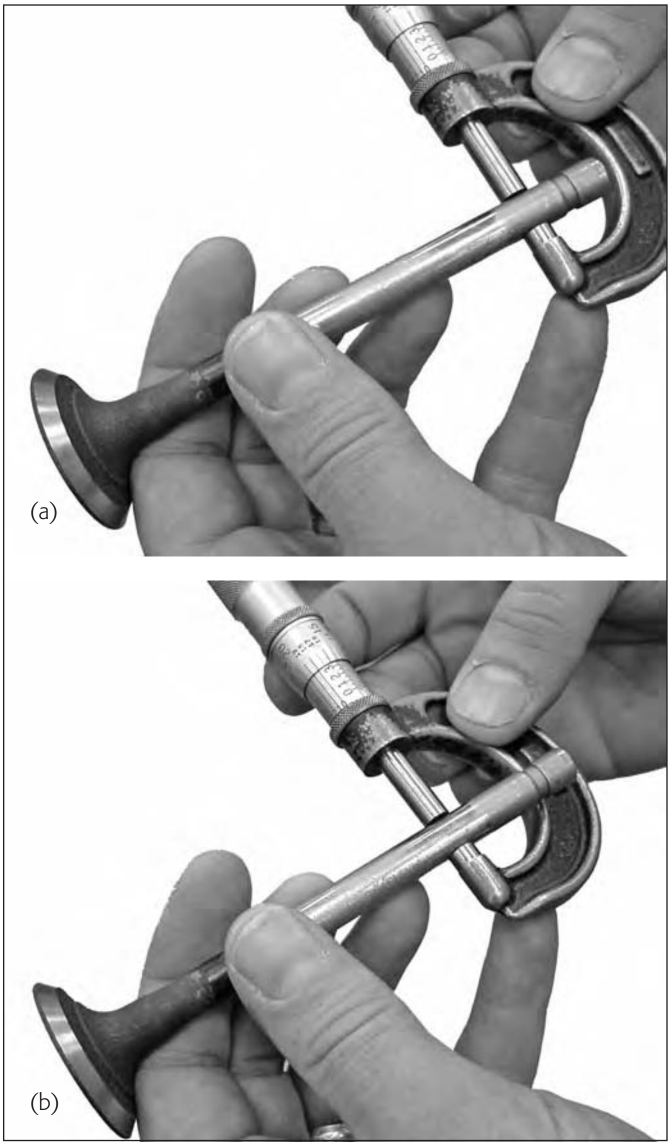


FIGURE 8.48 Inspecting the valve stem for wear. (a) Measuring the unworn portion. (b) Measuring the worn portion. (*Courtesy of Tim Gilles*)

section of the stem near the keeper grooves. Then compare the unworn section to worn sections of the stem that correspond to the top and bottom of the guide rub area.

Stems worn more than 0.002" (or half the recommended oil clearance) are excessively worn. A good rule of thumb is that if you can feel the wear on the valve stem, it should be replaced.

Tapered Stems Some exhaust valve stems are tapered about 0.001" larger at the tip end to allow for expansion near the neck. This helps prevent scuffing in the guide rub area. The tapered stem also helps retard carbon buildup at the lower stem and guide.

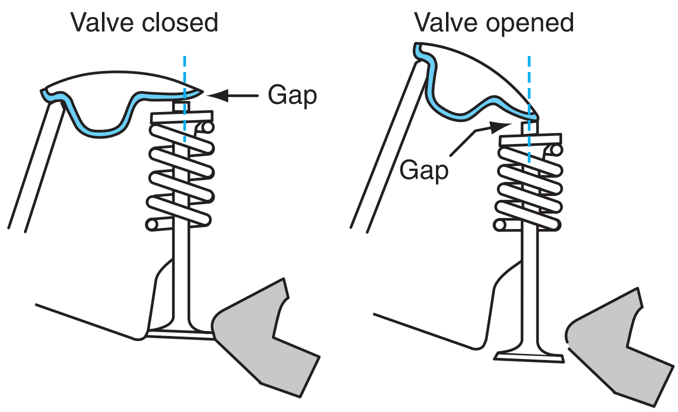


FIGURE 8.49 The rocker arm moves in an arc, across the tip of the valve stem.

Valve Stem Height/Rocker Arm Geometry

Grinding the valve face and seat moves the valve stem deeper into the valve port. To maintain rocker arm geometry, the tip is ground by an amount approximating that removed from the valve face and valve seat. The rocker arm starts at one side of the valve tip when the valve is closed and finishes at the other side when the valve is open (**Figure 8.49**). It should be centered on the stem tip when the valve is approximately half open. Otherwise, excessive wear of the valve guide will result.

Variations in valve stem height can affect the rotation of the pushrod. Also, some engines do not have adjustable rocker arms and the valve could be held off its seat by a bottomed-out hydraulic lifter (see Chapter 9). To a certain extent, the hydraulic lifter is able to compensate by movement of the plunger in the lifter bore.

NOTE

The plunger is usually centered in the lifter bore, so a change in stem height of more than about 0.060" to 0.085" can cause the valve to remain off its seat. Total plunger travel varies from about 0.120" (General Motors) to 0.170" or more (Ford).

A high lift camshaft or excessive machining of the cylinder head surface can also cause the plunger to move lower in the lifter bore. This must be taken into account when figuring out how much increase in stem height can be tolerated.

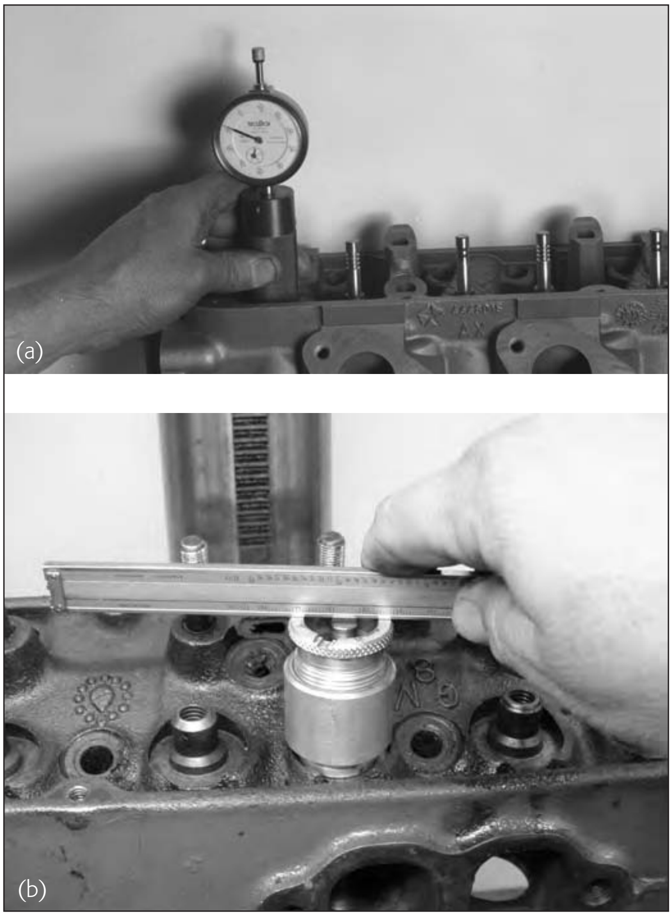


FIGURE 8.50 Tools used to measure valve depth into the head. (a) A dial indicator fixture. (b) This adjustable tool should be adjusted during disassembly of the head. (*Courtesy of Tim Gilles*)

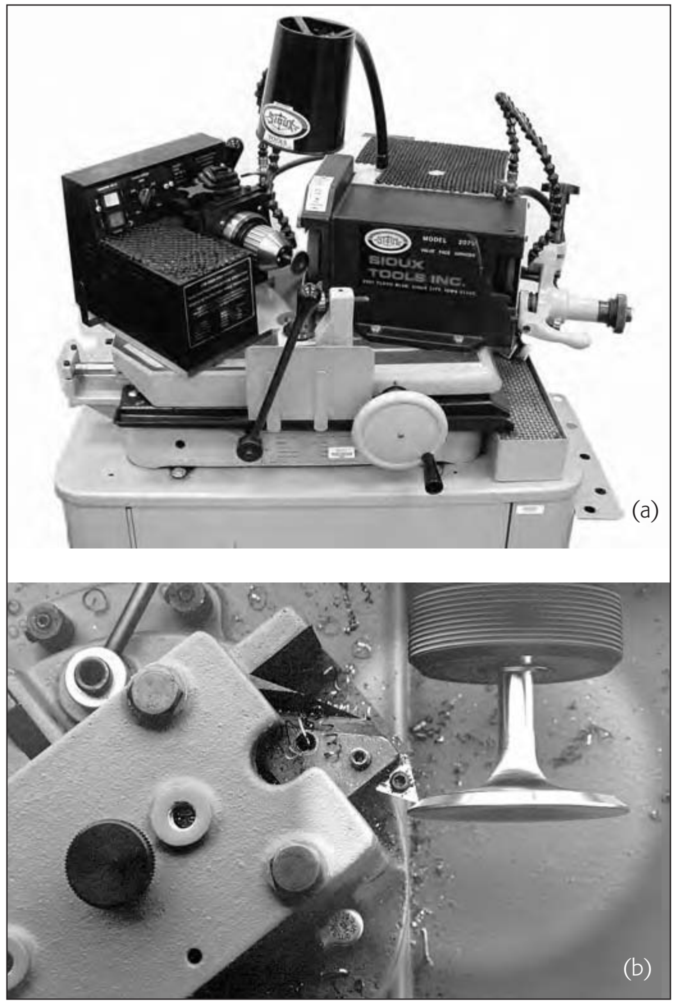


FIGURE 8.51 (a) A valve grinder. (*Courtesy of Tim Gilles*) (b) A valve face cutter. (*Courtesy of Neway Manufacturing, Inc.*)

NOTE

Valve stem height is especially important on overhead cam engines with hydraulic lash adjusters; very little increase in stem height is tolerated.

Dana Corporation recommends that valve stem height be measured before grinding the valve and seat, with height being allowed to increase by no more than 0.030". **Figure 8.50** shows some tools used to check valve depth in the head. Be sure to do this measurement before machining valves and seats because specifications for stem heights for various engines are not always available in service information.

NOTE

This important measurement is not to be confused with "valve spring installed height," although an increase in "spring height" indicates an increase in stem height.

Grinding Valves

Valve faces are ground on a valve grinder (also called a valve refacer), or machined with a valve face cutter (**Figure 8.51**). *Be sure to wear face protection on all operations*. Stones can explode and particles that can injure your eyes are constantly flying through the air.

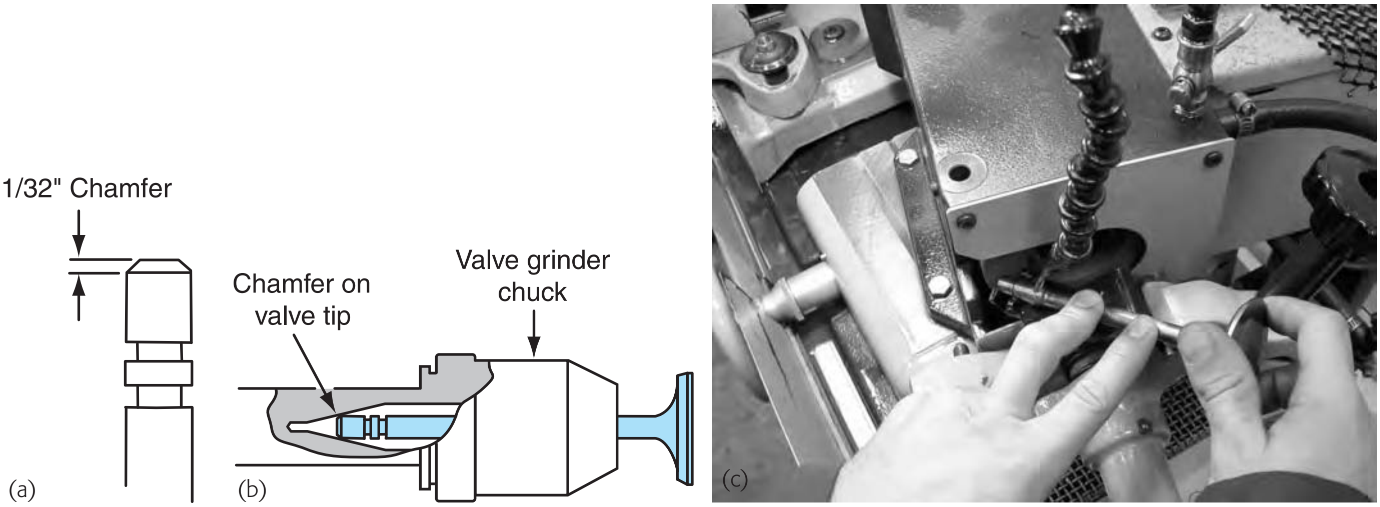


FIGURE 8.52 (a) The chamfer should be about 1⁄32". (b) The chamfer aligns the valve in the Sioux valve grinder. (c) This machine uses a chamfering attachment. *([c]Courtesy of Tim Gilles)*

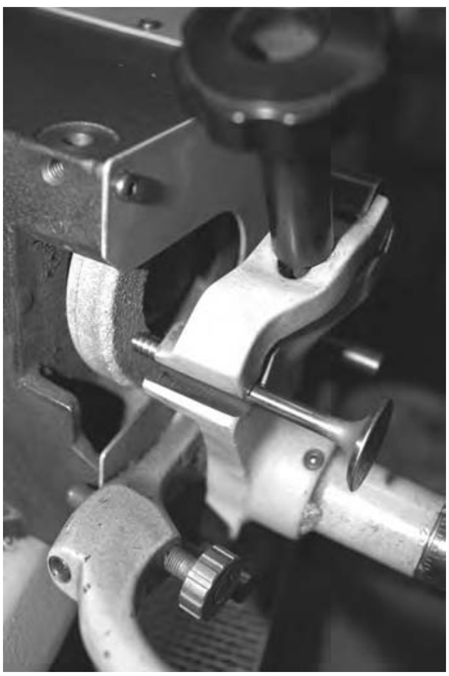


FIGURE 8.53 Grind an amount from the valve stem tip that is approximately double the amount removed from the face of the valve. (*Courtesy of Tim Gilles*)

Chamfer the Valve Tips. Grind the valve stem tips and faces on the valve grinder. On some valve grinders, the tip of the valve is aligned in the rear of the chuck; chamfering must be done first to ensure accurate grinding of the valve face (**Figure 8.52**). Grind only a slight chamfer—0.005" to 0.015"—and no more than 0.031" (1⁄32"). Too much chamfer can result in too small a rocker arm contact area and accelerated valve stem tip wear.

NOTE

If the chamfer on the valve stem tip is uneven and inaccurate, an incorrect angle will be ground on the valve face.

Grind the Valve Stem Tips. Some machinists keep track of the amount ground from the valve face and then double it to compensate for the amount ground from the valve seat. Then they grind this amount from the tip of the valve. Others simply grind 0.010" to 0.015" from all tips (**Figure 8.53**).

NOTE

When grinding a 45° seat, 0.010" of metal removal actually results in about 0.015" vertical movement of the valve stem tip into the head (**Figure 8.54**).

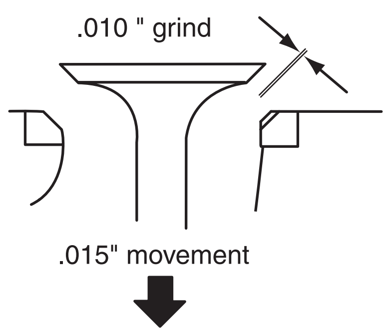


FIGURE 8.54 When grinding the seat, 0.010" of metal removal at the valve seat results in movement of about 0.015" of movement at the valve stem.

Remove less than 0.020" from stem tips. If too much metal is ground away, the hardened area can be eliminated. The tip can be checked for hardness with an old file. A file will not be able to cut a hardened valve tip (but the valve tip will ruin the cutting edge on a good file). Excessive stem tip grinding can also result in interference between the spring retainer and the rocker arm (**Figure 8.55**).

Lash Pad Adjusters. Chapter 17 discusses how to adjust valve lash on OHC heads equipped with shim-type lash adjusters, also called buckets. On these heads, the valve stem tip contacts a pad on the bottom of the bucket (**Figure 8.56**), so grinding the valve stem tip will increase the bucket-to-cam lobe clearance. Unless a collection of replacement shims is available (**Figure 8.57**), it is best to reuse the original lash shims.

The following is a method of adjusting these clearances to fit the original lash shims after grinding valves and seats:

- Leave out the valve springs and install all of the buckets and adjustment shims in the head (**Figure 8.58**).
- Bolt the camshaft in place.
- Individually install each valve in its guide and push it snugly against the inside of the bucket. Use a feeler gauge to measure the clearance between the shim and the heel of the cam lobe (**Figure 8.59**). Write down the measurement as you check each valve clearance.

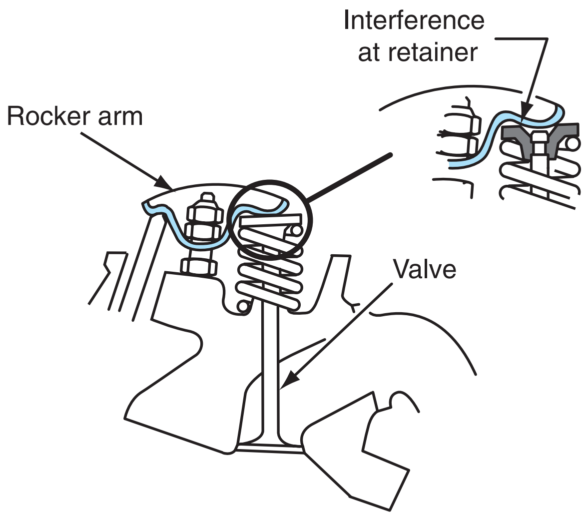


FIGURE 8.55 Excessive grinding of the valve stem tip can cause interference between the rocker arm and the valve retainer.

FIGURE 8.57 Appearance of the inside of a bucket. The valve tip contacts the shiny area at the center. (*Courtesy of Tim Gilles*)

FIGURE 8.56 A selection of valve adjustment shims. (*Courtesy of Tim Gilles*)

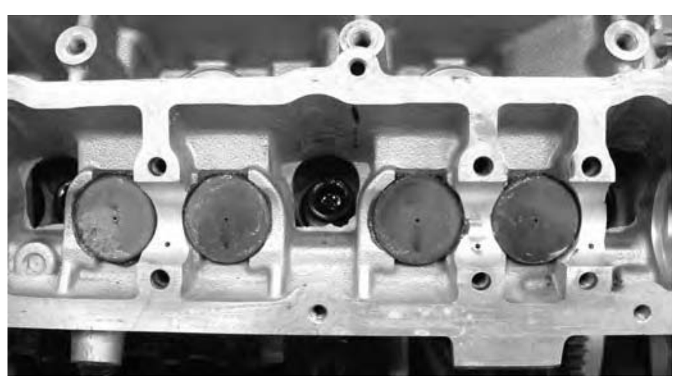


FIGURE 8.58 Cam followers (buckets) installed in the head. (*Courtesy of Tim Gilles*)

VINTAGE ENGINES

Ford flatheads (L-heads) did not have adjustable valves. The tips of the valves were ground to achieve the correct valve lash clearance in the same way lash can be adjusted following a valve job on a head with bucket adjusters. Aftermarket valve adjusters were available for Ford flatheads, however (**Figure 8.60**).

- Move shims around from one valve to another if this will give you a correct measurement.
- Finally, grind any remaining stem tips as needed. Be careful not to remove too much metal or you will have to buy a thicker shim.

Lash shims can also be ground thinner using a magnetic adapter with the valve grinder (**Figure 8.61a**). Grind the shim on the side that does not ride against the cam lobe (**Figure 8.61b**).

Grinding the Valve Face. New valves are already perfectly ground. If they come in an undamaged box, regrinding them before installation should not be necessary. Some technicians like to regrind all new valves because they are not sure whether or not an interference angle is ground on them. Interference angles are covered later in this chapter. Some valves have a dipped aluminum coating to resist corrosion. These aluminized valves should not be ground.

FIGURE 8.60 An aftermarket adjustable mushroom valve lifter for a vintage Ford flathead. *(Courtesy of Tim Gilles)*

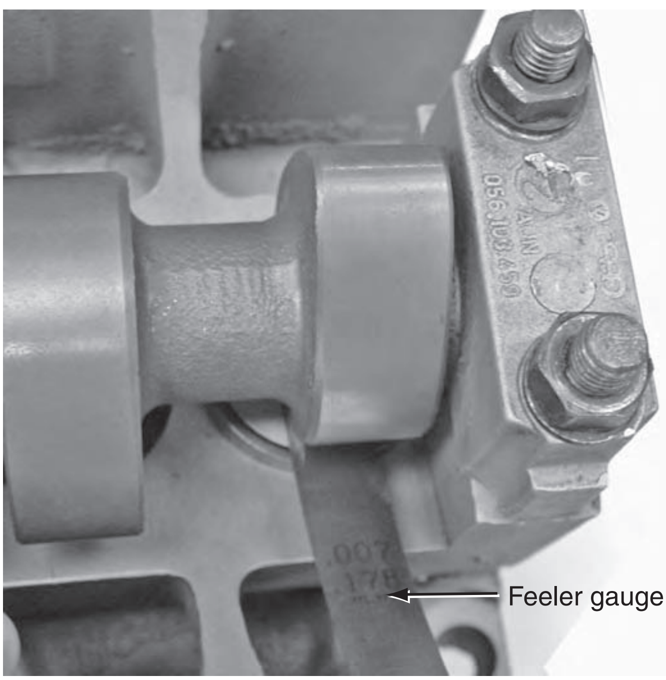


FIGURE 8.59 Push the valve up against the inside of the bucket while you measure the clearance between the heel of the cam lobe and the valve adjusting shim. (*Courtesy of Tim Gilles*)

Before grinding a set of valves, dress the stone with the diamond nib attachment on the valve grinder (**Figure 8.62**). Adjust the diamond tip to remove as little of the stone as possible. Removing too much stone at once can cause the brazed-on diamond tip to be undercut and lost (**Figure 8.63**).

SHOP TIP

A diamond has a sharp spot. Use a magnifying glass to find it. Then, turn it in the dressing attachment to line it up.

Adjust the flow of coolant and dress the stone with the diamond.

Adjust the chuck to grab the valve on the unworn section of the stem at the neck end of the guide rub area. This should be just past the place where the valve would normally contact the guide when the valve is fully closed (**Figure 8.64**).

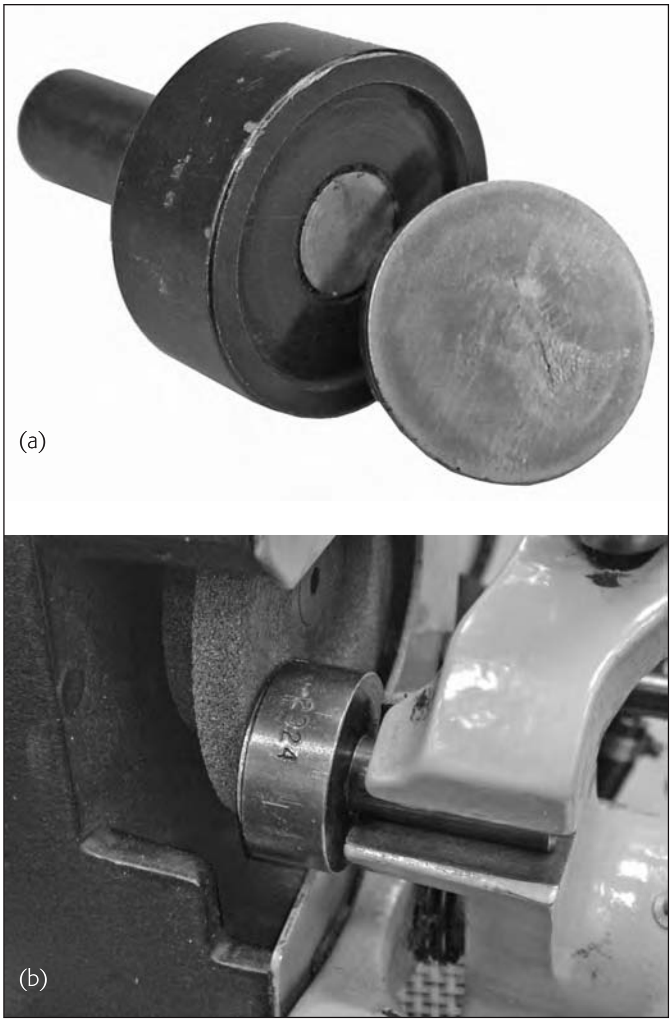


FIGURE 8.61 (a) A magnetic adapter for grinding the underside of the lash adjusting shims. (b) Grinding the lash adjusting shim on a valve grinder. (*Courtesy of Tim Gilles*)

FIGURE 8.62 The valve-grinding stone is dressed with a diamond nib. *(Courtesy of Tim Gilles)*

FIGURE 8.63 This diamond nib was undercut by taking too deep a cut. *(Courtesy of Tim Gilles)*

Adjust the carriage stop (**Figure 8.65a**) so that the valve can be stroked across the entire stone when grinding. (This is not always possible.) Do not allow the neck of the valve to contact the stone or let the valve move off the edge of the stone while grinding.

NOTE

The valve must be replaced if its neck is accidentally ground because this will weaken it in its most critical area (**Figure 8.65b**).

SHOP TIP

Most intake valves are larger than exhaust valves, and they are ground first because they can traverse the entire stone. This leaves the stone in relatively true shape for grinding the smaller, harder exhaust valves. If the exhausts were ground first, they might not be able to traverse the entire stone without striking their necks against the stone. Grinding exhausts first can leave a ridge on the stone that would have to be removed before grinding the intake valves. The stone can be undercut if it is too wide for the majority of valves being ground (**Figure 8.66**).

Valve-Face Angle. Adjust the valve grinding angle to 30° or 45°, depending on the specification for the cylinder head (**Figure 8.67**). Valve angles are usually 45°. A 1° flatter **interference angle** (44°) will exert more pressure on the contact area and can help the valve face and seat conform to each other (**Figure 8.68**). The interference angle helps keep heat in the combustion chamber rather than allowing it to be absorbed into the valve seat. This is because heat stops at a line, which, in this case, is the line that is formed at the top of the interference angle. It is important, therefore, that the interference angle be going the correct direction, with the valve flatter than the valve seat.

NOTE

According to the Dana Corporation, the interference angle is usually not evident after the valve and seat become mated to each other (usually within about 100 miles).

With hardened valves and valve seats, like those used on heavy-duty, propane, or natural gas engines, interference angles are not desirable; the face and seat are ground to the same angle.

FIGURE 8.65 The valve should traverse the entire grinding-wheel face. (a) Adjust the carriage stop so that the neck of the valve will not come into contact with the stone. (b) This valve has been ruined because the neck area was accidentally ground. It should be discarded. (*Courtesy of Tim Gilles*)

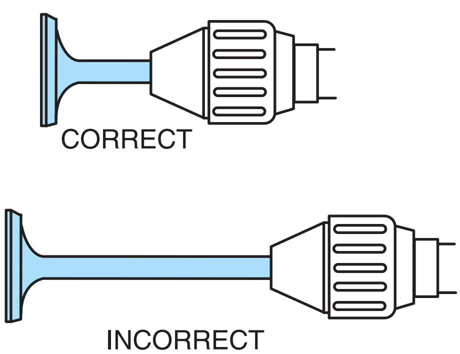


FIGURE 8.64 Adjust the depth of the valve in the chuck so it is clamped where it would normally contact the valve guide.

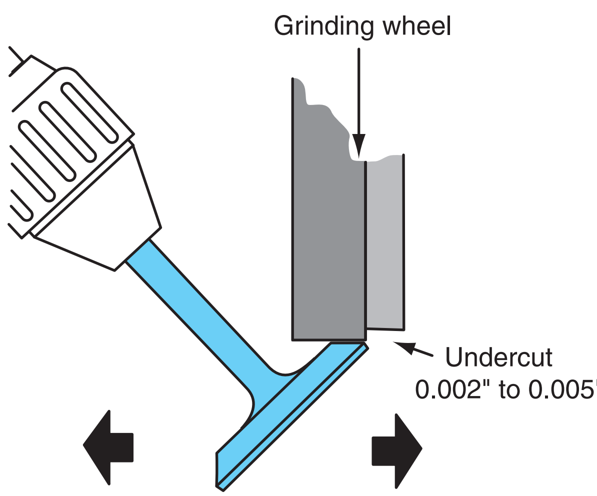


FIGURE 8.66 The grinding wheel can be undercut for smaller valves.

FIGURE 8.67 The head stock on the valve grinder is adjusted to the correct angle before grinding the valve. (*Courtesy of Tim Gilles*)

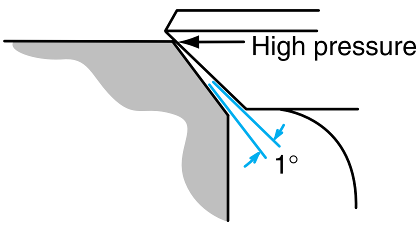


FIGURE 8.68 An interference angle causes high pressure to help the valve quickly conform to the valve seat.

Using a Valve Grinder

Before grinding a valve, adjust the coolant to flow onto the valve face (**Figure 8.69**).

NOTE

If the coolant is allowed to flow onto the grinding wheel, it will be sprayed onto the floor.

- Grind only enough to remove any area of the valve face that is worn. You will be able to hear noise when the wheel begins to touch the valve. At this point, note the reading on the hand wheel (**Figure 8.70**). Then check it again after the valve face is cleaned up so you know how much metal you are removing. Less than 0.005" is typical.
- Before pulling the valve sideways, out of contact with the stone, unload it by backing off the tension on the feed wheel. This provides a better

FIGURE 8.69 Adjust the coolant to flow over the valve face during grinding. (*Courtesy of Tim Gilles*)

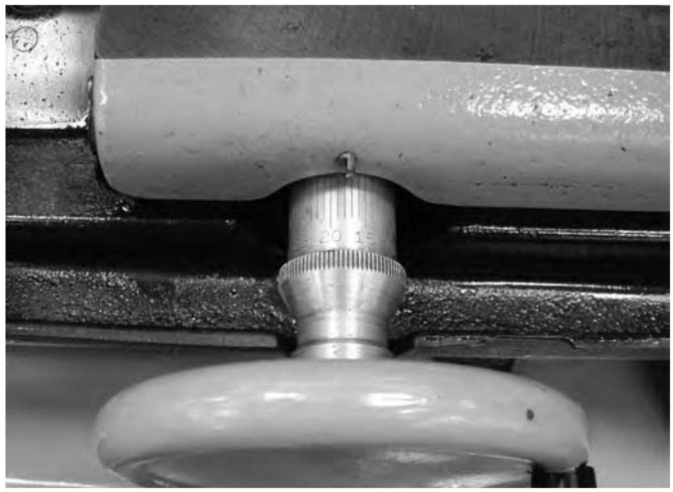


FIGURE 8.70 Note the amount of valve face removal by observing the total movement of the hand wheel. (*Courtesy of Tim Gilles*)

finish and ensures that the next valve will not accidentally run into the side of the stone.

A finer finish is obtained by letting the wheel "spark out," sometimes called finish grinding. Maximum runout following grinding of a face or seat should be less than 0.002".

Valve Margin. The margin of the valve should not be sharp after face grinding (**Figure 8.71**). If the margin is too thin, the valve (especially the exhaust) will glow red hot and can burn or distort. Some engine parts companies list specifications for margin size in their parts books. On pushrod engines with two valves per cylinder, the rule of thumb for minimum

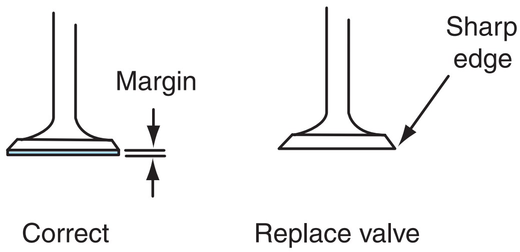


FIGURE 8.71 The margin should be at least $\frac{1}{32}$" after refacing. The valve on the right has been ground too much.

FIGURE 8.72 During valve grinding, it became obvious that these valves were defective and should be discarded. (*Courtesy of Tim Gilles*)

FIGURE 8.73 This valve has already started to burn. Its metallurgy has been changed and it should not be used. (*Courtesy of Tim Gilles*)

margin thickness is usually $\frac{1}{32}$" minimum. Today's valves tend to be smaller and lighter in weight. When in doubt, compare the margin thickness of the valve with that of a new valve to see if it is sufficient.

When the valves shown in **Figure 8.72** were ground, it was apparent that they were defective. Further grinding would provide a margin of unequal thicknesses around the circumference of the valve and unequal valve cooling would result.

NOTE

If a valve looks like it has started to burn, it should be replaced whether it will clean up during grinding or not. The structure of its metal has been changed by the severe heat and it will fail if reused (**Figure 8.73**).

VALVE SEATS AND SERVICE

Valve seats undergo tremendous punishment in modern engines, so they must be quite hard. Seats are either integral or replaceable (**Figure 8.74**). Integral seats are a part of the cylinder head. Most engines with cast iron heads use **integral seats** because they are less expensive to produce. To reduce seat wear, integral seats are usually **induction hardened,** which hardens only the seat area of the head. Integral seats operate approximately 150°F (66°C) cooler than replaceable seat inserts because there is no barrier to heat transfer.

Replaceable seat inserts are used in aluminum heads and in iron heads needing seat replacement. Seat inserts are made of iron, Stellite® (hard seats), or powdered metal. Check to see that replaceable seats remain tight in the head by prying on them, or hold a finger against the seat while tapping on the other side of it with a hammer. If a loose seat is found, the head may be cut to accept an oversized insert (**Figure 8.75**).

VINTAGE ENGINES

Some vintage automotive and motorcycle engines had bronze intake valve seats. During service, these were often removed and replaced with hard seats. Cutters should be used on bronze seats instead of stones, because stones will load up with bronze.

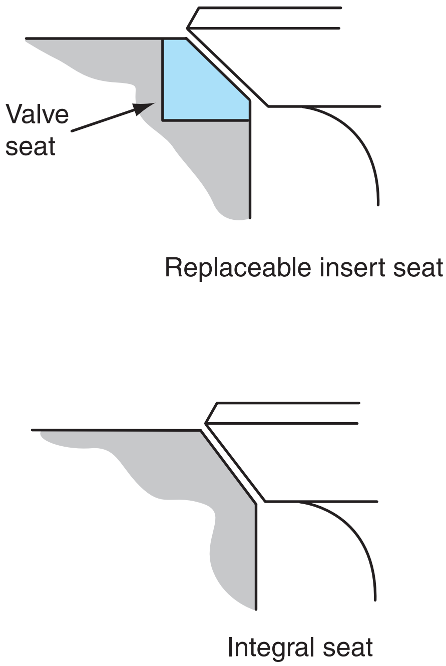


FIGURE 8.74 Replaceable and integral valve seats.

FIGURE 8.75 A replaceable valve seat insert is slightly oversized so it will be retained in the head.

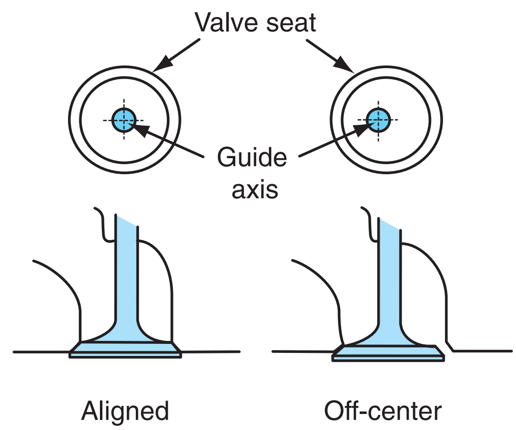


FIGURE 8.76 All guide work must be completed before refinishing valve seats.

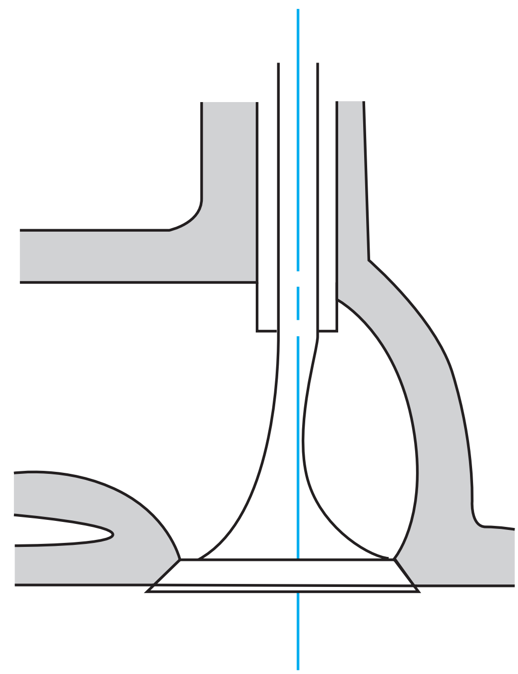


FIGURE 8.77 A valve that is slightly off-center on its seat can flex once it gets hot. The engine will have a rough idle when cold.

Repair Valve Guides before Machining Valve Seats

Any necessary valve guide repair must be done prior to machining the valve seats, or the result will be an off-center valve seat that must be remachined after the guides are repaired. **Figure 8.76** shows the result of an off-center guide axis, which will cause the valve to leak, resulting in a rough idle when the engine is cold. The valve will heat up very fast after startup, becoming like plastic and conforming to the valve seat, resulting in a smooth idle when warm (**Figure 8.77**).

Pilots

The pilot used when grinding or cutting a valve seat fits snugly in the valve guide to provide proper alignment between the guide and seat. First, the pilot is pushed tightly into the valve guide. Then the stone holder is slid onto the pilot.

Pilots are of two types (**Figure 8.78**). One type is available in increasing increments of 0.001". Select a pilot that fits the guide correctly. A small section at the top of the guide area of the pilot is tapered so that the pilot will be tight in the guide when pushed all the way in (**Figure 8.79a**).

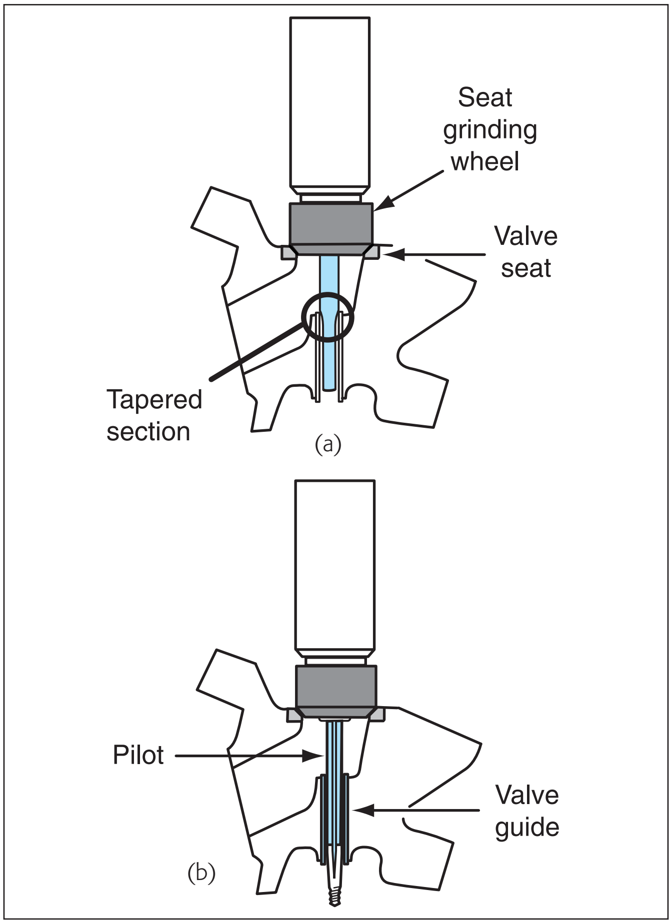


FIGURE 8.78 Valve-grinding pilots. (a) The top portion of a plug-type guide pilot is slightly tapered. The pilot aligns on the least worn area at the middle of the valve guide. (b) This pilot is tapered and has an expandable collet. Turning the top of the pilot clockwise tightens it in the guide.

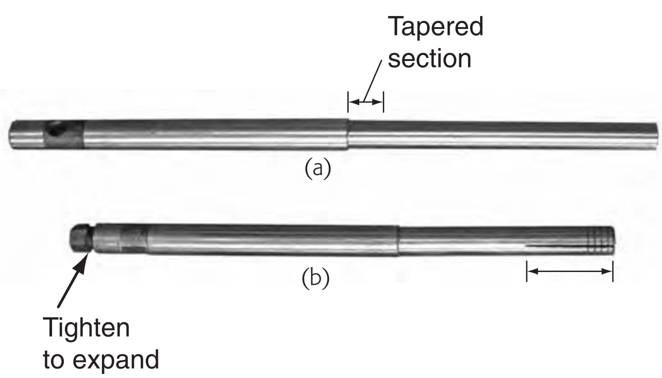


FIGURE 8.79 (a) A small section of this type of guide pilot is tapered to lock it against the top of the valve guide. (b) Tightening the nut at the end of this type of pilot expands the base of the guide. *(Courtesy of Tim Gilles)*

The other type of pilot is tapered, with an expander that wedges the pilot against the inside of the guide as it is tightened (**Figure 8.79b**). This type of pilot can be used with guide sizes that vary by a few thousandth of an inch, but it does not provide guide alignment that is as accurate as using individual pilots designed for each valve guide size. It can also cause problems with the bronzewall (thread) type of guide insert, which can be screwed out as the pilot is turned in the guide.

Grinding or Cutting Seats

Seats are usually finished to a 45° angle, although sometimes 30° seats are specified (usually only on intake valves in vintage engines). Seats are refinished with grinding stones (**Figure 8.80**) or with carbide cutters (**Figure 8.81**). Grinding produces a smoother seat than cutting and is effective on extremely hard seats. Wet grinding systems are available for controlling dust.

When selecting a seat grinding stone or cutter, choose one of the correct angle. It should be approximately ⅛" larger than the diameter of the valve head. Before grinding, seats must be cleaned of all dirt or carbon or the stone will "load up."

Dressing the Stone

Dressing the grinding stone cleans its surface and "trues" it to the specified angle (**Figure 8.82**). With a light cut, stroke the diamond dresser fast enough to keep the stone from becoming glazed. The surface of a stone that is overheated melts, resulting in a dull, glazed surface.

FIGURE 8.80 Grinding a valve seat. (*Courtesy of Tim Gilles*)

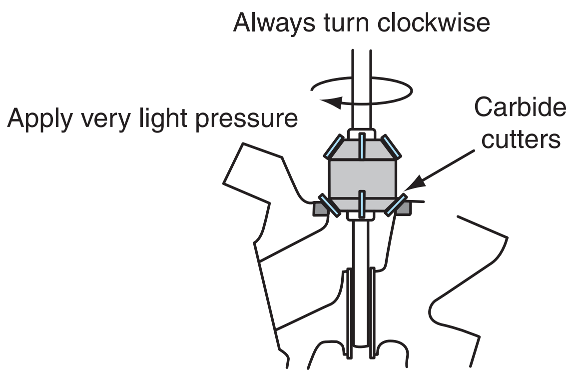


FIGURE 8.81 Seats are sometimes refinished with a carbide seat cutter.

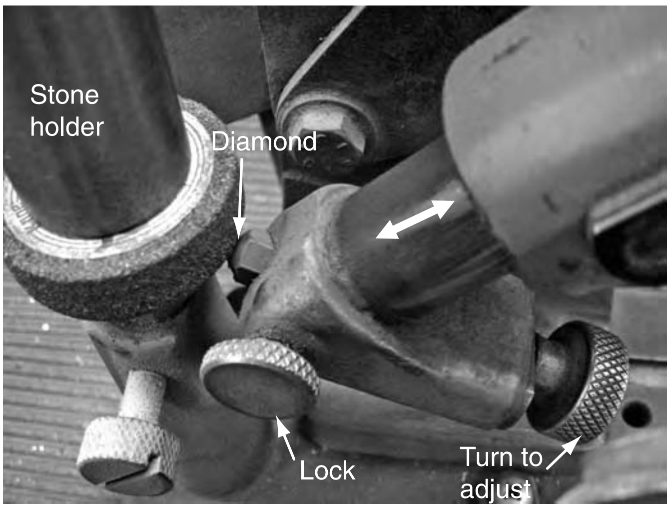


FIGURE 8.82 The stone holder is driven with a driving motor while moving the diamond up and down across the face of the grinding stone. *(Courtesy of Tim Gilles)*

CAUTION

Stones occasionally explode, so be sure to use face protection (**Figure 8.83**).

Diamond dressers can be damaged if too much stone is removed during the dressing process. The stone undercuts the brazed-in industrial diamond and the diamond is lost.

To ensure accurate angles, redress the stone every time it is unscrewed from the holder. For this reason, a different stone holder is used for each stone used during the grinding operation (usually three for each seat).

Stone Holders

Stone holders are either bushing or ball bearing types. Many of the more deluxe seat grinders use

FIGURE 8.83 These seat grinding stones exploded during use. Use eye protection! (*Courtesy of Tim Gilles*)

FIGURE 8.84 A ball bearing seat stone holder. The bottom thread was damaged by the diamond dresser when attempting to dress an excessively worn stone. (*Courtesy of Tim Gilles*)

ball bearing stone holders (**Figure 8.84**), which do not wear out the pilot. When using a bushing-type stone holder, lubricate the pilot. Ball bearing stone drivers can also be used with a lifting spring (**Figure 8.85**), which results in a smoother seat finish. A lifting spring cannot be used with a bushing-type stone holder so grab and lift the stone holder away from the valve seat while it is still spinning to obtain a smooth seat finish.

After grinding, valve seat runout should be less than 0.002". When grinding a seat, do not allow the weight of the grinding motor to rest on the stone holder. Support the motor, if necessary, with your free hand. Holding it incorrectly usually produces an abnormal sound, which goes away when the motor

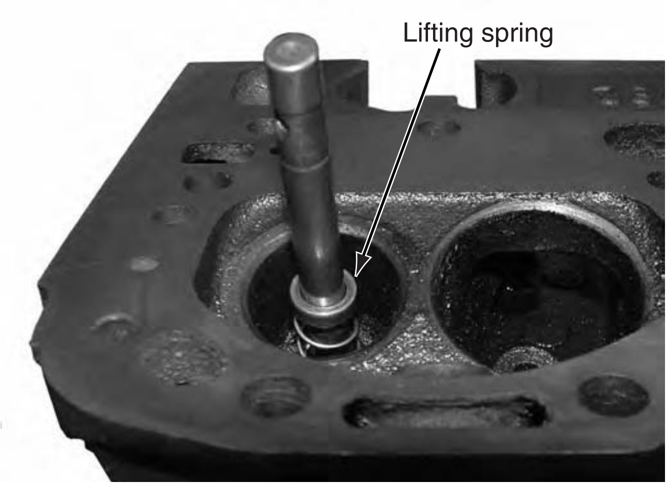


FIGURE 8.85 A lifting spring. *(Courtesy of Tim Gilles)*

and stone holder are aligned. Also, the stone holder will become hot if it is not held at 90° to the stone.

Seat grinding motors are air operated or electric. Electric motors are heavier but quieter than air motors. It is easier to cut a concentric (on center) seat with an air motor, which can be used with one hand.

Hard seats require a special hard-seat grinding stone. There are several grinding stone types and hardnesses. A stone can be made sharper during dressing by passing the diamond nib across the stone more quickly.

Portable Carbide Cutters. Carbide cutters are turned by hand or with an electric motor. We are *not* referring here to the high-speed three-angle cutters used in sophisticated valve seat machines but the two processes share some advantages.

Carbide cutters have several advantages:

- They are quiet.
- They remain clean.
- Their angle remains true.
- They do not blow grinding dust around the shop.

There are disadvantages to carbide cutters as well:

- Carbide is fragile. If the cutter is allowed to drop down the pilot onto the valve seat, the carbide can chip (**Figure 8.86**).
- Each carbide blade is relatively expensive. It is advisable to use a lifting spring, as shown in Figure 8.85, to avoid accidentally chipping the cutter.

Portable carbide cutters are not as fast as grinding and they do not produce as smooth a finish.

FIGURE 8.86 Carbide seat cutter bits are fragile and can chip easily. Using a lifting spring under the seat cutter can prevent accidental chipping. *(Courtesy of Tim Gilles)*

Seat Width

Intake and exhaust valve seats differ in width (**Figure 8.87**). Intake seats are narrower because intake and exhaust valves use interchangeable valve springs, even though intake valves are larger in diameter than exhaust valves. If intake and exhaust seat pressures are to be equal, the area of seat contact must be narrower on the larger intake valves.

Intake valves are cooled by incoming air and fuel. Therefore, a wide valve seat is not as crucial as it is with exhaust valves. Exhaust seats must have enough width and pressure to provide sufficient cooling through the water jackets, behind the valve seat and guide. Seat widths vary, depending on the application and the size of the valve.

Approximate valve seat widths are:

- 0.060" (1⁄16") for intakes
- 0.090" (3⁄32") for exhausts

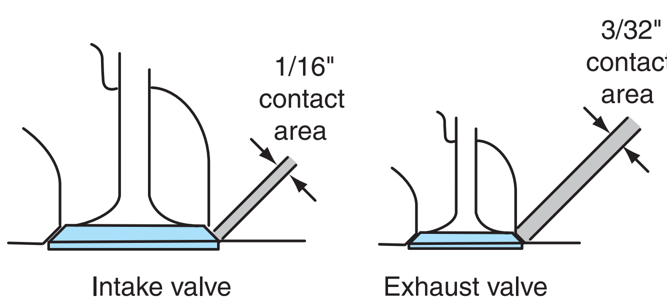


FIGURE 8.87 Intake and exhaust seat width.

- Some recent engines with smaller valves and lighter valve spring pressure use valve seat widths as narrow as 0.030"

NOTE

Seat width specifications are not always available. It is normal for valve seats to become wider as they wear, although modern hard seats do not usually experience appreciable wear. If valve face wear appears to be normal, it makes no sense to widen the valve seat further during the grinding process. It should be restored to its approximate original size.

Seat Refinishing Angles

Valve seat refinishing is a three-angle process (**Figure 8.88**). Cutting or grinding all three angles is not always necessary, but a good understanding of the process is needed before shortcuts can be taken. **Figure 8.89** shows a valve seat that is off-center in relationship to the valve guide. A three-angle valve seat will correct this, producing a 45° face angle of equal width around its circumference.

NOTE

A few manufacturers (Alpha Romeo, Porsche, Rolls Royce, and Harley-Davidson), have produced cylinder heads with a shroud area surrounding portions of the valve seat that does not allow narrowing from the top. These heads call for undercutting, or back-cutting, the valves instead. Some hemi-heads share this same situation.

The three angles are called the face, the top, and the throat.

Face Angle. The first valve seat angle to refinish is the angle that matches the valve face. This is usually 45°, but refer to the manufacturer's specification to be certain. Do not remove any more metal than what is needed to clean up the valve seat area. Removing too much of the valve seat will position the valve too far into the head. A seat positioned too low can result in an obstruction to air and fuel flow into or out of the cylinder. A low seat can also result in lower valve spring pressure, incorrect rocker arm geometry, and hydraulic lifters that bottom out in their bores.

NOTE

When remachining an exhaust valve seat, sometimes you will find that the valve seat does not align with the pilot, resulting in grinding on one side more than the other. This occurrence, known as a *migrated exhaust seat*, happens more commonly with aluminum heads because aluminum tends to move around.

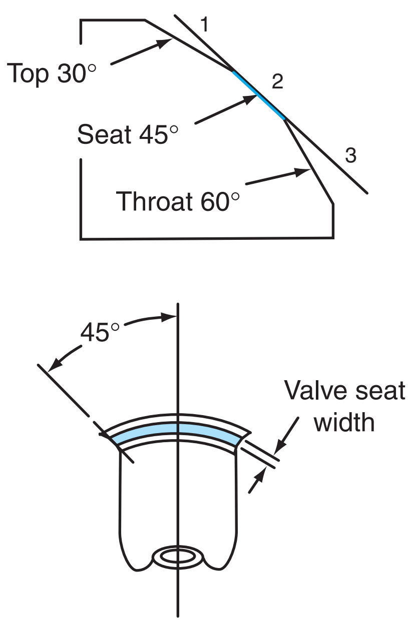


FIGURE 8.88 A three-angle valve seat.

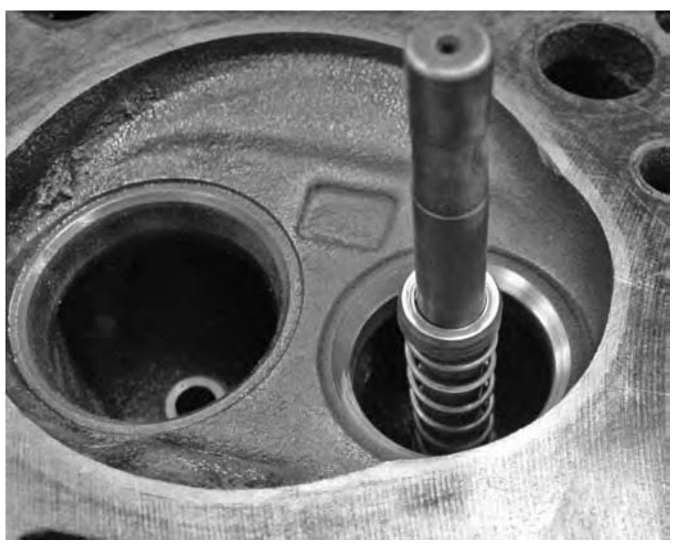


FIGURE 8.89 This valve seat is off-center in relation to the valve guide. A three-angle valve seat could correct this. *(Courtesy of Tim Gilles)*

SHOP TIP

You will sometimes grind a valve seat that turns out to be wider on one side than it is on the other (**Figure 8.90a**), especially after valve guides have been repaired. You can quickly correct this by grinding the face angle until the narrowest part of its refinished section is as wide as the seat width you want to achieve (**Figure 8.90b**). Then grind the top and throat angles until they intersect with the edges of the face angle.

Top Angle. After the face angle has been ground, it can be positioned using a stone of a flatter angle (either 30° or 15°). "Topping" the seat with a flatter angle will expose about 1⁄32" of the valve face to the combustion chamber. This is called *overhang* (**Figure 8.91**).

If you position the valve seat so it centers on the face of the valve, it will function correctly, but there are two drawbacks:

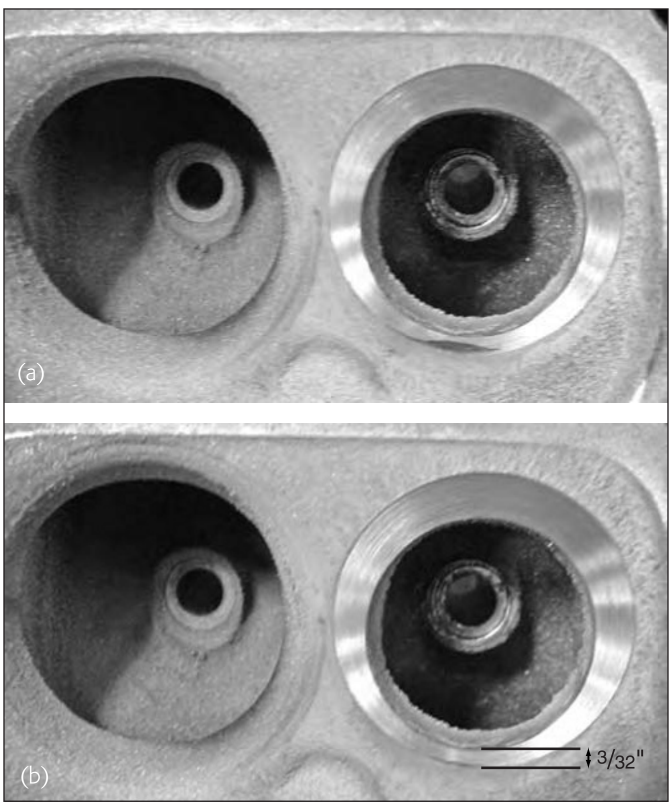


FIGURE 8.90 (a) This valve seat is badly misaligned to its valve guide but is good for illustration purposes. One 45° section of the valve seat still requires more grinding. (b) The narrowest part of the 45° angle is now wide enough to provide sufficient seating area following topping and throating. *(Courtesy of Tim Gilles)*

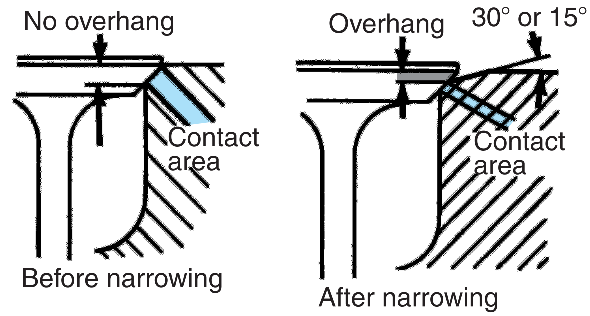


FIGURE 8.91 The top angle causes the valve to overhang 1⁄32" into the combustion chamber.

- When a valve is ground, its face becomes wider and the center of the wider valve face will be in a different position than it would be on a new valve.
- The valve expands as it warms up during use. This causes it to climb up the valve seat nearer the neck edge of the valve face.

In order to maintain consistency, and for faster, easier seat grinding, about 1⁄32" of overhang is recommended.

Overhang can be obtained using the following procedure:

1. Color the reground seat with a felt marker or Dykem® Hi-Spot Blue (**Figure 8.92**).
2. Set a pair of dividers to about 1⁄16" (1⁄32" per side) less than the diameter of the valve head (**Figure 8.93a**).
3. The top angle is 30° or 15°. Grind it until its lower edge meets up with the face angle at the same diameter as the divider setting (**Figure 8.93b**).

To verify the position of the valve seat, tap the valve down firmly against the valve seat to leave a distinct line where the top edge of the 44° interference angle intersects the 45° valve seat (**Figure 8.94**). The line should be 1⁄64" to 1⁄32" from the top edge of the valve face. Prussian blue works well to make the line easier to see. Coloring the valve face with a felt marker is another method.

Throat Angle. The last angle to grind is the "throat" angle, which is a steep angle of 60° to 70°. After the top angle is ground, if the seat width is equal on all sides, *the throat operation will not be necessary*. If the valve guide is not perpendicular to the valve seat, the face angle will be wider on one side than the other. Grinding all three angles corrects this (**Figure 8.95**). **Figure 8.96** shows the 45° seat, evened out in width after three-angle grinding.

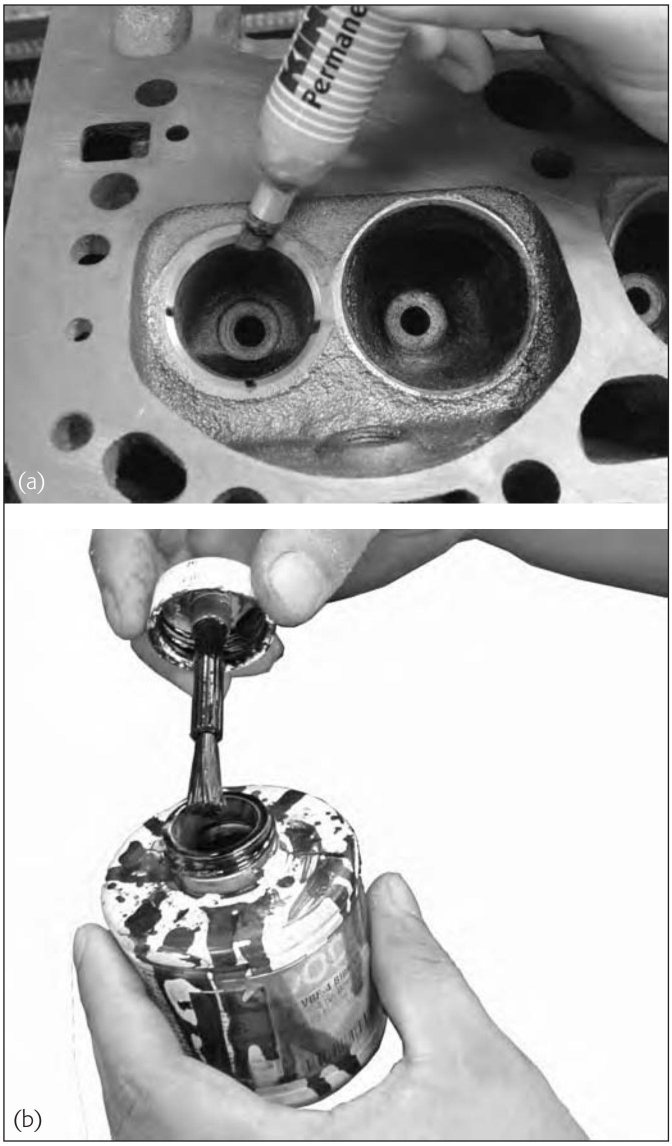


FIGURE 8.92 (a) Color the valve seat. (b) Dykem blue is a fast-drying liquid that can be painted onto metal surfaces prior to machining. *(Courtesy of Tim Gilles)*

Rarely, the seat width is still too wide after topping. Grinding the throat angle will narrow the seat. **Figure 8.97** shows seat width measurement.

Be careful! A 60–70° throat stone cuts very fast and can quickly ruin a valve seat. Cutting too much at this sharp angle on the inside of the seat will require the installation of a new replaceable seat insert. To see if the seat width is equal all around, the throat stone can be turned against the seat by hand *without* the grinding motor.

Some machinists like to grind the 60° angle after the 45°. A very light cut is taken (just so that it touches all along the lower edge of the 45° seat). Then the 30° angle is cut until the width of the seat is correct.

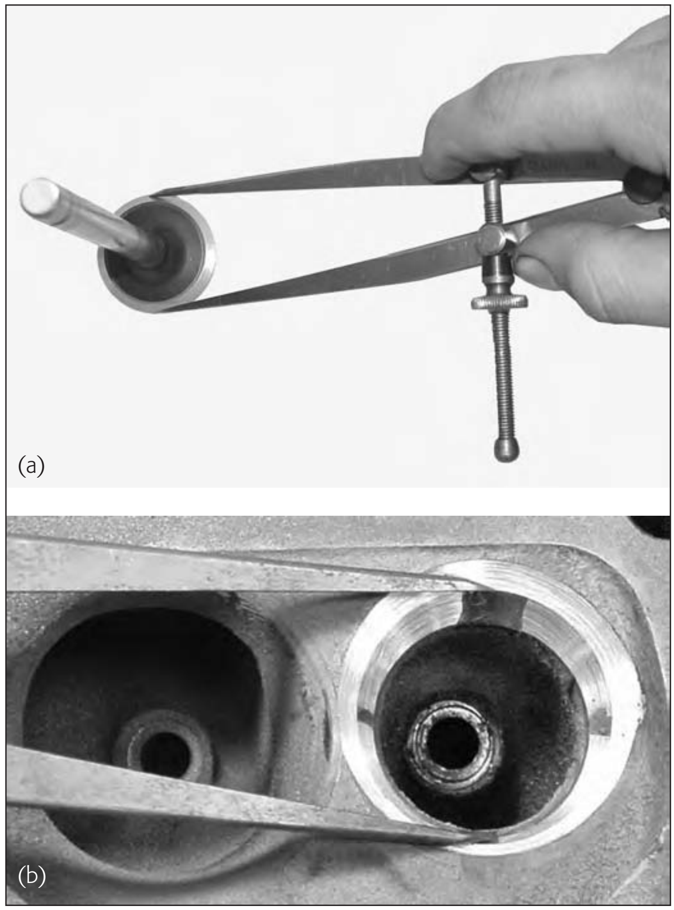


FIGURE 8.93 (a) Set the dividers 1⁄16" smaller than the valve head diameter. (b) Grind the top angle until the lower edge of the area being ground fits the dividers. *(Courtesy of Tim Gilles)*

If valves and seats are not ground evenly and accurately, the valve seats will not match their valves and a rough idle can result. This problem can usually be eliminated by polishing the seat with a fine 45° stone after the top and throat angles are ground. Grinding the top and throat sometimes leaves a small burr that the fine 45° stone removes.

After the seats have been refinished, they need to be cleaned thoroughly.

SHOP TIP

Before reassembling a cylinder head, perform a **solvent test** to see if any of the seats are leaking. Place the head on head stands on a platform in the solvent tank and install the spark plugs and all of the valves. Be sure the head surface is level and fill each combustion chamber with liquid (**Figure 8.98a**). If any liquid leaks past the seat (**Figure 8.98b**), that valve seat must be reworked before assembling the head to the engine.

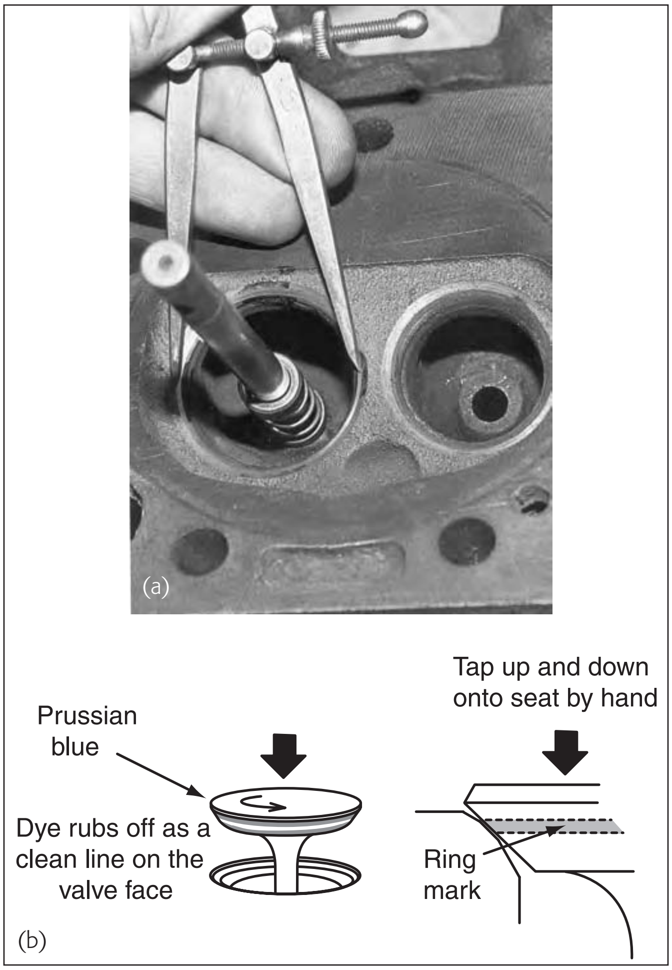


FIGURE 8.94 Tap the valve against the valve seat.

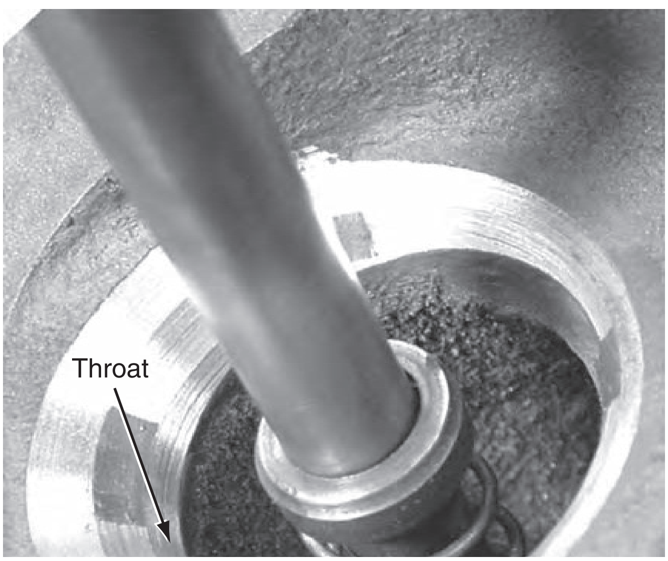


FIGURE 8.95 The throat (60°) angle is starting to correct the unequal width of the 45° face angle. A small amount of further throat grinding will equalize the 45° seat width when the stone begins to touch at the point shown by the arrow. *(Courtesy of Tim Gilles)*

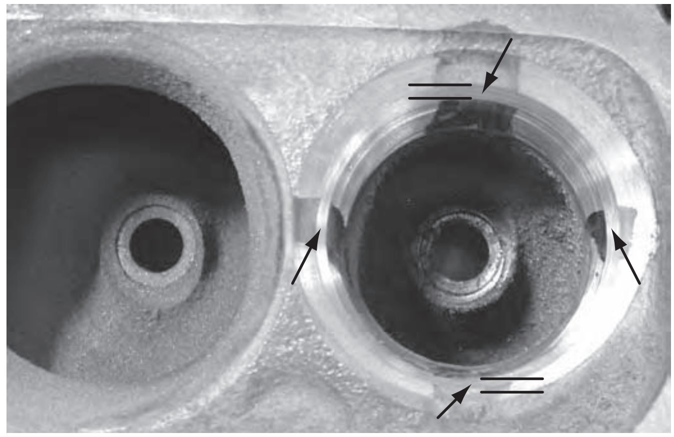


FIGURE 8.96 The shiny 45° area is of even width following three-angle grinding of the seat. *(Courtesy of Tim Gilles)*

FIGURE 8.97 Measuring seat width. *(Courtesy of Tim Gilles)*

Leaking valves and seats are easily corrected now. They can be *lapped* to correct or highlight a problem.

Lapping Valves

Sometimes valves are lapped with a fine wet grinding compound between the valve face and seat. Using a suction cup attached to the valve head, the valve is twisted against the valve seat. **Figure 8.99** shows a valve face that has been lapped. Students like to lap valves because it is reassuring to see a pattern like this after grinding the valve seats. But lapping valves is time consuming and the valve expands when hot, so that the lapped area of the valve does not align with the lapped area of the seat. Many consider lapping valves to be an obsolete

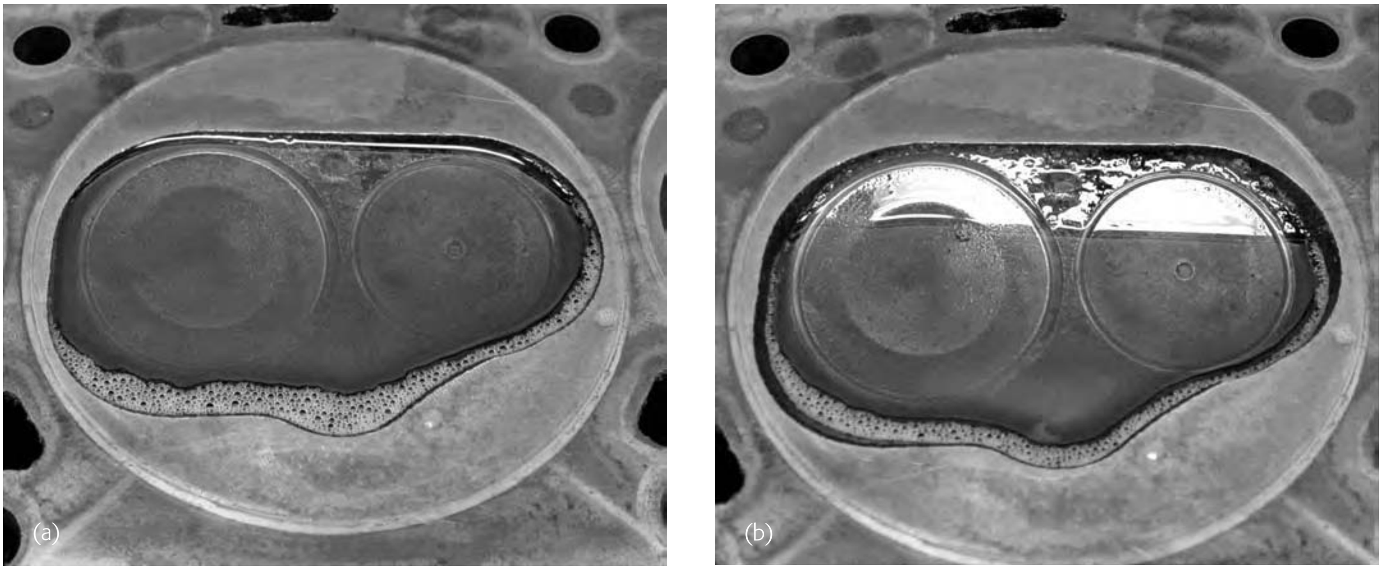


FIGURE 8.98 Solvent test for valve seating. (a) Fill the combustion chamber. (b) One of these valve seats is leaking. *(Courtesy of Tim Gilles)*

FIGURE 8.99 This valve has been lapped. Notice the pattern on the valve face, which is slightly high and with a small gap below the margin. *(Courtesy of Tim Gilles)*

practice. However, some Japanese and European service manuals still list lapping as the preferred method of refinishing valve seats.

SHOP TIP

Lap all the seats using one old valve ground to the same angle as the seats. This will provide a smooth seat without undercutting any of the reground interference-angled valve faces. To power lap the seats, a drill motor can be used to drive a piece of drill rod and $\frac{5}{16}$" fuel hose slipped over the top of the valve stem. There are also special tools for this purpose.

NOTE

Lapping compound leaves fine grit on the valve seat. Cleanup after lapping must be thorough.

Three-Angle Valve Seat Machines

Sometimes all three angles are cut at once with a single special cutter in a seat and guide machine, which also cuts all seats to the correct height (**Figure 8.100**). High-tech valve seat machines have air beds that allow centering with each individual valve guide instead of the machine bed. A solid carbide pilot (these do not bend) is inserted into the guide. The spindle free-floats to allow alignment with the valve guide, no matter how much the guide might be misaligned to the head. **Figure 8.101** shows how one type of seat cutter is adjusted.

Replacing Valve Seats

Valve seats sometimes crack, burn, or wear excessively. Whether the head has integral or insert valve seats, they can be replaced with new replaceable hard seat inserts. When a cylinder head has an excessively worn valve guide, the valve can pound and slide against the valve seat until it becomes excessively wide Replaceable hard seats are called

FIGURE 8.100 Cut the valve seat. *(Courtesy of Tim Gilles)*

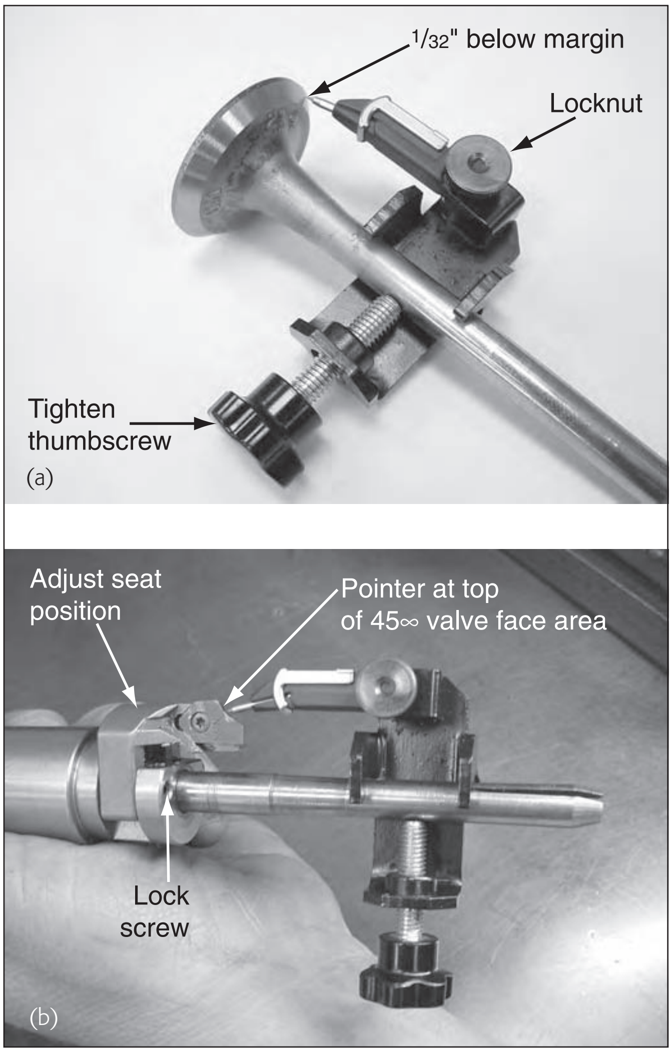


FIGURE 8.101 (a) Adjust the setting fixture on the valve. (b) Adjust the three-angle bit to match the setting fixture. *(Courtesy of Tim Gilles)*

for when propane fuel will be used, or when an older engine was not factory equipped with hardened valve seats.

Worn or damaged seats can be replaced using a seat and guide machine or a portable seat ring cutting tool.

The following procedures describe the valve seat replacement process.

Installing a valve seat in a cast iron head:

- Cut a counterbore (**Figure 8.102**). When cutting an integral seat, no lubricant is used.
- The guide and seat machine has a feature that allows the seat to be cut to the correct depth (**Figure 8.103**).

NOTE

When a valve seat extends above the surface of the surrounding combustion chamber surface, this is referred to as a **proud surface.** This term is also used when referring to cylinder sleeves and diesel precombustion chambers.

NOTE

Be very careful not to cut too deep or wide. Cutting into a water jacket will result in a ruined head.

Recommended Interference Fits, Hard Cast or Wrought Inserts; Cast Iron Port

Outside Diameter, in.	Insert Depth, in.	Interference Fit, in.
0–1	0–1/4	0.001–0.003
1–2	1/4–3/8	0.002–0.004
2–3	3/8–9/16	0.003–0.005
3–4	9/16–16/16	0.004–0.006

FIGURE 8.102 A counterbore is cut to the recommended size to fit a replaceable seat. *(Courtesy of Tim Gilles)*

FIGURE 8.103 The guide and seat machine has a feature that can be set to cut the seat to the correct depth. *(Courtesy of Tim Gilles)*

- The seat ring is pounded or pressed into a slightly smaller space; the outside diameter of the seat is approximately 0.003" to 0.006" larger than the cut (**Figure 8.104**). This is called an *interference fit.*

Installing a valve seat in an aluminum head:

- Use a lubricant when cutting.
- The interference is from 0.006" to 0.010".
- For easier installation, aluminum heads can be heated in an oven and the seat is frozen so it shrinks.

Following installation, some machinists stake the seat by peening around the edge to make sure that it stays in place. The interference fit of the seat is the most important factor, however, so most shops do not peen.

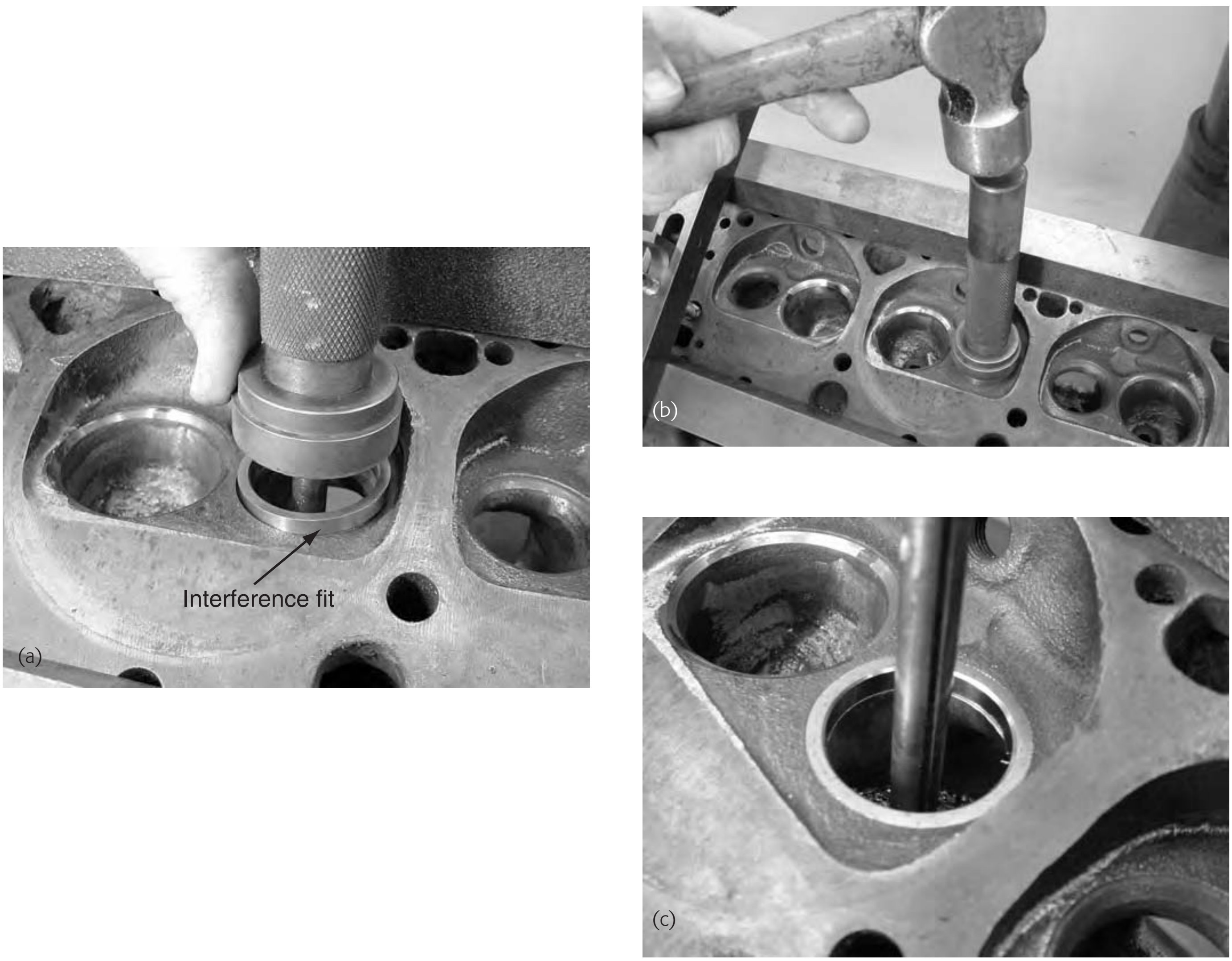


FIGURE 8.104 The new seat ring is pounded into place. *(Courtesy of Tim Gilles)*

After installing a seat, machine it so it is perpendicular to the valve guide. Then verify its correct depth in the head. This can be altered by machining the 45° angle until the valve stem tip height is the same as the previously ground neighboring valves. Sometimes a seat is being replaced because there was too much stem tip height. Obvious problems with tip height can be spotted by laying a straightedge across the tips of all the valves when the head is assembled (**Figure 8.105**). Stem height is covered earlier in this chapter.

Removing Valve Seats

Prying against a valve seat in an aluminum head can damage the head. To remove an old seat insert, cut the seat out using the next smallest seat cutter in the set, leaving a thin piece that can be easily removed (**Figure 8.106**).

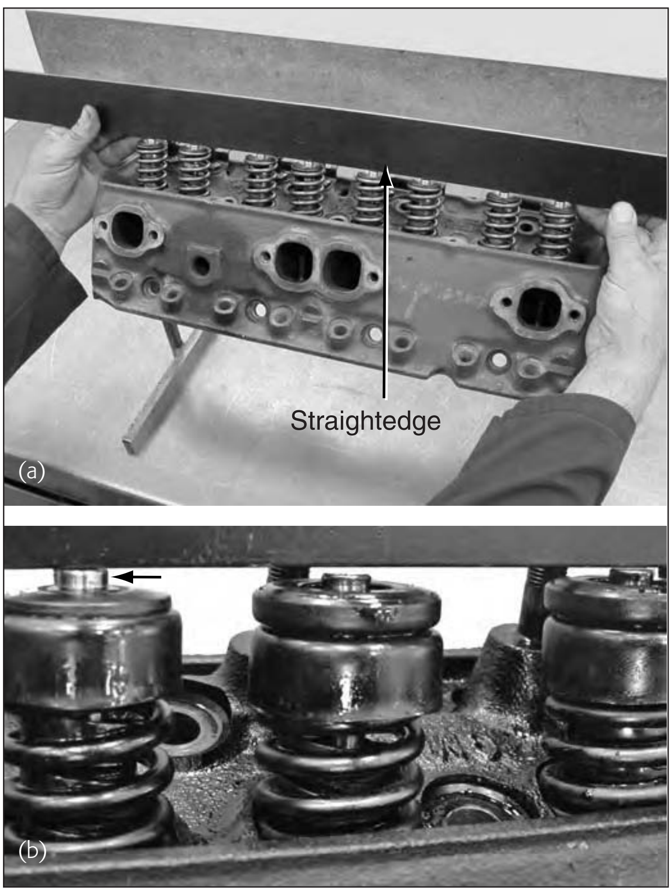


FIGURE 8.105 (a) Use a straightedge to look for obvious problems in valve stem height. (b) The valve stem on the left is too high because the valve seat was machined excessively. *(Courtesy of Tim Gilles)*

FIGURE 8.106 Cutting the I.D. of a seat ring makes removal easier. *(Courtesy of Tim Gilles)*

NOTE

Stainless steel contains nickel, which is very hard. It is better to cut stainless steel rather than grinding it, unless you are finish-grinding to provide a smooth surface. When machining stainless steel, use a sharp tool bit and do not let up on the cutting pressure or the stainless steel will work harden. You will notice this if you cut a stainless steel valve seat. If you do not keep sufficient pressure on the work, the seat will become very difficult to cut. If you drill stainless steel, do not let up on drilling pressure or the bottom of the hole will similarly work harden.

An insert valve seat can also be removed by welding. Here are two methods:

1. Weld a core plug or an old, smaller valve to the seat and knock the seat out by driving it against the stem.
2. Weld a bead of metal directly on the valve seat. When the weld cools, it will shrink, loosening the seat for easy removal. Be careful not to weld the seat to the combustion chamber.

REASSEMBLING THE HEAD

Clean the head thoroughly in the solvent tank. Before reassembling the valve and spring assembly, several items need attention:

- Recheck both the installed height of the valve spring and the valve stem tip.
- Grind the stem tip or install new valves, as necessary, to achieve the correct specifications.

- Install valve shims beneath their springs, as needed. Use only one shim (**Figure 8.107**). Do not stack them.
- Thoroughly clean all valve guides before reassembling the head.
- Lubricate all valve stems (**Figure 8.108**).

NOTE

It is *vital* that valve stems be adequately lubricated. **Figure 8.109** shows a valve that is welded to the valve guide in a newly rebuilt engine. A bent pushrod and piston damage can also result. The reason the valve stuck in the guide is because the student forgot to lubricate the valve stems during assembly.

Install the valve guide seals before installing the springs, unless the engine is an older General Motors engine with O-ring guide seals.

Sometimes intake and exhaust seals are different materials or shapes (see Chapter 7). Always check the gasket set or service information for instructions. Umbrella exhaust seals are sometimes shorter. To save money, manufacturers sometimes make intake seals from a material with a lower temperature rating than the exhaust seals.

Before installing a positive valve guide seal, remember to install the spring shim, if applicable. Remember to lubricate the seals before installing them (**Figure 8.110**). By the time splash lubrication reaches the seals, they will probably be ruined. Positive seals often come with a plastic installation tool to help push them into place without damaging the inner sealing surface (**Figure 8.111**).

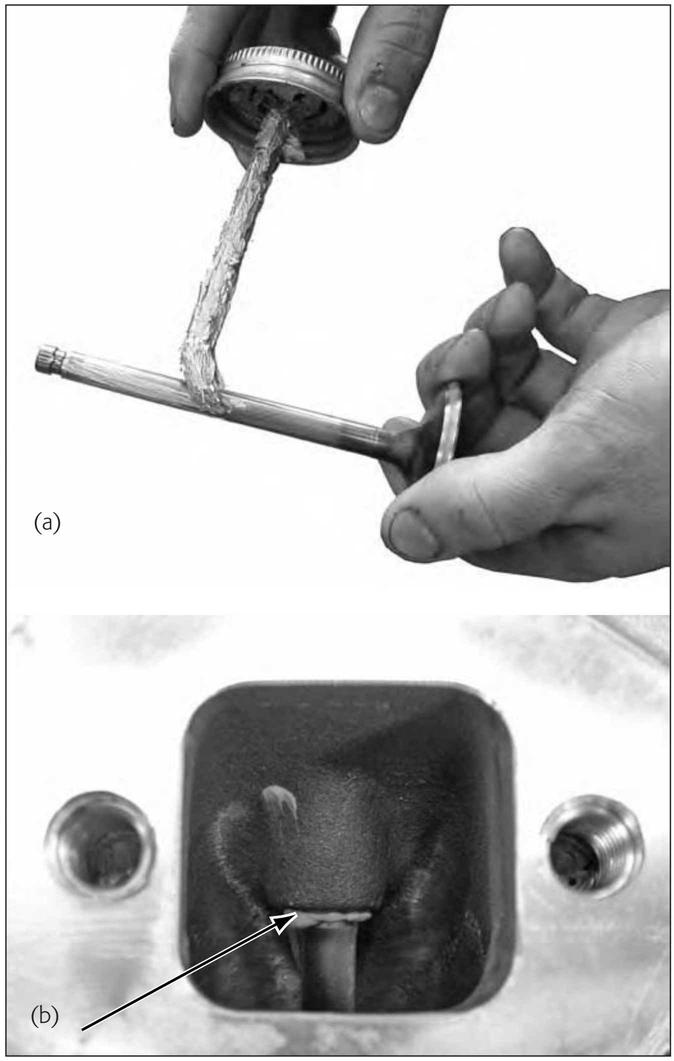


FIGURE 8.108 (a) It is very important to lubricate the valve stem before assembling the head. Antiseize lubricant is being applied here. (b) Lubricant is visible when viewing the bottom of the valve guide through the valve port. *(Courtesy of Tim Gilles)*

FIGURE 8.107 Two shims were accidentally installed beneath one of the valve springs on this head. The extra shim was not noticed until the shim for the last valve to be installed was found to be missing. *(Courtesy of Tim Gilles)*

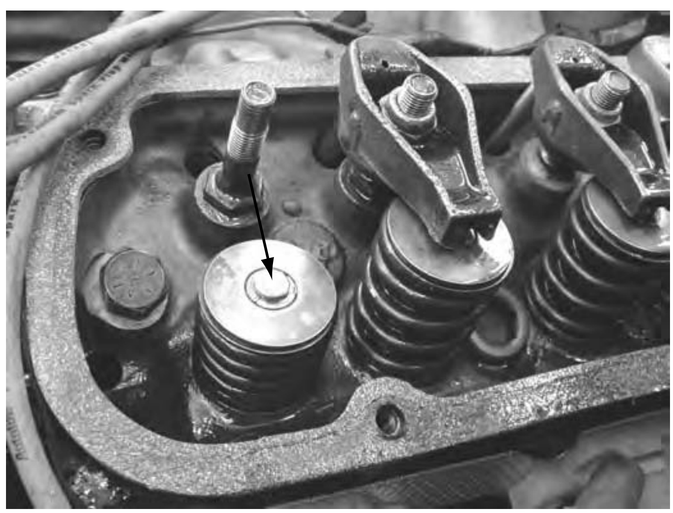


FIGURE 8.109 This valve stuck in the guide a few minutes after the engine was started following a valve job. The guides and stems had not been lubricated. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

A student was restoring a Camaro that had 90,000 miles on it. It did not smoke or use oil, but he wanted to put the engine in as-new condition. After a careful and complete rebuild, he took the car on a trip. It used a quart of oil every 200 miles. The spark plugs all had carbon deposits on one side of the center insulator only. With compressed air injected into the spark plug holes, the valve springs were removed to inspect the valve guide seals. It was discovered that the O-ring seals had been put onto the valve stem before the spring was installed. Each seal was twisted. Excessive oil consumption was the result.

O-ring valve guide seals must be installed after the valve spring is compressed, or they will be ruined during assembly. Be sure to oil the O-rings during installation so they can slip easily into the spring retainer and are not accidentally torn. O-ring seals can be tested after assembly by placing some solvent on the retainer to see if it leaks out, or by testing for leakage with a vacuum tester.

FIGURE 8.110 Lubricate valve stem seals. Dry seals will fail when burned by the motion of the valve stem. *(Courtesy of Tim Gilles)*

Inspect Keepers/Valve Locks

Before installation, inspect the fit of the keepers to the valve stem. With both keepers positioned in the groove in the valve stem, they should not touch each other at both ends. Otherwise they are not fully contacting the keeper groove and at high rpm they could come out. Keepers that have multiple grooves are *supposed* to touch each other. These keepers fit loosely on the valve, allowing it to rotate when open (see *valve rotation* in this chapter).

Install the Valve and Spring Assembly

Compress the valve spring just enough to install the keepers so you do not accidentally damage the

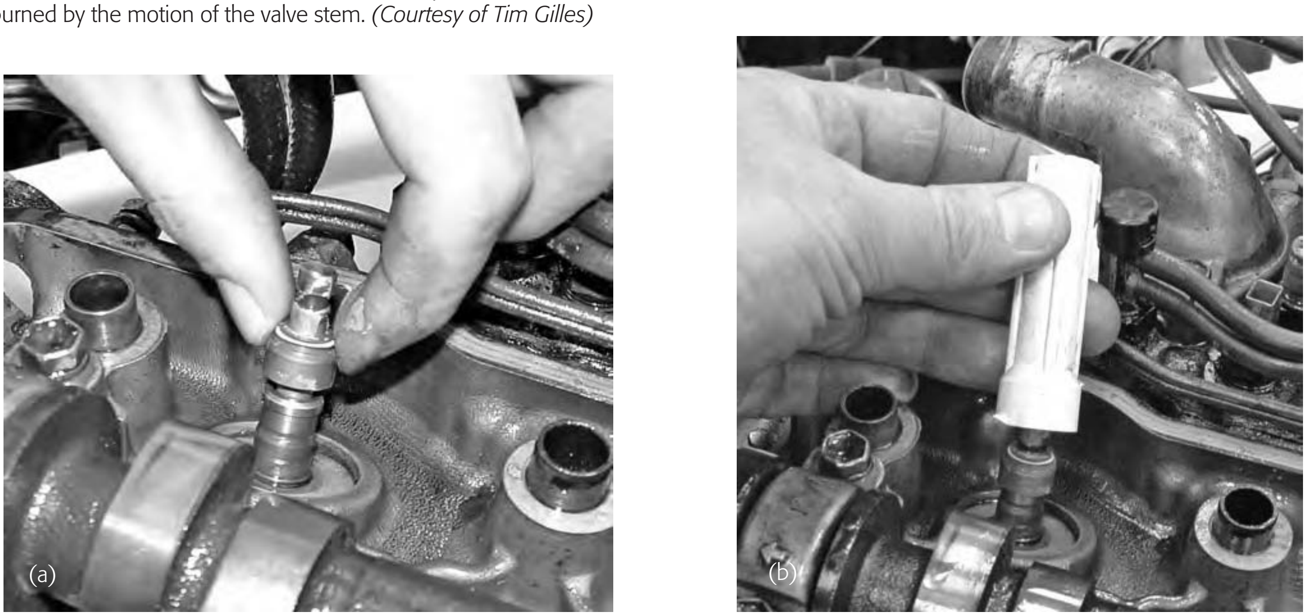


FIGURE 8.111 (a) Carefully slip the lubricated valve stem seal onto the valve stem. (b) Use a small hammer and installation tool to tap the seal onto the top of the valve guide. *(Courtesy of Tim Gilles)*

valve guide seal (see Figure 7.9). Use grease to hold the keepers in place during reassembly. Following assembly, tap the top of each valve tip with a soft face hammer to see that the keepers are seated (**Figure 8.112**). Keepers should always be replaced in pairs (**Figure 8.113**). Whenever a new valve is installed, new keepers should be installed too. If not, a valve could drop into the cylinder.

NOTE

Special aftermarket keepers are available to increase valve spring tension (**Figure 8.114**). The raised shoulder on the inside surface of each keeper has been repositioned 0.050" to hold the valve retainer lower on the valve, decreasing spring height. There are also keepers that increase spring height by 0.050".

FIGURE 8.112 These keepers are not seated correctly in the keeper groove. *(Courtesy of Tim Gilles)*

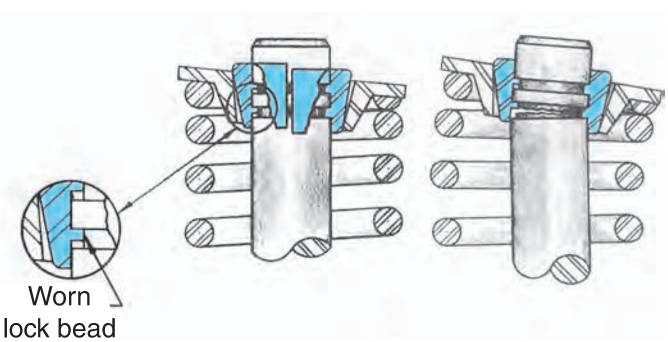


FIGURE 8.113 Replace keepers in pairs to avoid valve damage. *(Courtesy of Federal-Mogul Corporation)*

If a solvent check was not performed during the head cleaning operation, do it now as described earlier in this chapter. Vacuum and pressure testers are also available for testing the seal of the valve face and seat after the head is assembled (**Figure 8.115**).

Reassembling OHC Heads

On overhead cam engines, reinstall the camshaft in the head. Check to see that the camshaft cap alignment bushings are installed and positioned correctly before installing and torquing the cam caps (**Figure 8.116**). On bucket-type OHC heads, lubricate the buckets (**Figure 8.117**) and install them in the head prior to installing the cam.

On OHC heads with rocker arms, turn the cam until a cam lobe faces away from the valve. Reinstall the rocker arm by compressing the valve spring a small amount, using a valve spring compressor, a screwdriver, or a prybar as shown in Figure 7.3.

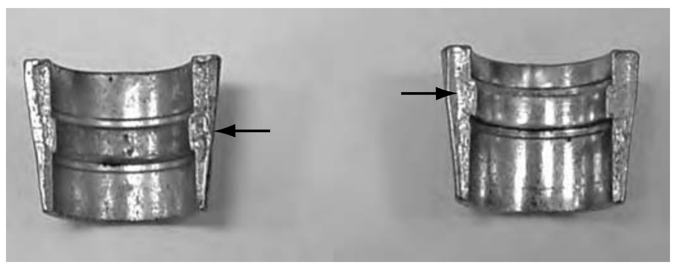


FIGURE 8.114 The keeper shown on the right increases valve spring tension. *(Courtesy of Tim Gilles)*

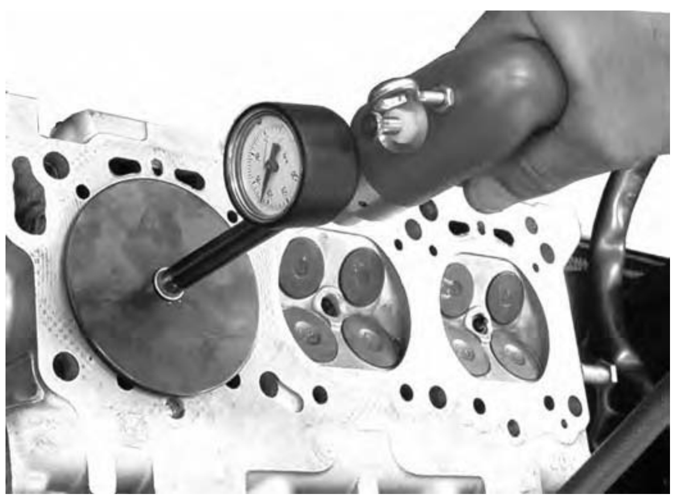


FIGURE 8.115 A vacuum tester used to test the seal of the valve faces and seats. *(Courtesy of Tim Gilles)*

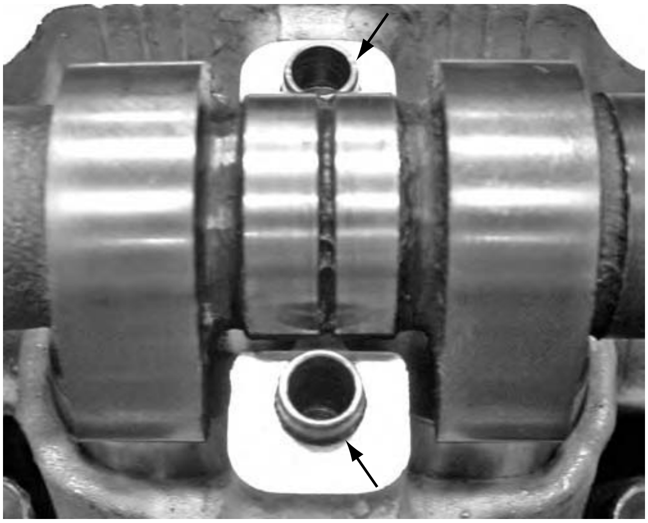


FIGURE 8.116 Cam cap alignment bushings. *(Courtesy of Tim Gilles)*

FIGURE 8.117 Thoroughly lubricate OHC buckets before installing them in the head. *(Courtesy of Tim Gilles)*

NOTE

Adjust the valve clearance before installing an OHC head on the engine.

Valve Clearance Adjustment

On OHC heads with bucket adjusters, the valve clearance can be adjusted using special tools so the adjustment disks, or pucks, can be removed and replaced as needed. One tool fits on the outside edges of two buckets. Prying the tool against the camshaft holds the two buckets down against spring pressure while the other tool reaches around the camshaft and lifts the disk from the bucket (**Figure 8.118**). A rubber-tipped blowgun can be used, as shown in **Figure 8.119**, to release the disk from trapped oil that tends to hold it against the bucket.

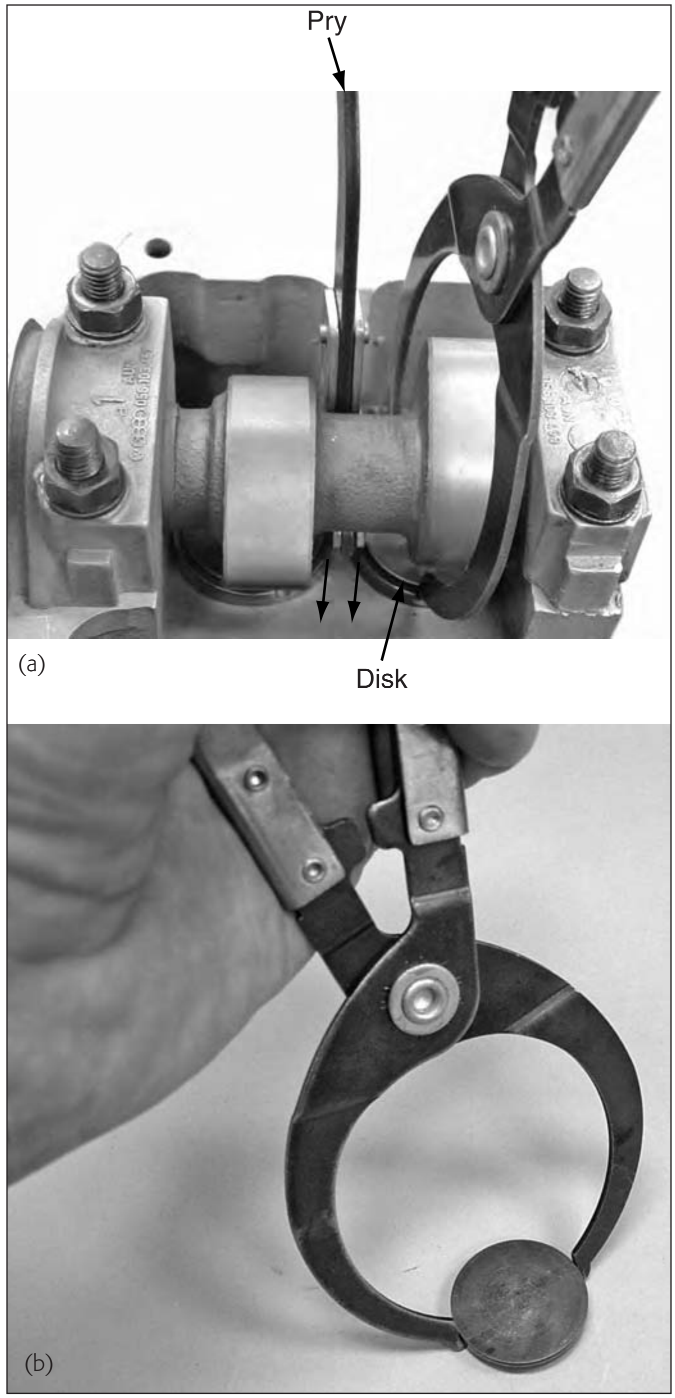


FIGURE 8.118 (a) Prying the special tool against the camshaft holds the two buckets down against spring pressure while another tool lifts the disk out of its seat in the bucket. (b) A tool for removing lash pad adjusting shims from an assembled head. *(Courtesy of Tim Gilles)*

FIGURE 8.119 A rubber-tipped blowgun being used to remove a lash pad adjusting disk from its bucket. *(Courtesy of Tim Gilles)*

Chapter 17 describes the procedure for adjusting valve lash on engines with an adjustment provision on the rocker arm or cam follower. Be sure to readjust the valves after they have seated, when the engine has been run at operating temperature.

Key Terms

induction hardened
integral seats
interference angle
proud surface
solvent test
valve lash
valve spring inserts

Study Questions

1. List three tests made on valve springs.
   a.
   b.
   c.
2. VSI shims are available in 0.015", 0.030", and 0.060" sizes. True or false?
3. Which valve would most often have a hardened tip?
   a. Intake
   b. Exhaust
4. What is the name of the part of the valve that becomes too thin when excessive metal is ground from the valve face?
5. By what process are integral seats usually hardened?
6. List three sources of valve seating pressure.
   a.
   b.
   c.
7. Repairs to what part of the head must be completed prior to refinishing the seats?
8. What are the names of the three valve seat angles?
   a.
   b.
   c.
9. To correctly position the valve seat about 1⁄32" from the outer edge of a 45° valve face, which angle would you grind?
   a. 30°
   b. 60°
10. What is the approximate width of an intake valve seat? _____"
11. What is the approximate width of an exhaust valve seat? _____"
12. What is done to a replacement valve seat ring to shrink it for easier installation?

13. Which length pushrod will be needed if a valve seat has been ground too deep?
    a. Shorter
    b. Longer
14. Are O-ring guide seals installed before or after the valve spring is compressed?
15. With what head design can valve clearance be adjusted prior to installation of the head on the engine?

ASE-Style Review Questions

1. Technician A says that basket-type coil springs are installed with the tighter part of the coil against the head. Technician B says that grinding a valve seat will decrease the installed height of the valve spring. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
2. Technician A says that a valve spring's pressure may be 10% less than the manufacturer's specifications before it must be replaced. Technician B says that valve seating pressure is the amount of force that the valve spring exerts on the area of contact between the valve face and seat. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
3. Technician A says that a burned exhaust valve can result from a valve seat that is too narrow. Technician B says that an exhaust valve seat should be wider than an intake valve seat. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
4. Two technicians are discussing the interference angle. Technician A says that it helps a reground valve to seat because it causes increased valve seat pressure. Technician B says that a 1° difference between the valve face and seat angles is enough to cause the valve to leak and burn. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
5. Technician A says to grind less than 0.020" from the tip of a valve stem to avoid grinding through the hardened area. Technician B says that the tip should be ground approximately the same amount as the face and seat in order to minimize valve guide wear by centering the rocker arm on the stem tip when the valve is half open. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
6. Technician A says that after refinishing a 45° valve seat, a 30° angle should be used to position the valve seat on the valve face. Technician B says that before a valve guide is repaired, the valve seat should always be ground. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
7. Technician A says that most exhaust valves are smaller than intake valves because exhaust gases are under high pressure. Technician B says

that intake valves are larger than exhaust valves. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

8. Technician A says that narrow valve seats exert a higher force on the seat area. Technician B says that if intake and exhaust valve springs are of equal pressure, then the larger valve must have a narrower seat in order to have the same seating pressure as the smaller valve. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

9. Technician A says that the face of the valve should overhang slightly into the combustion chamber when the valve is closed. Technician B says that the throat angle would most likely result in a ruined valve seat if ground too much. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

10. Technician A says that the sodium filling used in some exhaust valve stems lightens the valve for better low-speed operation. Technician B says that a valve that has a wide margin must be replaced. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

CHAPTER 9

Camshafts, Lifters, Timing Belts, and Chains

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Analyze the theories of the camshaft and related parts.
- Describe the operation of hydraulic lifters and lash adjusters.
- Install single and dual overhead camshafts with correct valve timing.
- Verify valve timing and be able to correctly position a camshaft in relation to TDC.

Introduction

The camshaft (typically called the *cam*) controls the opening and closing of the valves. It is the determining factor in how efficiently the engine pumps air as it operates at various speeds. Discussion in this chapter is limited to camshaft construction, lash adjustment (both mechanical and hydraulic), and cam drive mechanisms such as timing belts and chains. The overall performance of the engine is determined by the *grind*, or *profile*, of the cam. This aspect of camshaft theory is covered in Chapter 10, which includes discussion of cam grinds, profiles, and "degreeing the cam."

CAMSHAFT

The camshaft is located in the block or on the cylinder head, depending on the engine design. The cam-in-block design is commonly called a pushrod engine and the cam-in-head design is called an OHC, or overhead cam engine. Parts of a pushrod engine camshaft are shown in **Figure 9.1a**. The camshaft is often made of hardened cast iron (**Figure 9.1b**), although cams used on cam-in-block engines with roller lifters are made of steel (**Figure 9.2**). **Figure 9.3** compares OHC and cam-in-block camshafts. OHC camshafts with removable bearing caps have smaller bearing journals.

Camshafts on pushrod engines and single overhead cam (SOHC) engines have two cam lobes for each cylinder. One lobe operates the intake valve, and the other operates the exhaust valve. Cam lobe design differs from engine to engine, depending on the level of performance.

Camshaft and cylinder head design can increase the engine's breathing ability and power band across a wider rpm range. Individual cylinder heads on racing engines and many modern OE high-performance engines have two separate camshafts for intake and exhaust with four valves and four cam lobes for each cylinder. Because there are two

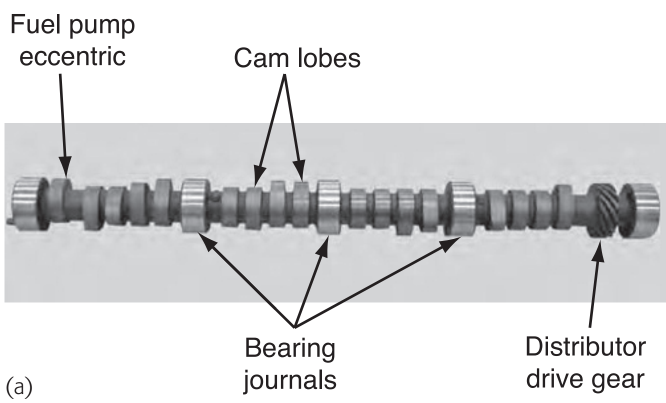


FIGURE 9.1 (a) Parts of a camshaft for a pushrod (cam-in-block) engine. (b) This broken cast iron camshaft that was dropped by a student shows the cast grain structure. *(Courtesy of Tim Gilles)*

FIGURE 9.2 This camshaft, used with roller lifters, is made of steel. Due to advances in automotive design, there is no distributor drive gear or fuel pump eccentric. *(Courtesy of Tim Gilles)*

camshafts, this design is referred to as dual overhead cam (DOHC). Other cylinder head designs have three, five, or more valves, but these are uncommon.

CONTROLLING CAMSHAFT END THRUST

When a cam-in-block engine has an ignition distributor, it is driven by a gear on the camshaft (**Figure 9.4**). A shaft from the bottom of the distributor drives the oil pump. Pushing oil through the oil pump consumes power and causes the camshaft to be forced toward the rear of the engine. This motion, called *end thrust*, must be kept to a minimum or the distributor timing will advance or retard as the cam moves fore and aft

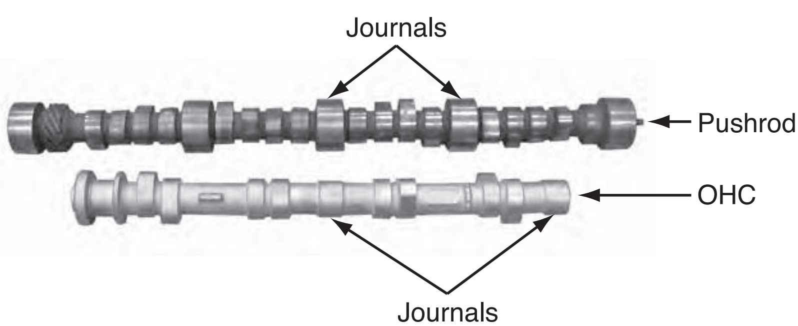


FIGURE 9.3 Comparison of pushrod and OHC camshafts. Notice that the OHC cam has smaller journals. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

- Opposed engines, such as the air-cooled Volkswagen, have half as many cam lobes, because the lobes of one cylinder are shared with its companion cylinder on the opposite side of the engine.
- The fuel systems on older engines use carburetors with mechanical fuel pumps, which are driven by an *eccentric* (an off-center lobe) on the camshaft. Typical fuel pump spring pressure ranges from only 3 to 9 pounds, so wear on the eccentric lobe is minimal. Instead of a cast-in fuel pump eccentric, some engines use a separate stamped-steel eccentric that bolts to the front of the cam sprocket. With advancing technology, many popular engine designs previously equipped with carburetors evolved to fuel injection. Although it was no longer required, camshafts on these engines sometimes included a cast fuel pump eccentric.

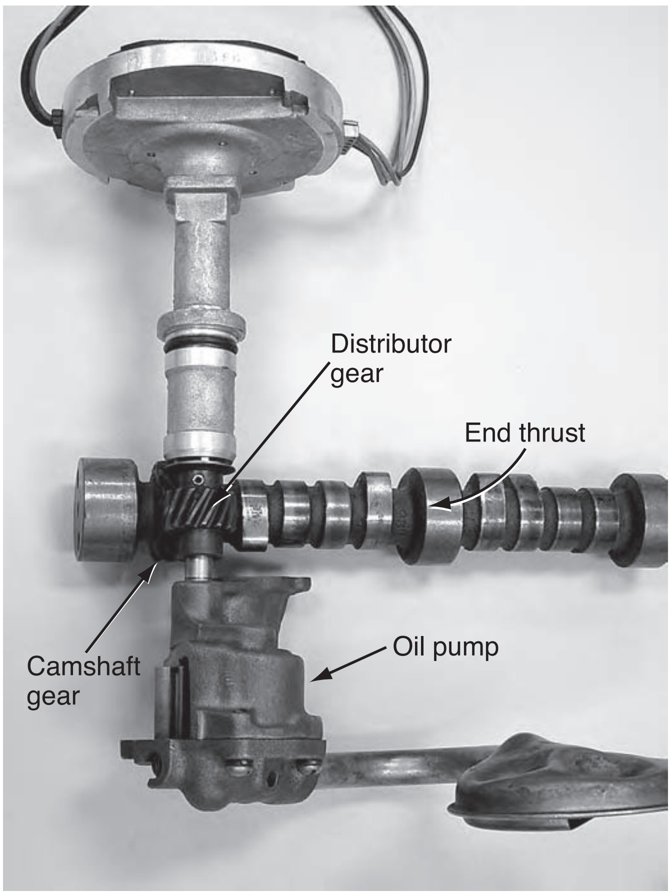


FIGURE 9.4 The helical gear on this pushrod engine camshaft drives the distributor and oil pump. Camshaft end thrust results. *(Courtesy of Tim Gilles)*

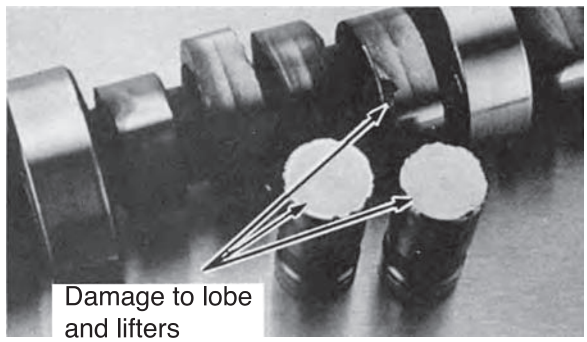


FIGURE 9.5 Problems with camshaft end thrust can cause interference between the lifter and neighboring lobe. *(Courtesy of Federal-Mogul Corporation)*

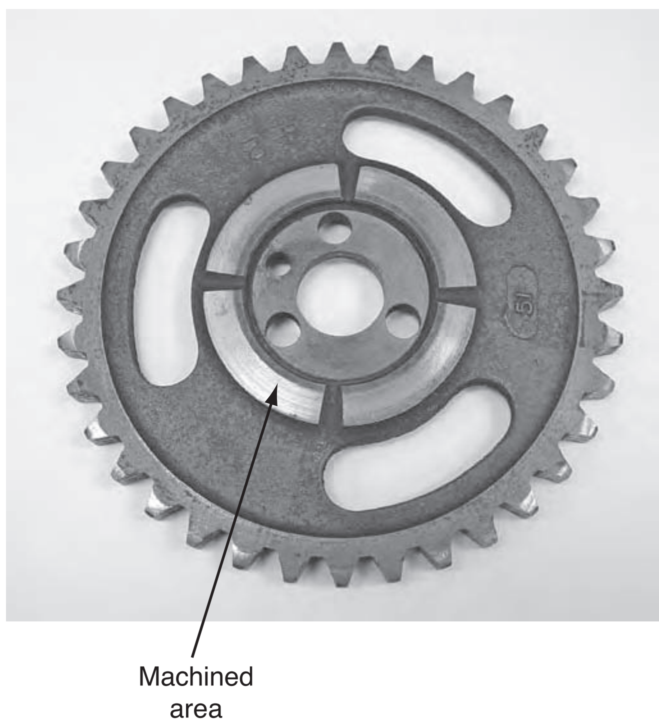


FIGURE 9.6 This machined area rides against a machined area on the block. The notches allow oil to enter from the front cam bearing. *(Courtesy of Tim Gilles)*

against the distributor gear. Excessive cam thrust can also cause damage to the cam and lifters (**Figure 9.5**).

The gear on the distributor is sometimes made of a softer material such as aluminum, plastic, or

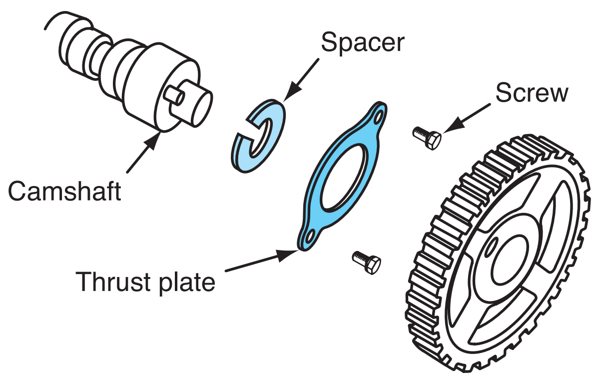


FIGURE 9.7 Camshaft end thrust on some engines is controlled by a thrust plate and spacer.

brass because a failure of one of these soft gears would not be as likely to damage the cam.

Sometimes the timing chain provides sufficient end thrust control on cam-in-block engines. These engines have a machined area on the rear of the cam sprocket (**Figure 9.6**). Other engines use a *thrust plate* and spacer (**Figure 9.7**) to control cam thrust.

Thrust Clearance

Camshaft thrust plate clearance specifications vary from 0.0015" to 0.005" After installation, the machined surface on the back side of a gear or sprocket will be sandwiched against the shoulder

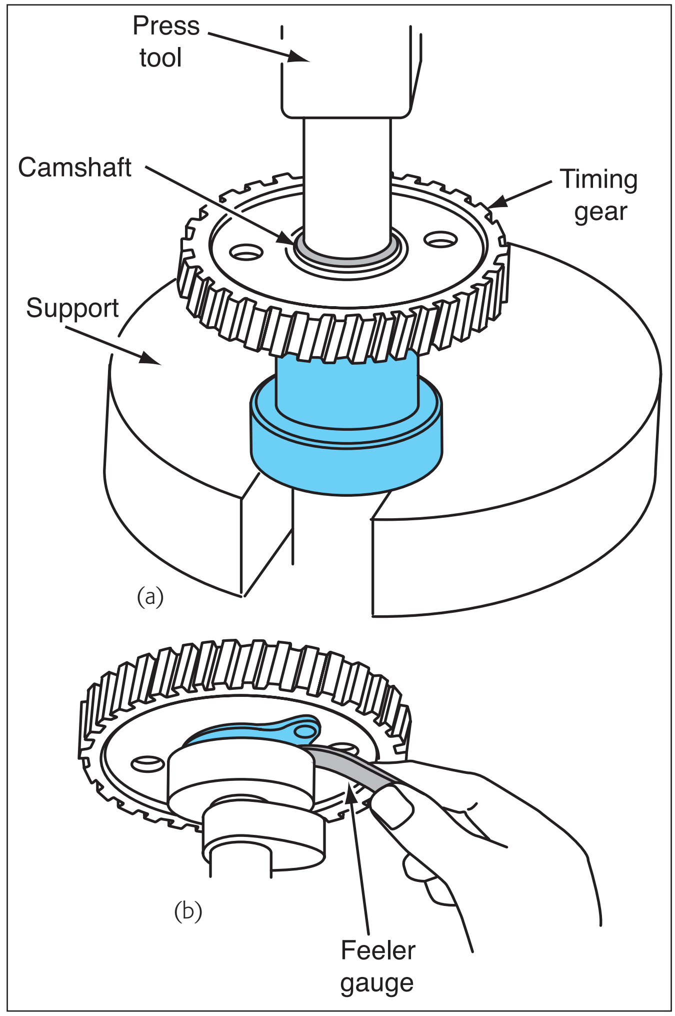


FIGURE 9.8 Vintage pressed-fit cam gear installation. (a) The back of the timing gear is supported and the press is applied to the camshaft. (b) Check clearance behind the thrust plate to determine camshaft end play.

VINTAGE ENGINES

On many older in-line engines, the cam sprocket was pressed-fit to the camshaft. If you replace a cam gear on one of these cams, follow this procedure:

- The rear of the cam gear must be supported while the cam is pressed from its center (**Figure 9.8a**).
- End play is determined by the thickness of the thrust spacer. After pressing the new cam gear in place, check end play with a feeler gauge (**Figure 9.8b**).
- Aluminum gears can be heated for easier installation, but they must not be heated to more than 300°F (149°C). If aluminum is overheated, it will not return to its original size when it cools and will be loose on the camshaft. An old-time trick when flame heating an aluminum gear is to coat the gear with oil and heat it until the oil begins to smoke. This is the temperature when it can be installed. Once it has been installed, it cannot be removed and reinstalled but will have to be replaced.

of a replaceable spacer or a machined area at the front of the camshaft. The shoulder fits inside the center of the thrust plate. To provide thrust clearance, the shoulder needs to be 0.0015" to 0.005" thicker than the thrust plate. If clearance is more than 0.005″ or less than 0.0015", the thrust plate must be replaced. On some engines, the spacer can be replaced instead.

NOTE

If you forget to install the spacer on a camshaft with a bolt-on sprocket, the camshaft will not turn after you tighten the bolt.

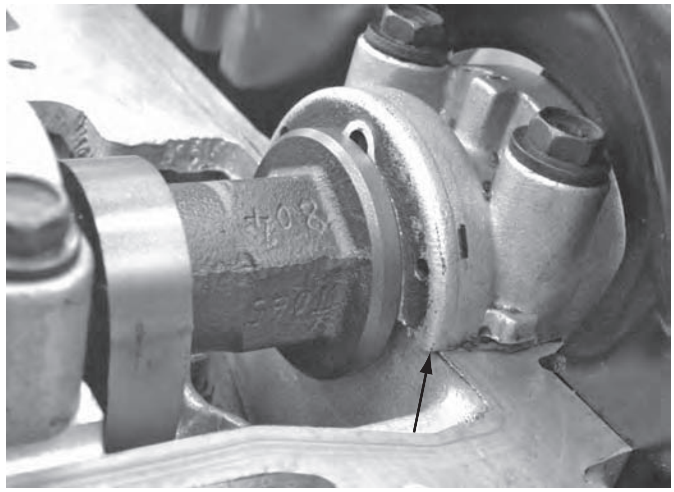


FIGURE 9.9 Cam bearing thrust cap. *(Courtesy of Tim Gilles)*

Cam Button. To control end thrust in some cam-in-block OE and high-performance engines, a nylon button or a spring-loaded needle thrust bearing (Torrington bearing) is installed in front of the cam sprocket. Some racing engines use a spacer between the timing cover and coolant pump to prevent the cam from bending the timing cover.

Cam-in-block cylinder blocks usually have an oil drain hole between the rear cam bearing and the camshaft core plug that allows oil to drain back into the crankcase. If the oil return is blocked, the camshaft can be forced forward when oil pressure builds behind it. This can result in a knock or rubbing noise if the camshaft is pushed forward into the timing cover. Sometimes the oil hole can become restricted if the rear camshaft core plug is pounded too far into the block. Some camshafts are slotted at the rear end surface to prevent this from occurring.

Overhead Camshaft Thrust Control

Camshafts on OHC engines do not have end thrust like camshafts on pushrod engines. Manufacturers use different methods for positioning the camshaft in the head. One design uses a cam cap with a wider thrust surface; the head side of the cam bore is not machined (**Figure 9.9**). Another method uses a spacer or washer (**Figure 9.10**).

Auxiliary Shaft

Some OHC engines use an *auxiliary shaft* to drive the oil pump and distributor. This extra shaft is driven by the crankshaft timing belt and is easily identifiable because there is an additional timing sprocket (**Figure 9.11**). Some other OHC engines have the distributor mounted on the cylinder head, which is driven by the camshaft.

VALVE LASH (CLEARANCE)

Some OHC engines have hydraulically adjusted valve clearance, whereas other engines have a mechanical provision for adjustment.

Some OHC heads use rocker arms. One design has one end that pushes against the valve stem and the other end sits on a ball pivot. The cam lobe pushes on a pad in the middle of the rocker arm. When valve clearance is adjusted mechanically, the ball pivot is equipped with threads. Another design uses rocker shafts and has a threaded adjusting screw and locknut (**Figure 9.12**).

Other OHC engines have cam lobes that act directly on the valves. These cam lobes are larger than lobes on engines with rocker arms. This is because there is no rocker arm ratio (see Chapter 10) to multiply movement caused by the lobe. On this type of engine, lash is usually adjusted by adding or subtracting shims (called lash pad adjusters) (**Figure 9.13**).

Chapter 17 discusses the adjustment of mechanical valve lash in detail. Mechanical valvetrains are adjusted to provide some extra clearance when cold so that they will have the proper running clearance at engine operating temperature.

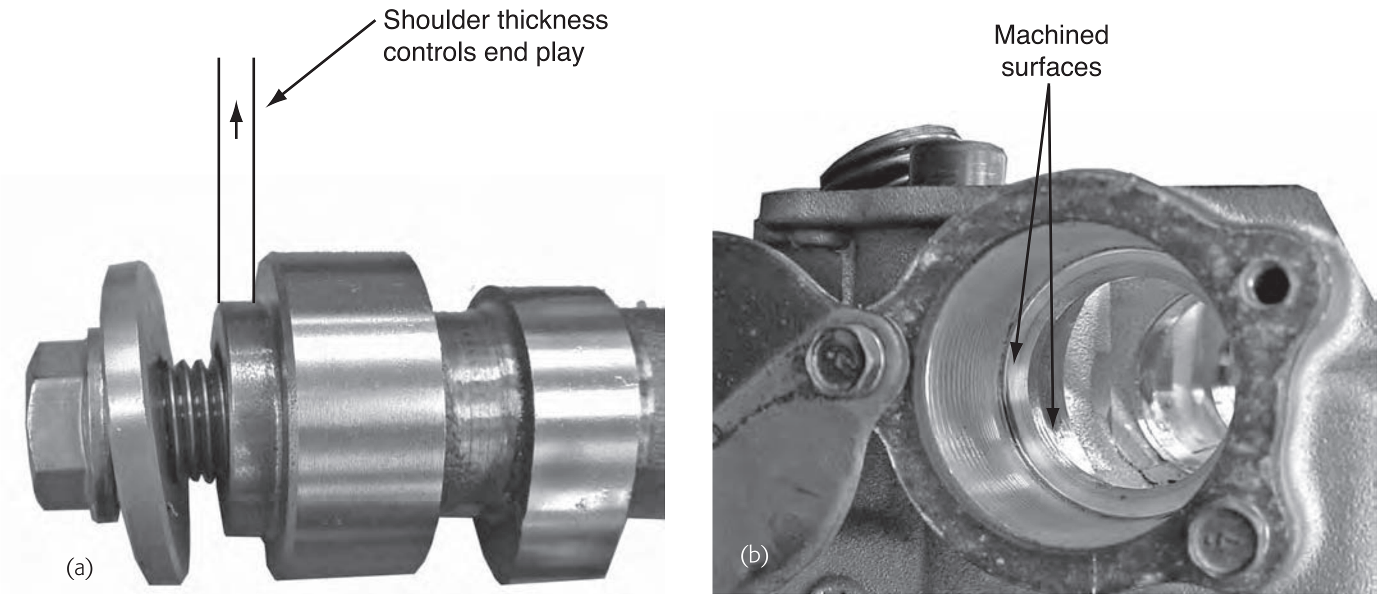


FIGURE 9.10 To control the lateral position of the camshaft, this OHC design has a washer that rides against a machined surface in the cam bore. *(Courtesy of Tim Gilles)*

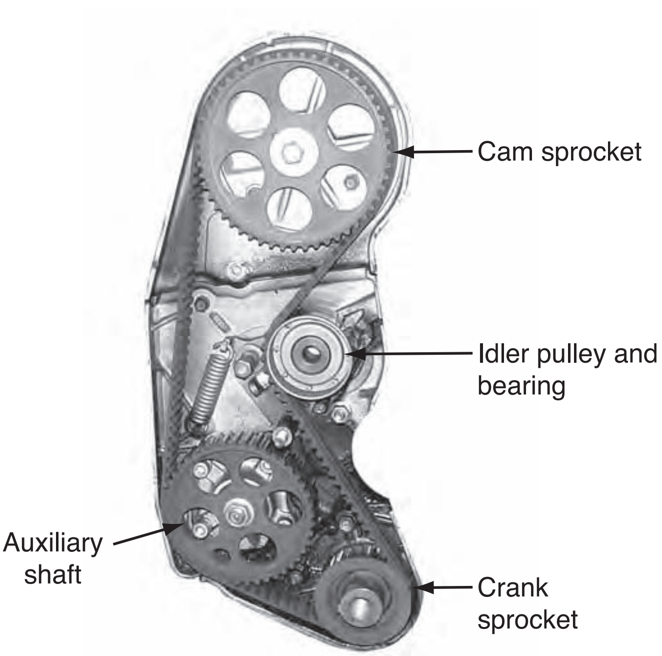


FIGURE 9.11 This OHC engine has an auxiliary shaft. *(Courtesy of Tim Gilles)*

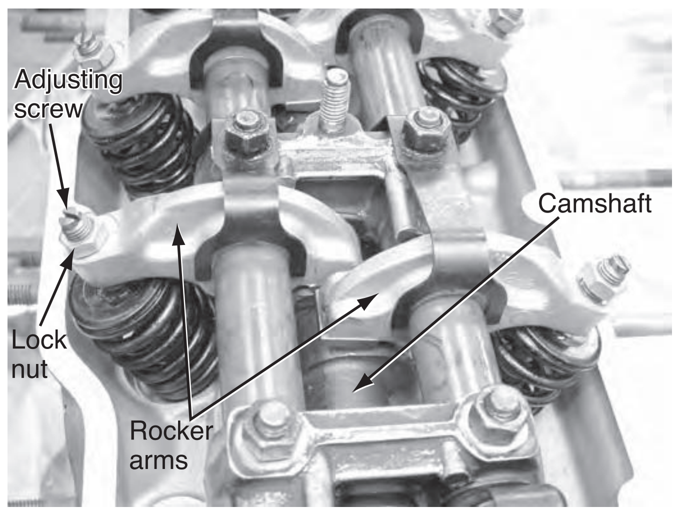


FIGURE 9.12 This OHC head has adjustable valve clearance on the rocker arms. *(Courtesy of Tim Gilles)*

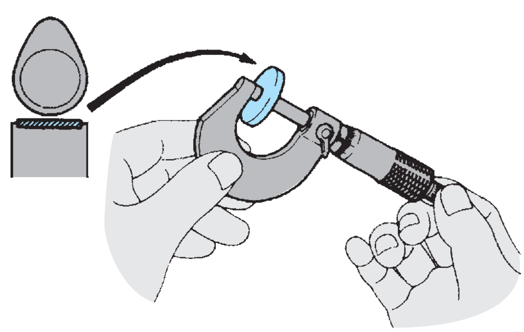


FIGURE 9.13 A lash adjusting shim.

On a pushrod engine, valve lash changes with wear to parts as follows:

- Valve lash *increases* as pushrods and rocker arms become worn.
- Valve lash *decreases* as the valve and seat wear, allowing the valve stem to move up into the

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Pushrod engines in older vehicles had mechanical valve adjustment. Sometimes the valve lash specification calls for a "hot" lash setting. In this case, an approximate adjustment is made to the cold engine, 0.005" looser, for instance. To get a more accurate approximation for a particular make of vehicle, perform a hot adjustment. Then let the vehicle sit overnight and check lash again to determine the difference.

guide. A decrease in lash, therefore, can cause inadequate valve cooling, leading to burned valves.

VALVE LIFTERS

Valve lifters, also known as cam followers, can be either mechanical or hydraulic. Mechanical lifters are also called solid lifters or tappets (**Figure 9.14**). Lifters are either flat or roller (**Figure 9.15**). Flat tappets and their camshafts are discussed first, and roller lifters are covered later in the chapter.

Flat tappets are made of the same material as the camshaft, which is hardened cast iron.

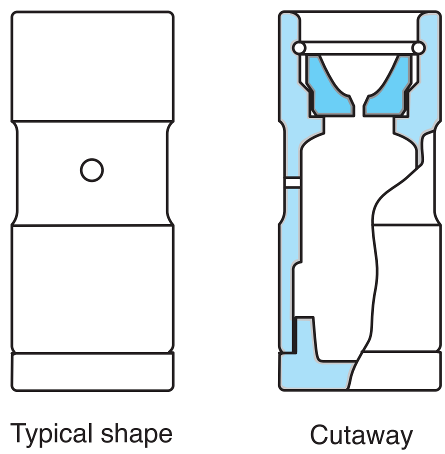

FIGURE 9.14 A solid lifter.

NOTE

New flat lifters often have a small, shallow pinhole in their base. This hole is normal; it is a mark resulting from hardness testing of the lifter during manufacture.

HYDRAULIC LIFTERS AND LASH ADJUSTERS

Hydraulic valve lash adjustment is found on almost all later model cam-in-block engines and many OHC engines. Hydraulic lifters and lash adjusters automatically maintain **zero lash**, which is when there is no clearance between the valve stem and its actuator. Hydraulic adjusters are quiet and eliminate unnecessary valvetrain wear due to lack of maintenance. Cam-in-block hydraulic lifters and OHC lash adjusters operate in a similar manner. Cam-in-block hydraulic lifters are discussed first.

FIGURE 9.15 A flat tappet and a roller lifter. Roller lifters were installed on some production engines beginning in 1985. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Some older engines had mushroom lifters. These have a narrow section that fits into the lifter bore with a large foot that contacts the camshaft. They were found on flathead engines, like the Studebaker engine shown in **Figure 9.16**, and were also used in Volkswagens and Fords. Some hydraulic racing tappets were made in a mushroom shape that allowed for a smaller cam lobe as well.

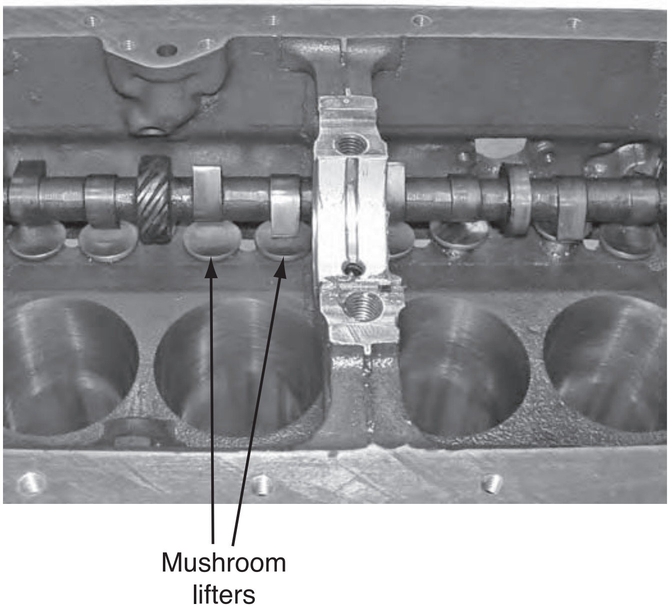

FIGURE 9.16 Mushroom lifters like the ones in this vintage Studebaker engine are removed from the bottom of the engine after the camshaft is removed. *(Courtesy of Tim Gilles)*

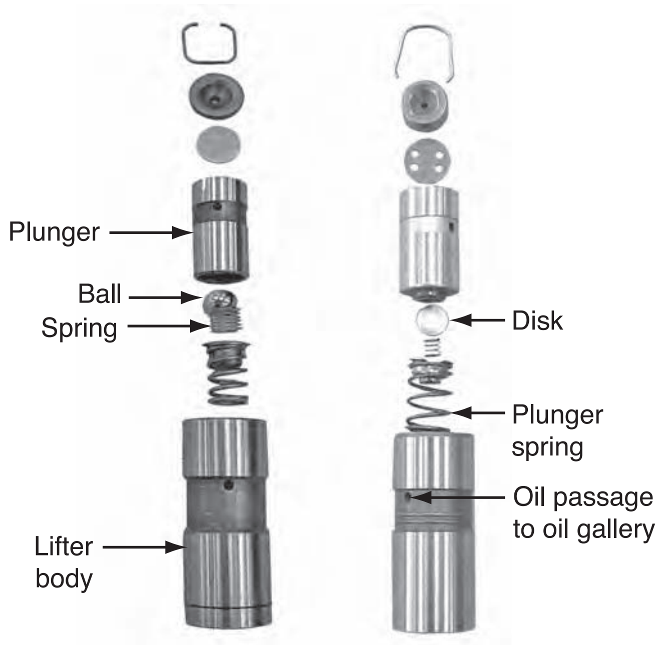

FIGURE 9.17 Hydraulic lifter parts. The lifter on the left has a ball check valve. The lifter on the right uses a disk check valve. *(Courtesy of Tim Gilles)*

Cam-in-Block Hydraulic Lifters

Parts of the hydraulic lifter include a precision steel plunger match fitted very closely to the lifter body, a check valve assembly, and a plunger spring. The plunger is chrome plated to resist wear and corrosion. The check valve can be either a ball or a flat disk, depending on the manufacturer (**Figure 9.17**). Lifters from different manufacturers sometimes have different outward appearances, even though they are for the same engine.

Lifters are fed with oil through an oil gallery that runs the length of the engine block (**Figure 9.18**). The long, wide recess on the side of the lifter body (see **Figure 9.17**) is the area that is exposed to the lifter gallery. Cam-in-block engines often feed oil from the top of the lifter to the rocker arms through hollow pushrods (**Figure 9.19**). One advantage to this arrangement is that oil flowing through the pushrods helps flush the hydraulic lifters. This advantage is lost with solid pushrods.

HYDRAULIC LIFTER OPERATION

Whenever clearance occurs in the valvetrain, a spring between the plunger and lifter body causes the lifter to expand (**Figure 9.20**). This results in a cavity beneath the plunger that is empty of oil. Oil under pressure rushes into the cavity and fills it. If the lifter fills with too much oil, a slight amount of

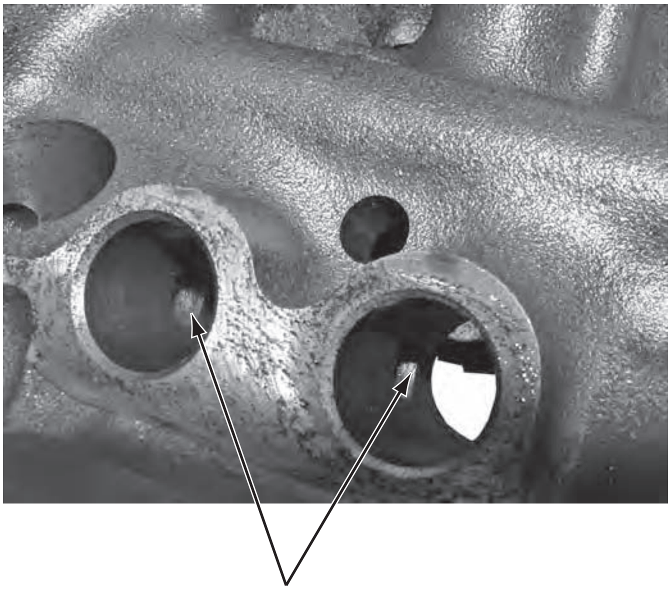

FIGURE 9.18 An oil gallery running the length of a pushrod engine dissects each lifter bore. *(Courtesy of Tim Gilles)*

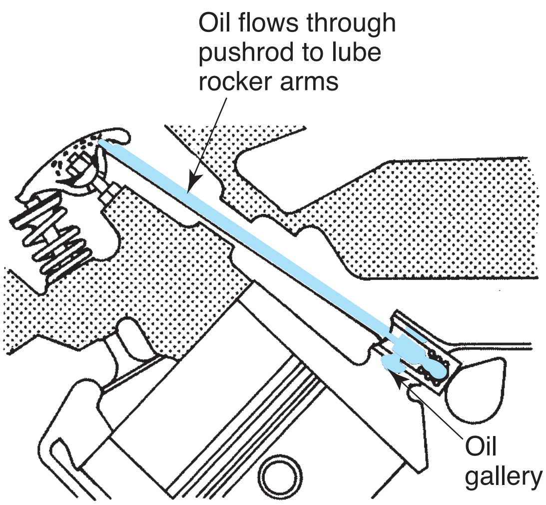

FIGURE 9.19 The stud-mounted rocker arm area is lubricated through hollow pushrods.

leakage between the plunger and the lifter body allows it to leak down.

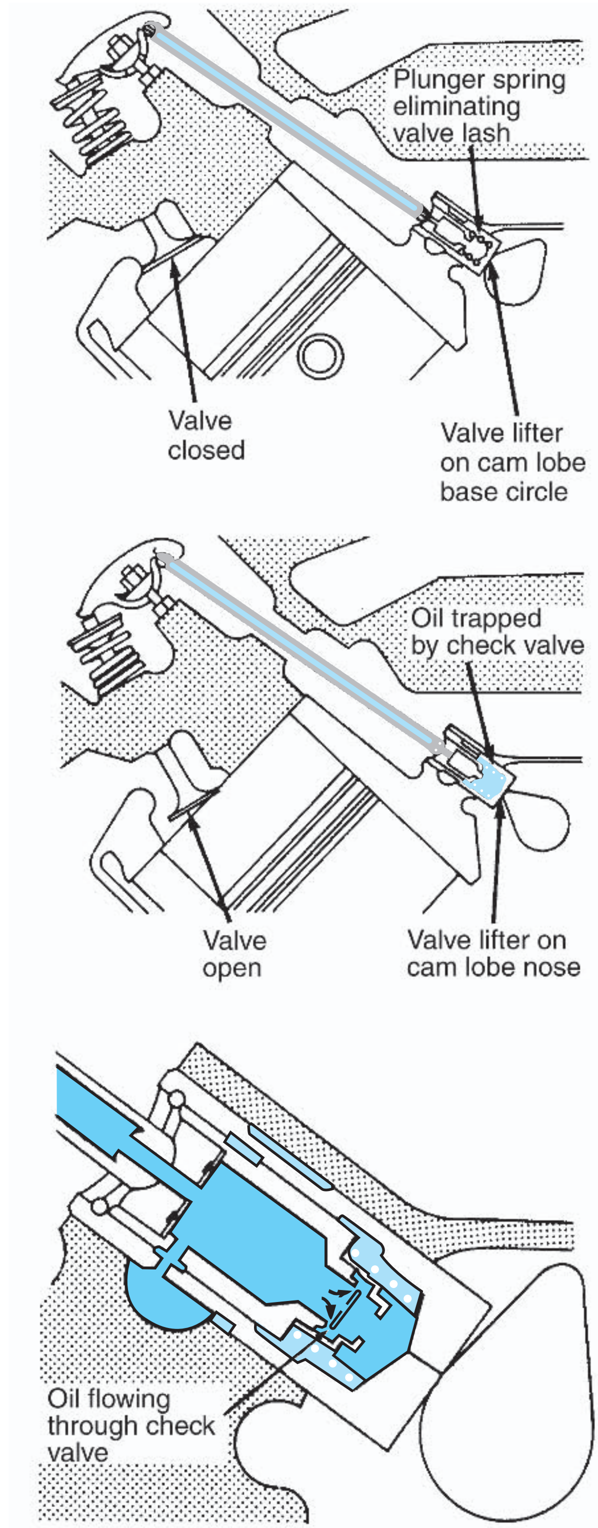

FIGURE 9.20 Hydraulic lifter operation.

Lifter Leak-Down

The lifter will **"leak down"** as engine parts expand. The amount of leak-down is very small, because there is only about 0.0002" (count the zeros) clearance between the plunger and the lifter body. The small amount of clearance is beneficial, because dirt particles are generally larger than 0.0002" so they cannot easily lodge between the lifter body and the plunger.

OHC Lash Adjusters

Many OHC engines use hydraulic adjusters, also called compensators, to eliminate valve lash (**Figure 9.21**). Two styles of hydraulic lash adjusters are shown in **Figure 9.22**. They operate in the same manner as a cam-in-block hydraulic lifter, but they are especially susceptible to failure due to lack of lubrication. It is especially important that the recommended oil (usually of a lower viscosity) be used with these engines.

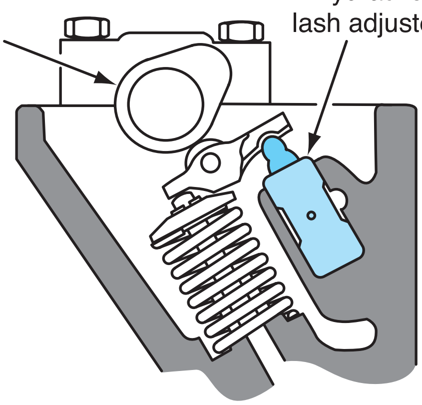

FIGURE 9.21 An overhead cam head with hydraulic lash adjustment.

FIGURE 9.22 Two types of hydraulic lash adjusters/compensators. *(Courtesy of Tim Gilles)*

Some OHC hydraulic lash adjusters are fitted in rocker arms (**Figure 9.23**). Others operate directly off the valve and are part of the bucket (**Figure 9.24**). **Figure 9.25** shows the top and bottom sides of a removable lifter block from an OHC V6. These cam followers are of the mushroom style described earlier.

Hydraulic Lifter Failure

The following are some examples of hydraulic lifter failures:

- Dirt lodged in the check valve can allow the lifter to leak internally.
- Too much wear between the plunger and the lifter body can cause excessive leak-down, resulting in a noisy lifter.
- A lifter might be noisy because of an oil pressure problem. This will be evident on hollow pushrod engines if no oil is reaching the rocker.
- Lifters can also become "stuck" because of varnish between the plunger and body. This condition can sometimes be corrected by using an oil additive or by spraying fuel system spray cleaner down a hollow pushrod oil channel.

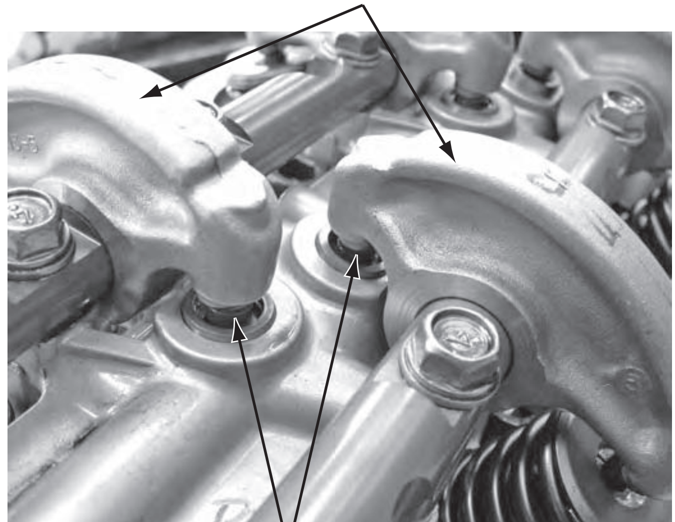

FIGURE 9.23 Hydraulic lash adjusters/compensators used with OHC rocker arms. *(Courtesy of Tim Gilles)*

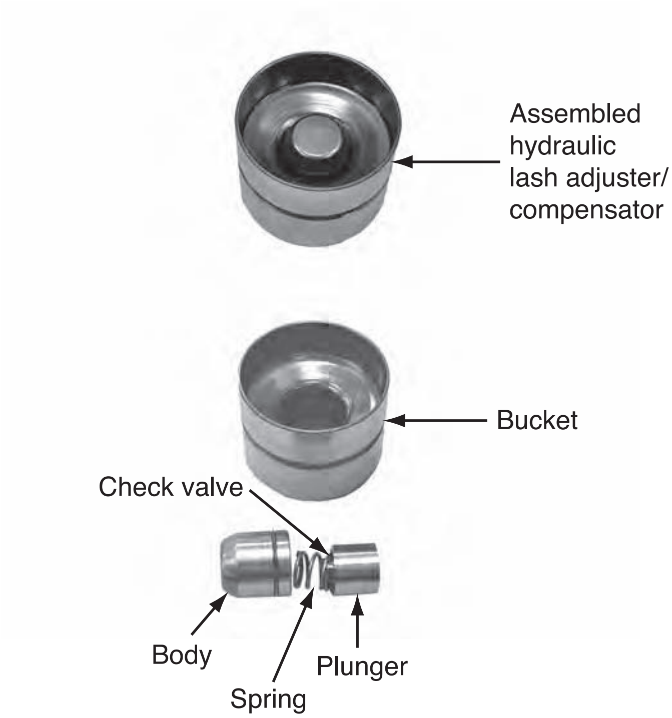

FIGURE 9.24 A bucket-type hydraulic lash adjuster/compensator assembled and disassembled. *(Courtesy of Tim Gilles)*

Adjusting Hydraulic Lifter Lash

Correct valve lash is achieved when the plunger is depressed into the lifter bore approximately half the total travel of the plunger (**Figure 9.26**). On later model engines, this is usually a fixed setting, which is determined by the height of the valve stem tip above the valve spring seat. This measurement, called *stem tip height*, is changed by wear or when the valve face and seat are remachined (see Chapter 8). Newer engines rarely suffer enough wear to the valve face or seat that cannot be compensated for by plunger travel within the lash adjuster.

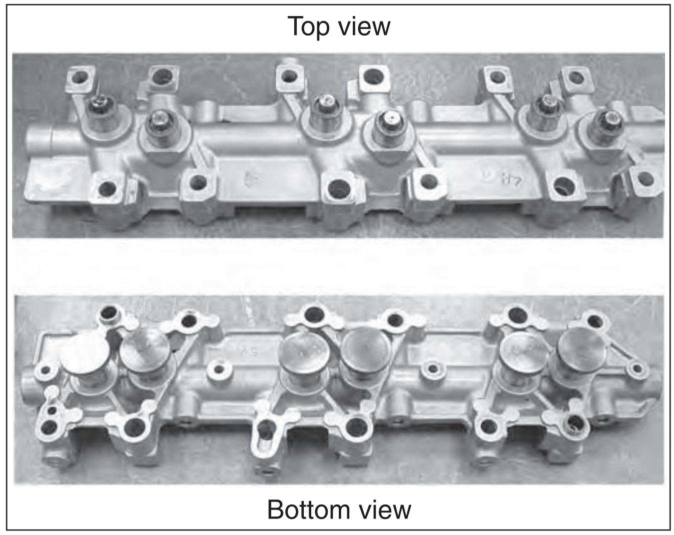

FIGURE 9.25 A removable lifter block assembly from a late-model V6. *(Courtesy of Tim Gilles)*

When a cam-in-block engine has no provision for lifter adjustment, there is a torque specification used on the rocker arm nuts (20 ft.-lb, for instance). Adjust the clearance in this valvetrain simply by tightening the rocker arm nut against a shoulder on the rocker stud (**Figure 9.27**). This is called a *positive stop* adjustment.

Hydraulic Lash Adjustment—Engine Running

When clearance is adjustable, it is sometimes adjusted with the engine running at slow idle.

NOTE

This procedure may not be performed on diesel engines because there is not enough clearance between the piston and valve.

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Until the 1970s, it was common for engines to have adjustable hydraulic lifter lash. The aim of this adjustment is to center the plunger in the lifter bore. A typical repair manual specification calls for an adjustment ranging from 4/3 to 1 1/4 turns of the adjusting nut past zero lash, depending on the manufacturer.

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For checking lifter plunger travel in its positive stop engines, Ford Motor Company recommended the following procedure: Collapse the lifters with a special collapsing tool (**Figure 9.28**). Then measure the clearance between the rocker and valve stem. It should be between 0.100" and 0.200". If not, use a shorter or longer pushrod. **Figure 9.29** compares adjustable and nonadjustable rocker arms.

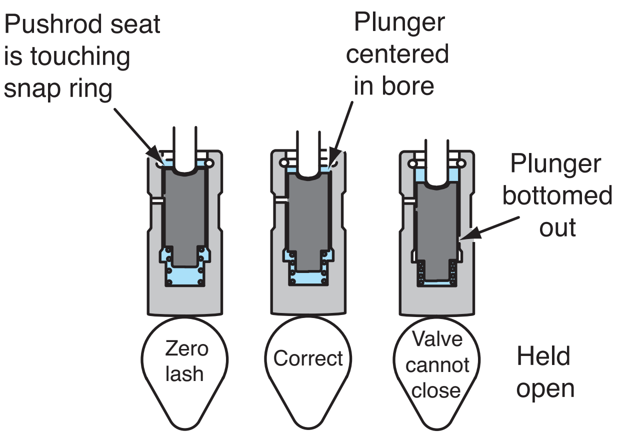

FIGURE 9.26 During lash adjustment, the plunger is depressed to center it in the lifter bore.

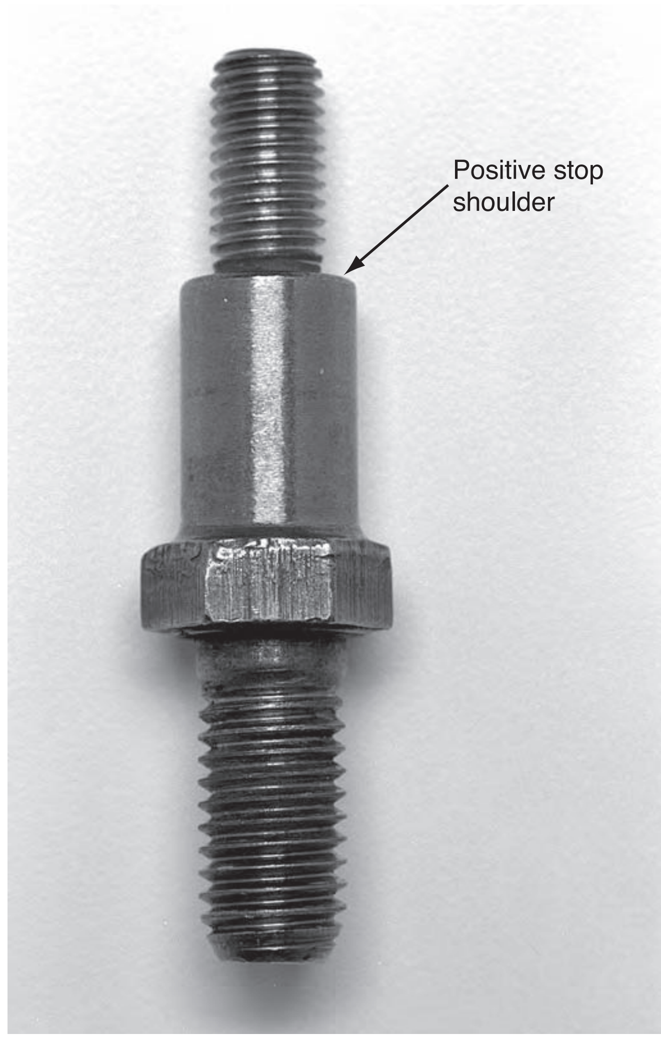

FIGURE 9.27 With a "positive stop" lash adjustment arrangement, the rocker ball is adjusted against the shoulder on the stud.

Zero lash can be determined in a running (idling) engine by loosening the adjusting nut until a clicking sound is heard. Next, the adjusting nut is tightened until the noise just stops. Adjust each valve to this point, which is called zero lash. Then shut the engine off and tighten each valve the specified amount. Wait at least 20 minutes before restarting the engine. You can install the valve covers while you wait. Chapter 17 has more information on valve adjustment with the engine running.

Hydraulic Lifter Pump-Up

Lifter pump-up can occur when the engine is revved to the point where the valve train components separate due to inertia (momentum). This condition, known as valve float (**Figure 9.30a**), occurs because the valve does not close fast enough and clearance occurs. The spring below the lifter plunger takes up this clearance and the cavity below the plunger fills with oil (**Figure 9.30b**). The problem is that the valve is now held off its seat and can actually collide with a piston in cases of extreme pump-up. The lifter cannot leak down quickly

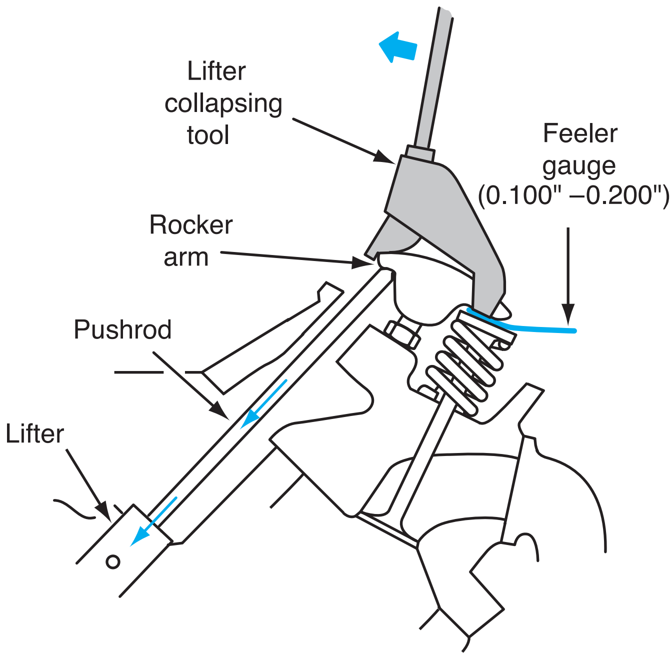

FIGURE 9.28 Collapsing a hydraulic lifter with nonadjusting rocker arms to check for clearance. The tool is a Ford dealer item.

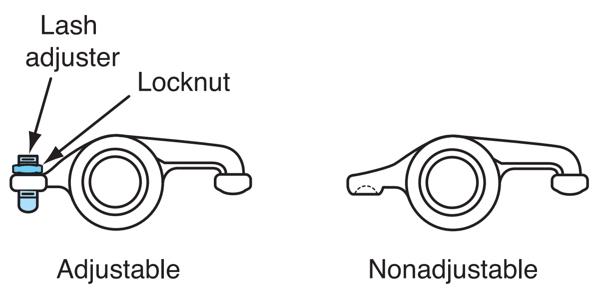

FIGURE 9.29 Adjustable and nonadjustable shaft-mounted rocker arms.

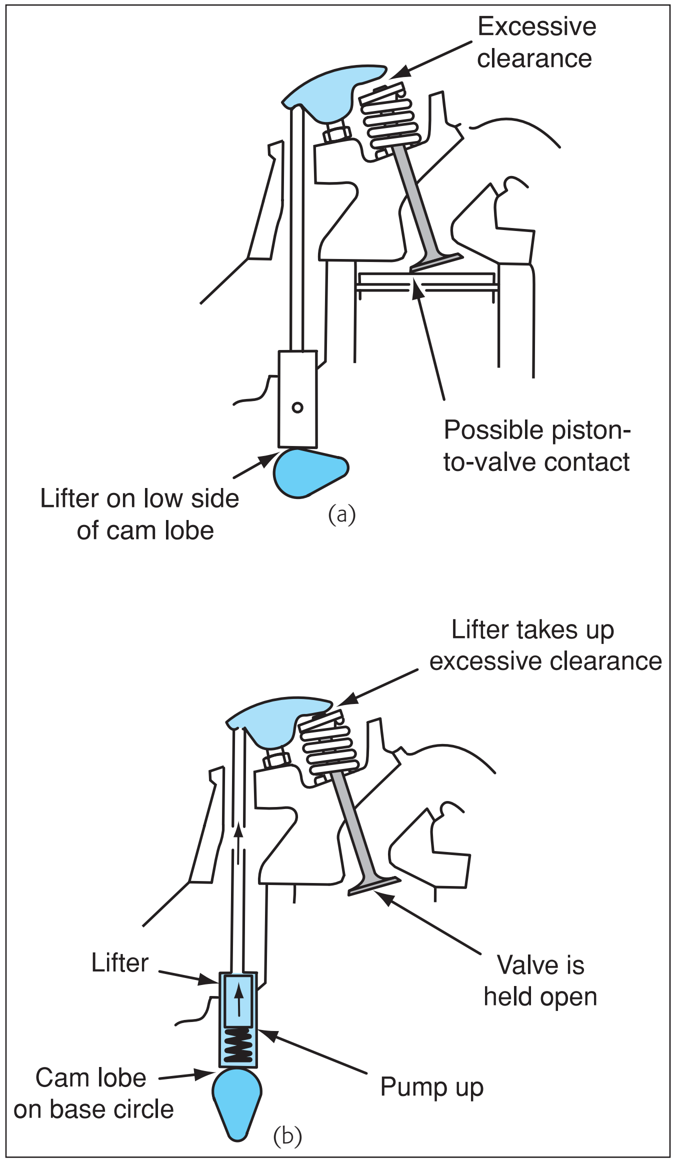

FIGURE 9.30 (a) When excessive clearance occurs during valve float, (b) the lifter "pumps up."

enough when *the valve is opening and closing 50 times per second* at 6000 rpm. Some high-performance lifter designs resist pump-up. More information on dealing with lifter pump is included in Chapter 10.

NOTE

Do not dry parts of a lifter with a shop towel. Lint from towels can get between the plunger and body. Disassembled parts must be air dried and must be absolutely clean.

Cam Lobe Shape

The cam lobe has several parts. The *base circle* is what the cam would be if there were no lobe (**Figure 9.32**). The lobe has an opening and closing flank on each side of its nose (**Figure 9.33**). Each cam lobe is ground to a precise contour. The shape of the lobe is a compromise, because a cam grind that will benefit performance at high rpm will hurt performance at low rpm. The reason for this is the inertia of the gases. How well an engine breathes is called its volumetric efficiency (see Chapter 10). The largest

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Cleaning Hydraulic Lifters

Lifters can be disassembled and cleaned, but they must be reassembled with their mated parts. Because of the labor time involved, this procedure is usually not cost effective. Lifter disassembly is a good exercise, however, for a student or apprentice technician or machinist in order to examine the parts and describe the operation of the lifter.

Sometimes a piece of foreign material becomes lodged in the lifter check valve. If the lifter is removed and disassembled before serious wear between the lifter and cam lobe results, it can be cleaned. Disassembling a lifter that has bled down is easy. Hold the plunger down with a small punch through the oil hole (**Figure 9.31a**) and remove the snap ring.

When its check valve is functioning properly, it is not easy to bleed down a lifter that is full of oil. A helpful hint is to install a pushrod in the drill press and apply pressure to the plunger during disassembly. After depressing the plunger with the pushrod, remove the snap ring. The plunger will tend to remain in the lifter body because of vacuum. Strike the top of the lifter against a block of wood or use a special tool to remove the plunger. When the plunger comes out, pour the oil from the inside of the lifter onto a paper towel. Look for dirt particles as a clue to a malfunctioning lifter. The check valve assembly can be disassembled for inspection and cleaning (**Figure 9.31b**).

gulp of air occurs when piston speed reaches maximum velocity, which is when the pressure differential between the inside and outside of the cylinder is greatest.

The two factors of cam lobe profile are called *lift* and *duration*. **Lift** is the height to which the lobe raises the lifter, and **duration** is the number of degrees of *crankshaft* travel while the

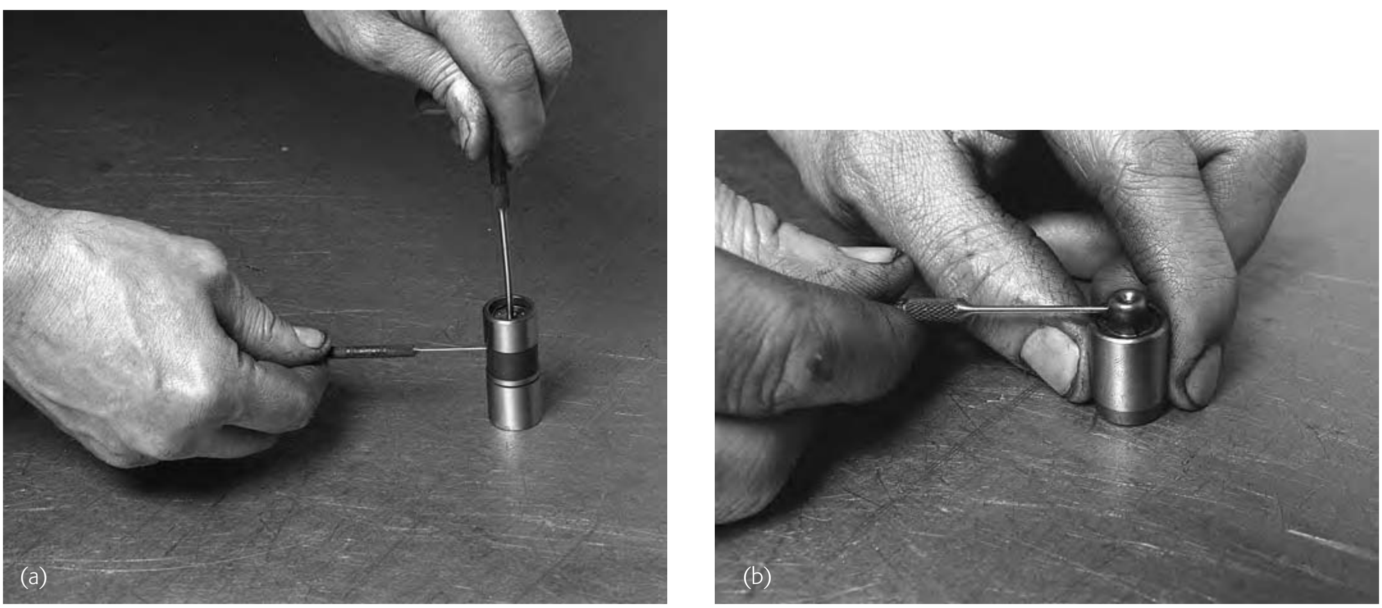


FIGURE 9.31 Disassembling a vintage flat bottom hydraulic lifter. (a) Hold the plunger down and remove the snap ring. (b) Removing the snap-fit check valve from the bottom of the plunger.

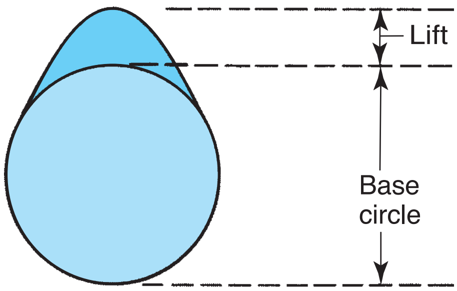


FIGURE 9.32 Base circle and lift. The base circle is what the cam would be if there were no lobe.

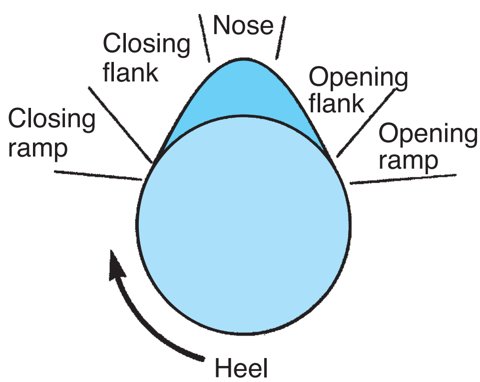


FIGURE 9.33 A cam lobe has an opening and closing flank on each side of its nose.

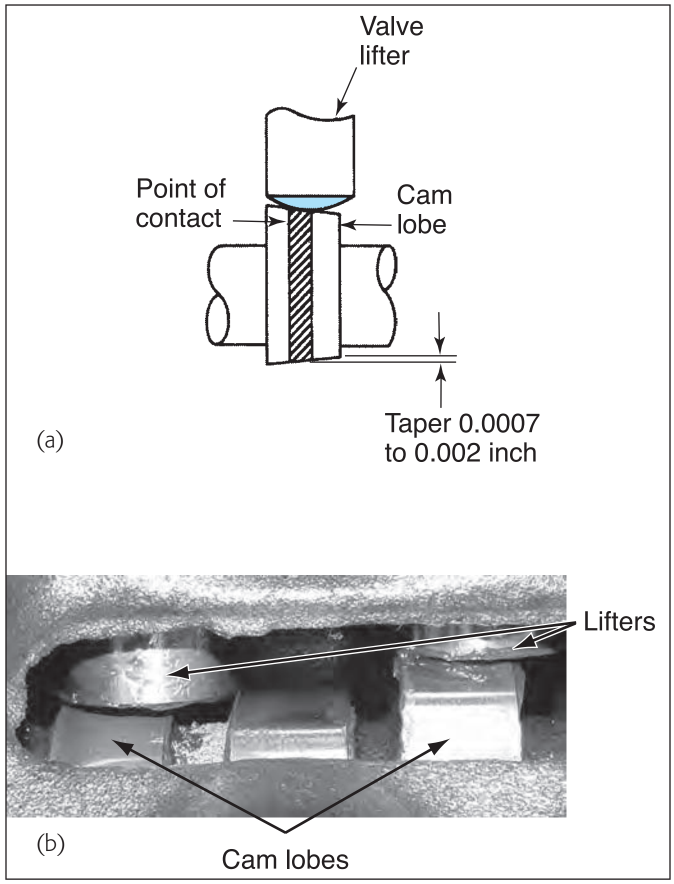


FIGURE 9.34 (a) The lifter face is convex and is offset from the center of the cam lobe. (b) The lifters in this pushrod engine are off-center in relation to the cam lobes. *(Courtesy of Tim Gilles)*

valve is off its seat. The number of degrees of crankshaft travel is often referred to as crank angle. Original equipment cams are referred to as stock cams.

Lifter and Cam Lobe Relationship—Cam-in-Block Engine

The lifter and cam lobe have a unique relationship. On most cam-in-block engines, the lifter face, or crown, is radius ground about 0.002″ to provide a convex contact surface (**Figure 9.34a**) with its centerline offset from the center of the cam lobe (**Figure 9.34b**). In addition, the cam lobe is tapered from approximately 0.0007" to 0.002" across its face. These factors are all introduced to cause the lifter to spin. Spinning is desirable because it helps to dissipate the tremendous load—up to 100,000 psi—to which the lifter is subjected. Lobe taper has a big effect on the speed of lifter rotation. You can observe the results of this with the engine running and the valve cover removed. The normal condition is for the pushrods to be spinning. When a lifter fails to spin at the correct speed, cam and lifter wear results. **Figure 9.35** shows wear from lifters that failed to spin.

The lifter's convex shape also helps to prevent edge loading, which can destroy a cam lobe. Normal wear occurs near the center of the cam lobe. During edge loading, the lifter face contacts the outside edge of the cam lobe and severe loading causes rapid wear of the cam lobe and lifter face. A lifter with concave wear on its face results in edge loading (**Figure 9.36**).

The cam and flat lifters on a cam-in-block engine become wear-mated during the first few minutes that the engine is run. If the cam is replaced, replace the lifters also. With pushrod engines, used lifters will rapidly wear out a new cam.

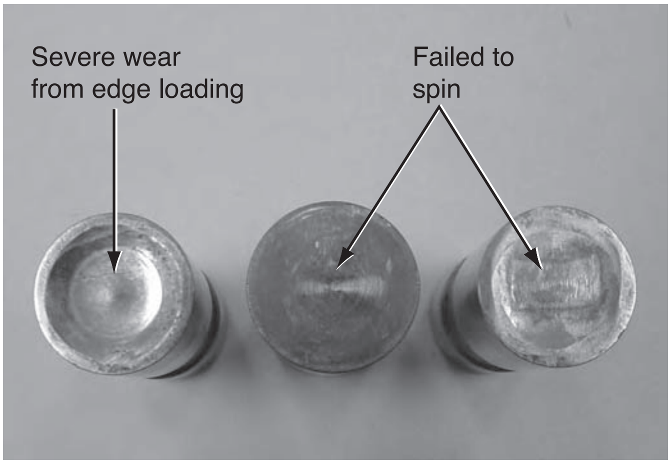


FIGURE 9.35 Examples of lifter wear: the two on the right resulted from a lifter failing to spin. *(Courtesy of Tim Gilles)*

NOTES

- If a camshaft for a pushrod engine is to be reused, it is imperative that the lifters be kept in order for replacement on their respective lobes.
- Sometimes a single lifter will fail in an otherwise good engine. In this case, it is an acceptable trade practice to use a new lifter on an old cam lobe as long as the lobe is unworn.

Lubrication and break-in are critical to the life of a flat tappet camshaft. The cam lobes are usually lubricated by oil thrown from the connecting rod journals on the crankshaft. Therefore, long periods of idle are hard on the cam. A cam that survives the first half hour of use without wear should last the life of the vehicle with minimal additional wear. Apply an extreme pressure (EP) lubricant to the cam and lifters before starting the engine. This will ensure adequate lubrication until enough oil is thoroughly distributed throughout the engine so the cam and lifters can wear together easily.

NOTES

- Flat tappets and their camshafts require sufficient ZDDP for protection. ZDDP is covered in Chapter 14.
- The idle rpm on a new engine should be varied and not be allowed to drop below 1500 rpm for the first 20 minutes. It is also important to set the ignition timing accurately, adjust the valves, and prime the lubrication system before starting the engine. These procedures (covered in Chapter 17) will prevent the engine from cranking for long periods, which can dilute the oil with fuel and help to ruin the cam lobes.

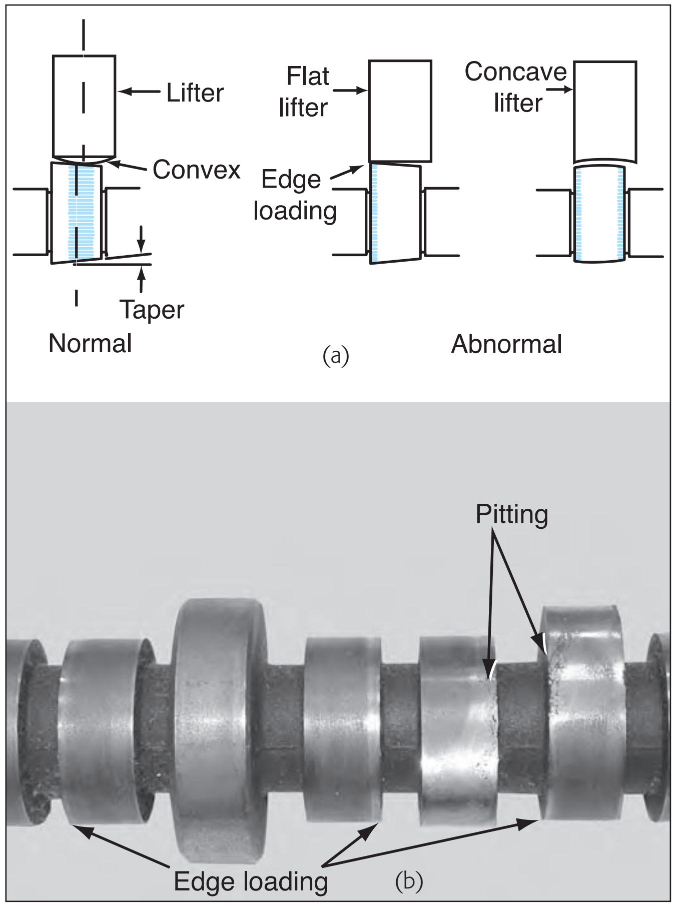


FIGURE 9.36 (a) A convex lifter prevents edge loading. (b) Notice the bright area on the bottom of the lobes. This indicates edge loading. *([b] Courtesy of Tim Gilles)*

If a lobe "goes flat," it is usually the *exhaust* lobe, because it must always force the valve to open against the pressure of combustion. There is little pressure when an intake valve opens at the end of the exhaust stroke.

Overhead Camshafts

Unlike cam-in-block engines, OHC engines have no oil throw-off from valve lifters. Some OHC camshafts are hollow, with oil holes on each cam lobe providing pressure lubrication (**Figure 9.37**). If the oil holes remain clean and unrestricted the cam will suffer very little wear. Periodic oil changes are

FIGURE 9.37 This overhead camshaft has an internal oil gallery and direct lubrication to the cam lobes. *(Courtesy of Tim Gilles)*

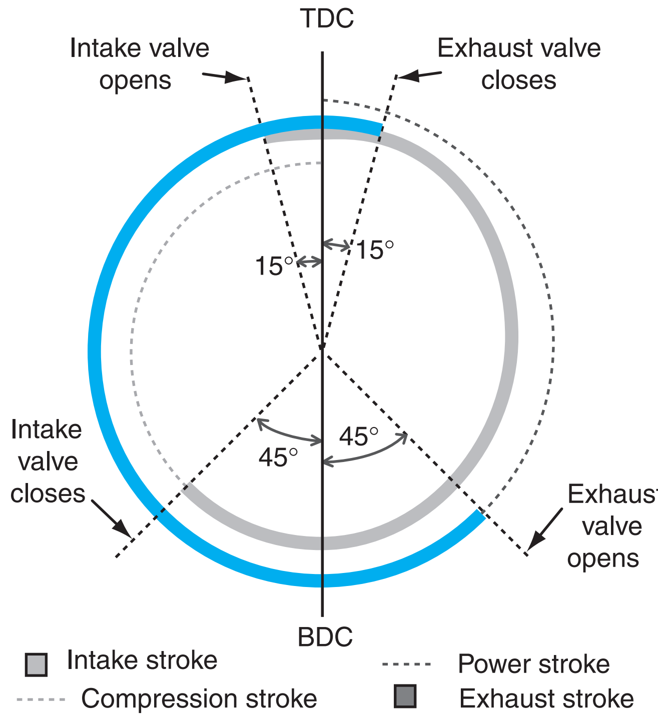


FIGURE 9.38 A valve timing/duration chart.

especially important in these engines and poor oil maintenance can result in camshaft failure. When cleaning the camshaft, be sure to verify that all cam lobe oil holes are open.

VALVE TIMING

As you look at the valve timing chart in **Figure 9.38**, several points should be noted:

- The intake valve opens before TDC to allow the cylinder to fill with air and fuel as the piston begins its descent on the intake stroke.
- The intake valve remains open after BDC, into the compression stroke. This allows the cylinder to continue to fill even as the piston begins to move upward.
- The exhaust valve opens considerably before the end of the power stroke. This allows pressure to bleed off before the piston moves up on the exhaust stroke.
- The exhaust valve remains open past TDC as the piston begins to move back down on its intake stroke.

These concepts are covered in detail in Chapter 10.

Valve Overlap

The **valve overlap** period occurs at the top of the intake stroke when the intake valve is beginning to open and the exhaust valve has not yet finished closing (**Figure 9.39**). You can see the position of valve overlap when you look at a camshaft. Overlap occurs at the start of a four-stroke cycle. Compare the positions of the number one cylinder's cam lobes when the crankshaft timing mark is aligned with the TDC pointer. This means the number one piston is at TDC. More information on this topic is included later in this chapter.

When an engine has mechanical valve adjustment, the clearance setting is very important. The shape of the cam lobe is different from those used with hydraulic cam followers. There is a *clearance ramp* at the beginning and end of each lobe, which is comparable to a wedge that cushions the opening and closing of the valve (**Figure 9.40**). Too much valve lash (clearance) will cause the lifter to miss the clearance ramps altogether. This, in turn, can cause extra shock loads that can seriously damage valvetrain parts.

Regrinding Lifters

When a flat tappet is manufactured, its foot is ground to a radius where it contacts the cam lobe. Hydraulic lifters are not usually reground but are replaced. Solid lifters, however, are most often found in vintage engines. Often, these lifters are rare and expensive. Therefore, they are sometimes reground to the same radius grind as a new lifter, which is approximately 0.005".

VINTAGE ENGINES

Regrinding cam lobes. Reground camshafts were common with vintage engines and you should be aware of them in case you restore an older engine. Cam lobes can be reground to the same specifications as the original cam, although the lobes will be smaller (**Figure 9.41**). More metal is removed from the bottom of the lobe, allowing the cam lobe to have the same contour as the original cam.

Reground cams are somewhat limited if high valve lift is desired. Because metal is removed from the base circle, the base of the cam lobe will become too small as the lift is increased. A reground cam with characteristics similar to a new cam is somewhat less expensive than a new cam provided it is properly remanufactured. A reground cam should retain substantial hardness. According to Wolverine Cams, the depth of base circle hardness ranges from 0.035" to 0.240" with nose hardness from 0.155" to 0.400".

The following are some concerns with reground cams:

- Be sure that the cam has not been excessively ground to the point that the base circle is even with rest of the camshaft (no lobe is visible on the bottom).
- Excessive lobe grinding presents a serious problem, especially when rocker arms are nonadjustable. The pushrods might not be long enough to provide proper depression of the valve lifter plunger.
- Measure the size of a base circle on a good lobe on the original camshaft that is to be replaced and compare its size with a lobe on the reground cam. If the reground lobe is more than 0.050" smaller, get another cam.
- On some camshafts (small block Fords in particular) alternating lobes are tapered in different directions (**Figure 9.42**). Lifters are offset to contact the high side of each lobe. On a poor quality regrind, the machinist might neglect to readjust the camshaft grinder to make the slant on half of the lobes go in the opposite direction. With all of the lobes slanting in the same direction, half of the lifters will not be centered correctly on their lobes, leading to excessive wear after a period of time. If the forward side of the cam lobe is taller than the rear side, this is called a left taper.

Cam journals rarely wear, so they are not reground.

Camshaft surface coating. Camshafts used with flat tappets are made of cast iron darkened by *parkerizing*, a process that coats the camshaft with phosphate to provide resistance to scuffing between the cam and lifter, especially during the break-in period (**Figure 9.43**). To protect them journals are masked during the parkerizing and polished afterwards.

Welding worn cam lobes. Sometimes cam lobes wear severely (**Figure 9.44**), usually on the exhaust lobe, because it has to open against combustion pressure. Flat cam lobes can be welded to build up enough metal for regrinding. Unless the cam is an expensive one from a heavy-duty vehicle, it is usually impractical to repair a cam that requires welding on more than two lobes.

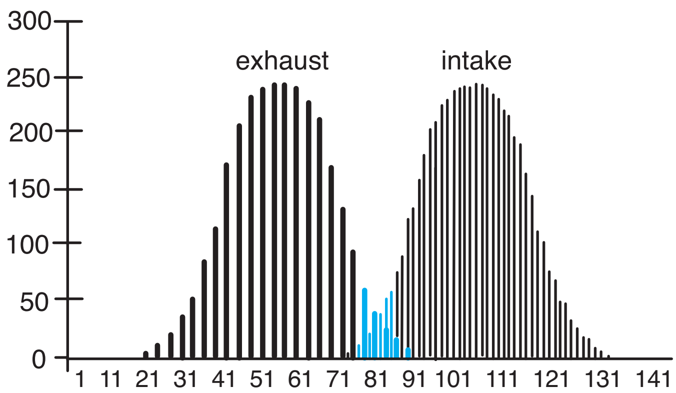


FIGURE 9.39 Valve overlap. *(Courtesy of Dimitri Elgin and D. Elgin Cams)*

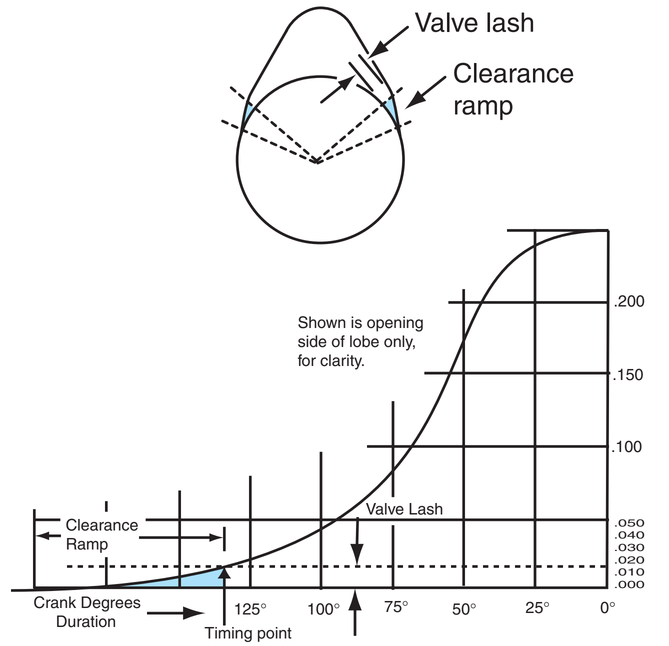


FIGURE 9.40 A clearance ramp cushions the opening and closing of the valves.

ROLLER CAM AND LIFTERS

Roller lifters were developed in the mid-1930s. The roller lifter used throughout the years in diesels and race cars has been used since the mid-1980s in production gasoline engines.

Roller Lifter

A roller lifter intersects the camshaft differently than a flat tappet (**Figure 9.45**). Because of this, it can accept a much higher rate of movement without wear to the lifter or cam lobe. The roller cuts valvetrain friction almost in half, resulting in an increase in horsepower and fuel economy. Even though it is more costly to produce, the savings in fuel economy is incentive enough for manufacturers to use a roller cam. This is due to government regulation.

During the 1960s and early 1970s, a gallon of gasoline could be purchased in the United States for about 25 to 30 cents. An oil embargo by Middle Eastern countries in 1973 caused the price of gasoline to quadruple. In 1975, the United States Congress passed fuel economy standards. Corporate Average Fuel Economy (**CAFE**) is the name of these standards. The fuel economy for different models sold by each manufacturer is averaged to come up with the CAFE number. The CAFE standard at this writing is 27.5 miles per gallon. When a

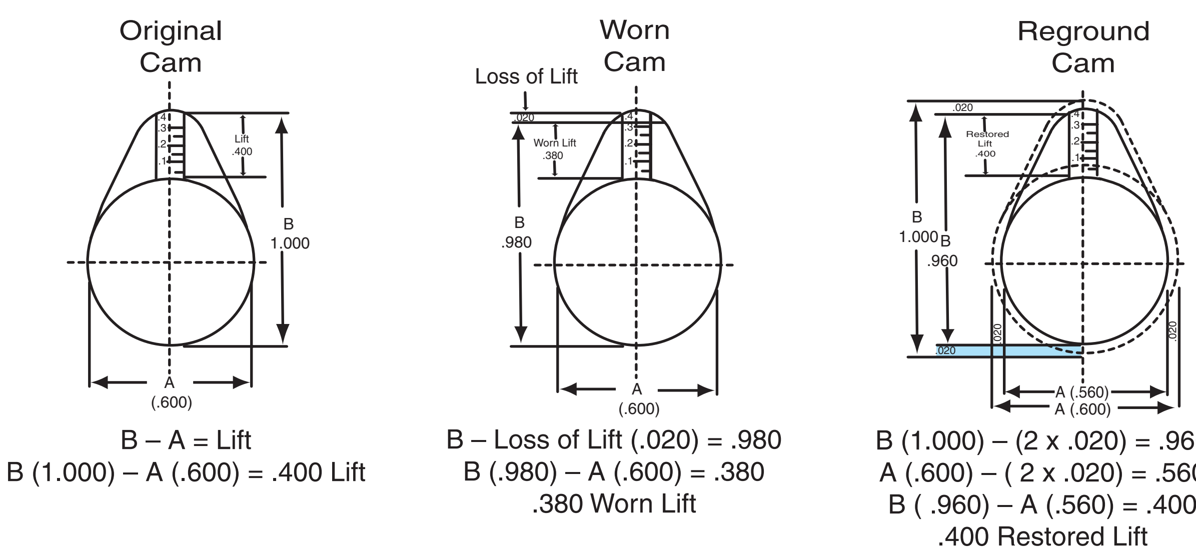


FIGURE 9.41 Camshaft regrinding was popular on vintage engines. The original lift is restored when a camshaft is reground.

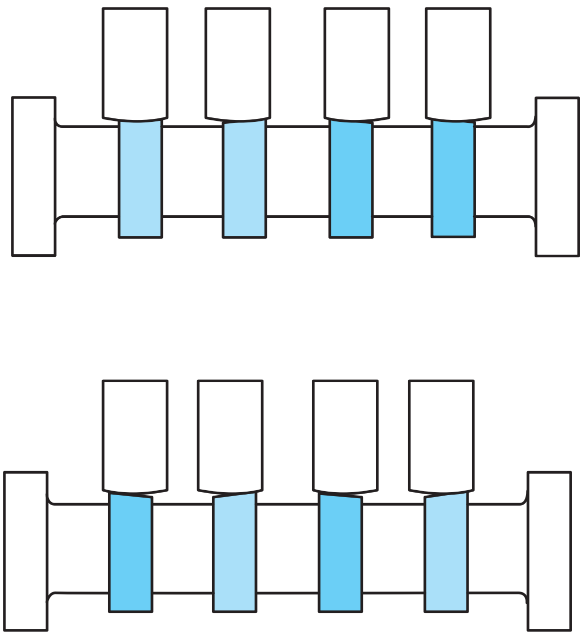


FIGURE 9.42 Flat tappet cam lobes are sometimes tapered in different directions.

FIGURE 9.43 A camshaft for a flat tappet pushrod engine has a black coating from parkerizing to help protect the lobes. Note there is no coating on the bearing journals. *(Courtesy of Tim Gilles)*

FIGURE 9.44 This vintage flat tappet camshaft has several worn lobes. Notice that the corresponding lifters are concave. *(Courtesy of Tim Gilles)*

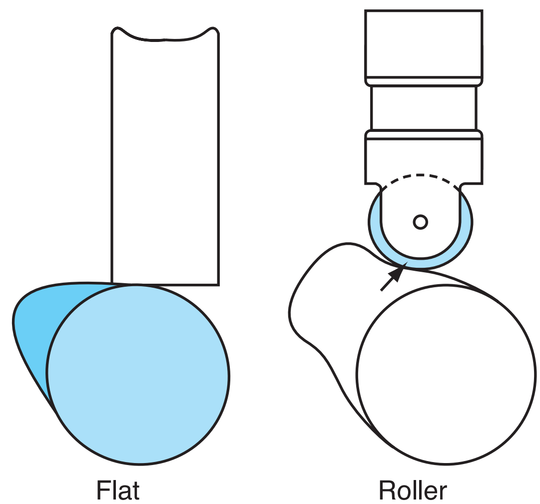


FIGURE 9.45 A roller cam and lifter intersect at different points than a flat tappet and cam. The shape of the roller cam is exaggerated here for emphasis.

manufacturer makes cars that get poor fuel economy, they pay a heavy penalty to the government. When a consumer buys a "gas guzzler," a tax is included in the purchase price.

NOTE

For racing purposes, hydraulic roller lifters are not practical because they are too heavy and tend to float.

Figure 9.46 shows a roller lifter contacting the cam lobe. Notice that it is centered and flat against the lobe, unlike a flat tappet, which is convex and off-center.

Roller lifters require a means to keep them from turning—either a pin or a bracket that holds two lifters in the correct plane (**Figure 9.47**). If the lifter could turn sideways, the roller would not work and damage would result. Roller lifters have a longer service life than standard lifters. Wear can occur on the roller pin, but some pins are serviceable.

Roller Camshaft

The camshaft used with a roller lifter is made of steel (**Figure 9.48**). The lobes have a different shape than standard cam lobes and allow faster acceleration rates. Lobes on roller cams are polished to a fine matte finish. During engine break-in, the lifter burnishes the lobe to a smooth mirror finish. One newer roller camshaft design uses powdered metal lobes fitted to a steel tube and expanded to hold the lobes in position (**Figure 9.49**).

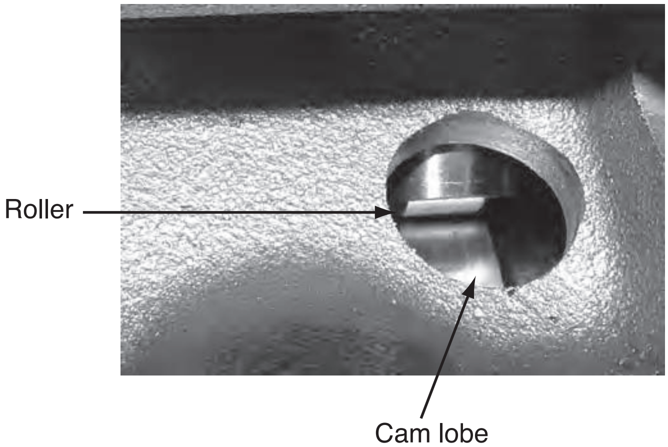


FIGURE 9.46 A roller cam and lifter. Notice that the lifter is centered on the cam lobe and the lobe is not tapered like a flat tappet cam. *(Courtesy of Tim Gilles)*

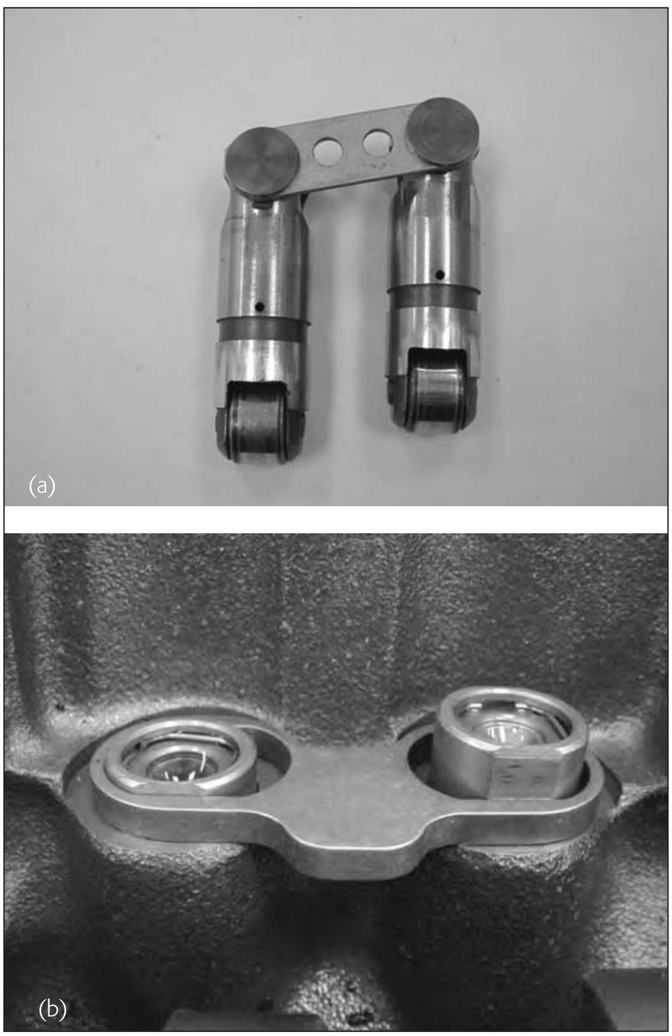


FIGURE 9.47 (a) A bracket keeps roller lifters from turning in their bores. (b) Another style of roller lifter bracket. *(Courtesy of Tim Gilles)*

FIGURE 9.48 This roller cam is made of steel and is very strong. *(Courtesy of Tim Gilles)*

FIGURE 9.49 A steel tube roller cam assembly. *(Courtesy of Tim Gilles)*

NOTE

The visual wear pattern for a roller cam lobe is not as important as it is with flat tappet cam lobes. To inspect for wear, measure the lobe and look for a wear ledge greater than 0.005".

Roller cams can be replaced without replacing the lifters. Roller lifters make much less friction against the cam lobe than flat tappets.

CAM DRIVES

The camshaft is driven by the crankshaft using two gears or with sprockets connected by a chain or belt (**Figure 9.50**). Gear drives are found on older engines. Gear-driven camshafts use helical gears; the crank drives the cam in the direction opposite to the direction of crank rotation.

VINTAGE ENGINES

Many older engines had direct gear-driven camshafts (**Figure 9.51**). A gear drive is more positive than a chain (less chance of excessive backlash), but it is limited by gear size. The cam gear is usually made of a soft material, either fiber or aluminum.

Gear drives are inspected for wear with a feeler gauge or a dial indicator (**Figure 9.52**). Clearance of more than 0.006" (called **backlash**) is cause for gear replacement. Cam gears sometimes break, so inspect them for cracks. Usually, gears do not wear excessively unless they are used on a rough-running engine, such as an uneven firing V6 or an engine with uneven compression.

Gears are either pressed on or bolted on. Pressed-fit aluminum gears should be preheated to about 200°F (93°C) before installation.

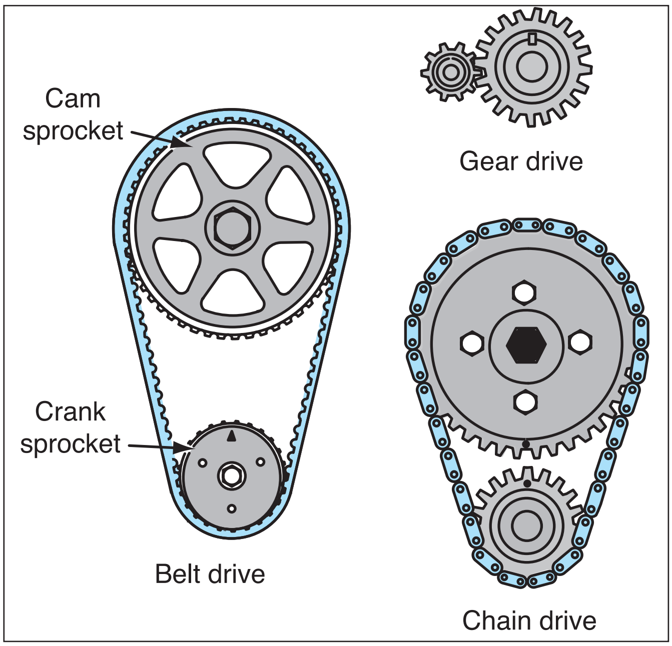


FIGURE 9.50 There are half as many teeth on the crank drive as there are on the cam drive.

NOTES

- A conversion kit to change a chain drive to a gear drive is available from racing parts distributors. It uses idler gears so that the cam and crank will rotate in the same direction as they do with a chain drive (**Figure 9.53**). A disadvantage of idler gear drives is that they are noisy.
- Some expensive automobiles and V-type racing engines have a multiple gear drive powering dual overhead cams. This arrangement is impractical for use in conventional passenger cars.

TIMING CHAINS AND BELTS

It is not unusual to hear stories of engines with 200,000 miles that are still running. Long engine life is due to a combination of regular periodic maintenance and the way a vehicle is driven. Even when an engine has experienced regular oil maintenance, the belt or chain will still require replacement. Belts have prescribed replacement intervals, whereas timing chains typically do not. This does not mean that they should not be replaced on a preventive maintenance basis, however. This section of the text deals with the theory and service of timing chains and belts.

Freewheeling and Interference Engines

On some engines, piston-to-valve interference can occur if the timing chain or belt skips or breaks (**Figure 9.54**). These engines are called nonfreewheeling or interference engines. When this happens on a pushrod engine, pushrods will usually bend (**Figure 9.55**), although the valves and pistons might survive. But on OHC engines, the valves must bend or a valvetrain part might break. When the piston and valve are forced hard against each other, the result can be serious engine damage. **Figure 9.56a** shows a notch that was created in the top of the piston as the piston was driven against the valve. **Figure 9.56b** shows the crack in the piston pin boss that resulted. An indentation resulting from contact between a piston and a valve is called a *"witness mark."*

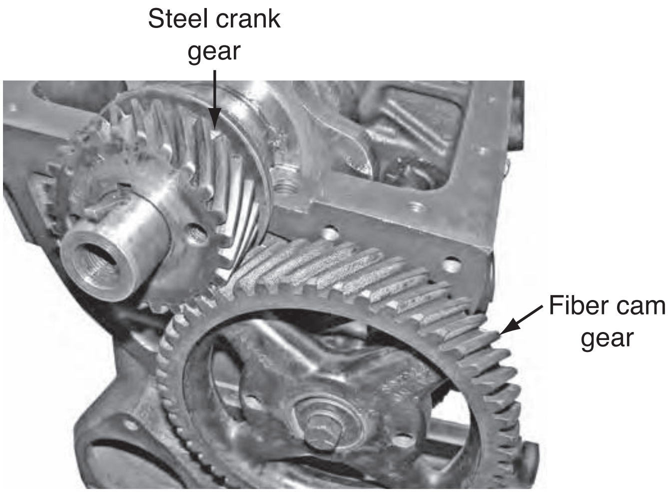


FIGURE 9.51 A vintage gear-to-gear drive. *(Courtesy of Tim Gilles)*

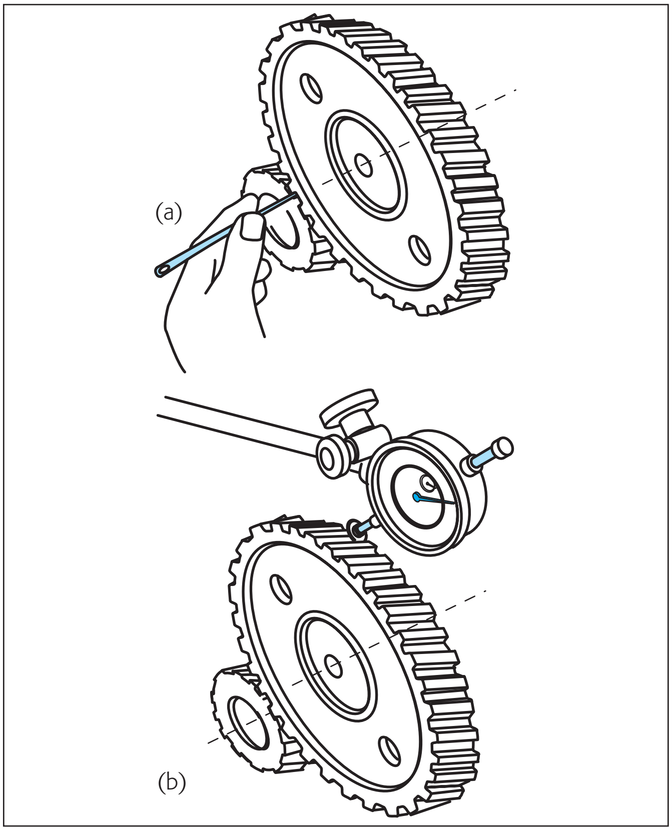


FIGURE 9.52 Check vintage cam gear drives for wear with (a) a feeler gauge or (b) a dial indicator.

NOTE

When an interference engine suffers a chain or belt failure in a front-wheel drive vehicle with a manual transmission, the front wheels can lock up. This can be pretty exciting for the driver.

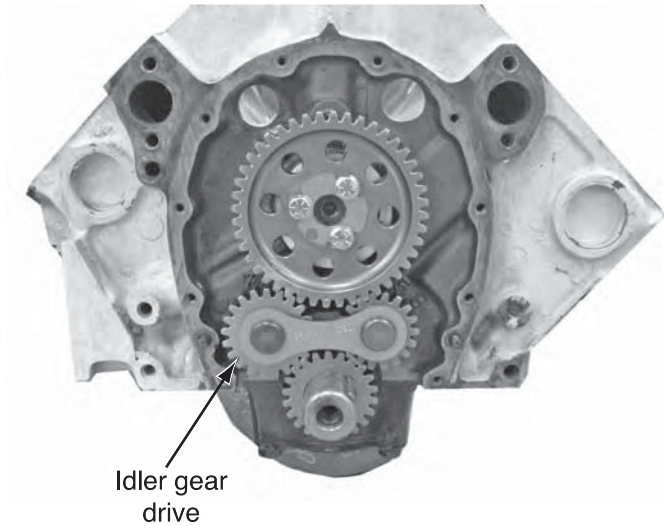


FIGURE 9.53 This aftermarket idler gear drive is used to replace a timing chain. These tend to be loud. *(Courtesy of Tim Gilles)*

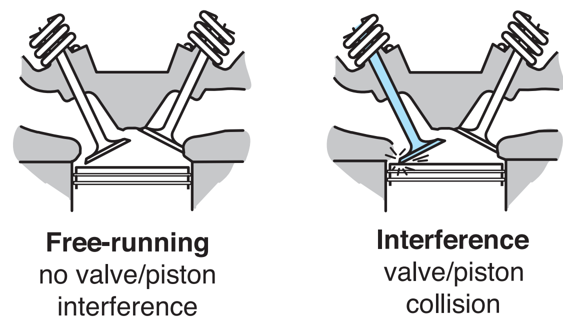


FIGURE 9.54 Free-spin and interference engines.

FIGURE 9.55 This pushrod was bent when a piston collided with an open valve. *(Courtesy of Tim Gilles)*

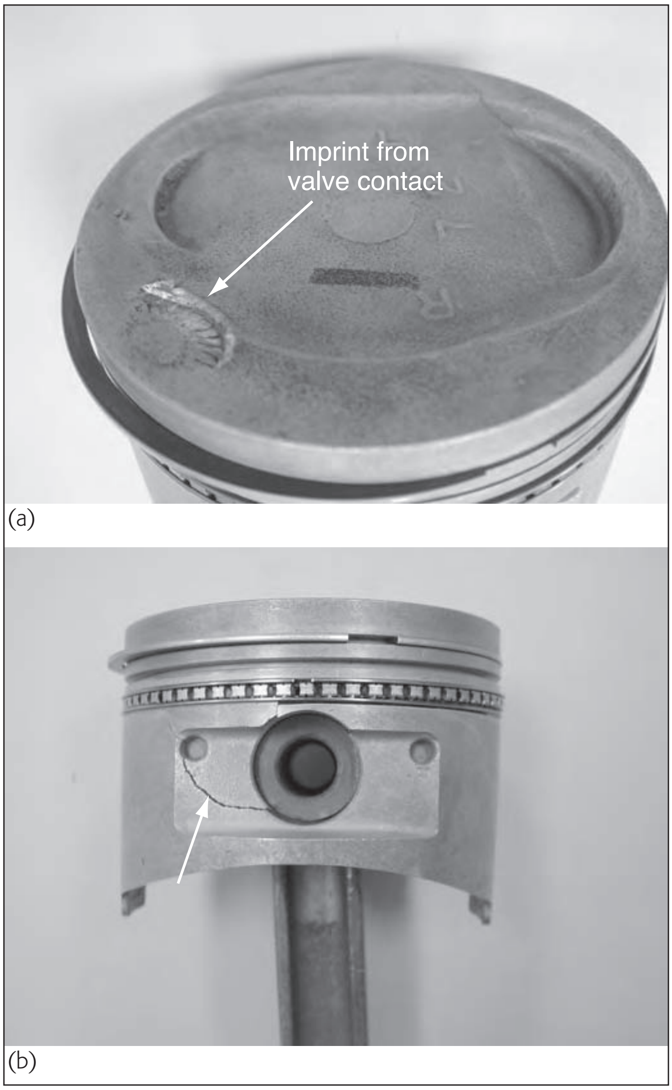


FIGURE 9.56 A piston damaged by a collision with a valve. (a) This imprint happened when the piston and valve collided. (b) This crack in the piston pin boss resulted from the impact. *(Courtesy of Tim Gilles)*

When the timing chain on an interference engine skips a tooth due to excessive chain slack and/or damage to the sprocket teeth, all exhaust valves can be bent at the same angle (**Figure 9.57**). This happens because the cam lobes are now opening the valves later because the chain has skipped. The exhaust valve normally closes just in front of the piston as it moves up on the exhaust stroke, but now when the pistons reach TDC on their exhaust strokes each exhaust valve is still open too far and a collision takes place.

In a freewheeling or free-running engine, the pistons and valves cannot contact each other when the valve timing is wrong or the drive chain or belt breaks or slips. Almost all American cars are freewheeling and Japanese imports are more likely to be interference engines. Interference engines in American vehicles most often are foreign made. Four-valve-per-cylinder configurations are often interference engines.

FIGURE 9.57 These exhaust valves from a four cylinder OHC engine were all bent when the timing chain skipped. *(Courtesy of Tim Gilles)*

SHOP TIP

On an interference belt-driven OHC engine, if the heads are already installed on the engine and you need to turn the camshaft to set camshaft timing, you might force a valve into a piston that is at TDC. To avoid this, first rotate the crank backward until it is about 45° before TDC (BTDC). At this point, all of the pistons will be slightly down in their bores and valve-to-piston interference will not occur.

Camshaft Drive Sprockets

Depending on the application, sprockets are made of steel, iron, aluminum, or fiber (**Figure 9.58**).

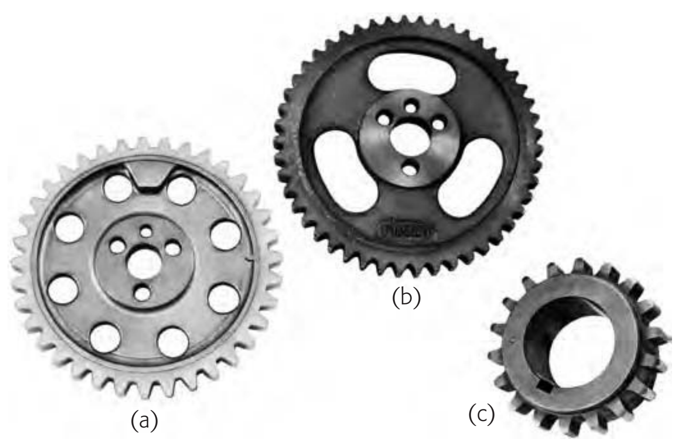


FIGURE 9.58 Different types of timing sprockets. (a) Nylon tooth/aluminum. (b) Cast iron. (c) Steel. *(Courtesy of Federal-Mogul Corporation)*

VINTAGE ENGINES

Aluminum sprockets, used in older engines, came from the factory with injection molded nylon teeth. which were less expensive to produce and reduced noise. When the chain developed slack, the nylon teeth would sometimes shear off the sprocket (**Figure 9.60**). Pieces of nylon from a damaged sprocket can stick in the oil pump pressure relief valve. In the aftermarket, these sprockets are typically replaced with steel sprockets. Nylon sprockets should not be used in heavy-duty vehicles such as trucks or high-performance cars with standard transmissions.

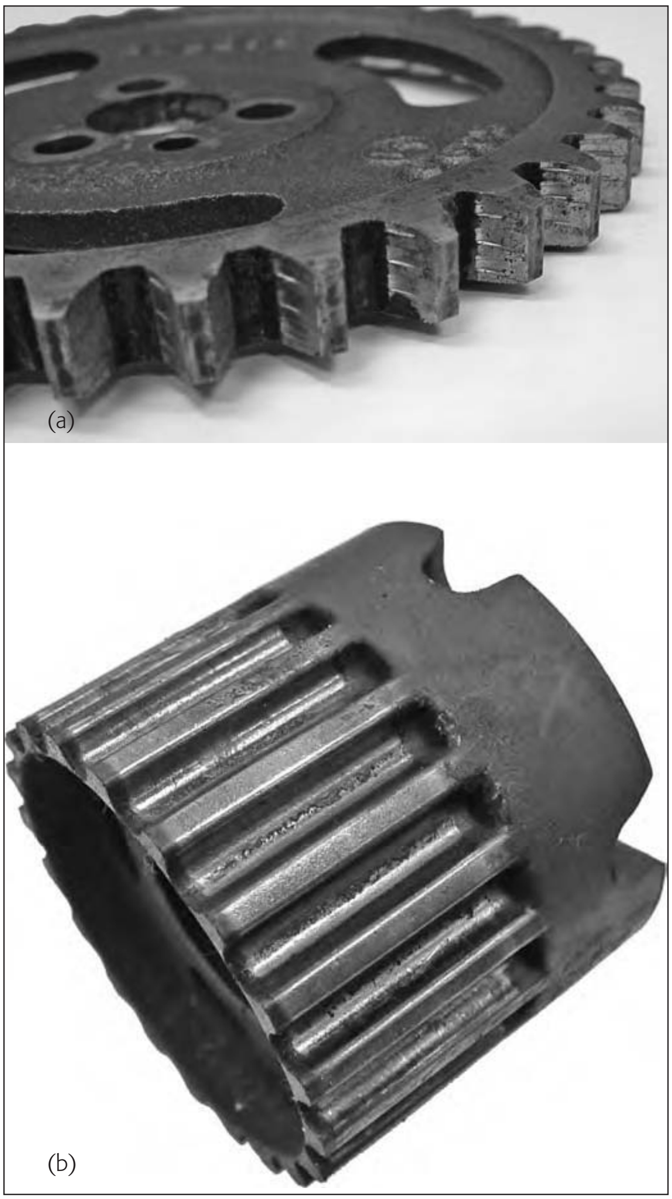


FIGURE 9.59 Worn sprockets. (a) A worn cam sprocket for a timing chain. (b) A worn crankshaft belt sprocket. *(Courtesy of Tim Gilles)*

A worn sprocket should not be used with a new chain or belt; it must be replaced. **Figure 9.59** shows worn sprockets—one from a chain drive and one from a belt drive.

Installing the Crankshaft Gear or Sprocket

When old parts are available, carefully compare them to the new gears or sprockets. Make note of the locations of the keyway and timing marks to be sure they are the same. There have been cases where a sprocket was stamped backward during manufacturing.

FIGURE 9.60 Some of the nylon teeth are missing from this vintage engine cam sprocket. *(Courtesy of Tim Gilles)*

Timing Chains

Some engines use a timing chain instead of a belt. One advantage to a chain is that it is narrower than a belt, so the engine can be slightly shorter in length. The two types of chain are *roller* and *silent* (**Figure 9.61**). A roller chain has less friction than a silent chain. It can be either single or double row and it does not stretch as much. Roller chains are sometimes used on pushrod engines. Chain-driven OHC engines almost always use roller chains, which are lighter and are more suited to high rpm than the silent chains most often used with lower rpm pushrod engines.

Silent chains, as the name implies, are quieter. Newer silent chains are the large-pin design. These "floppy" chains are twice as strong as older silent chains. The large-pin silent chain eliminates chordal action, which is a problem with roller chains. Chordal action means the chain operates on a constantly changing diameter, which causes varying camshaft speeds. Due to their greater flexibility, large-pin silent chains are also less susceptible to misalignment and overload problems than roller chains.

NOTE

Large-pin silent chains are so flexible that they appear excessively sloppy when new. According to Link-Belt Automotive Products, typical movement on the slack side is around 0.200" in and out (0.400" total). Replacement is suggested when total movement is 1.00".

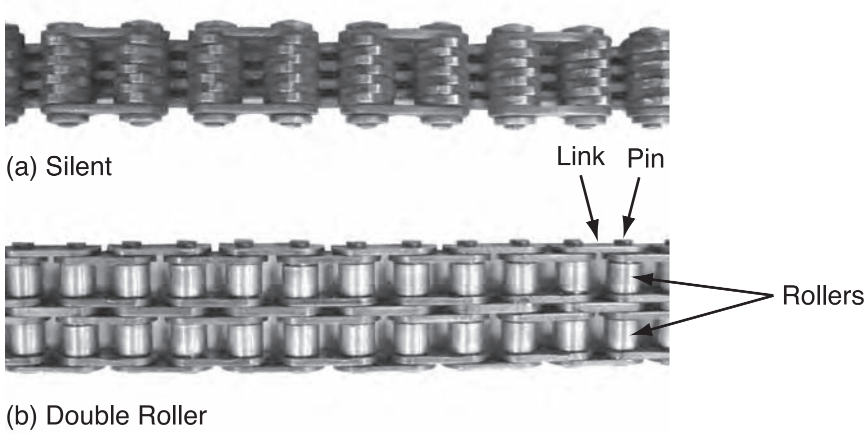


FIGURE 9.61 Timing chain types. (a) Silent. (b) Roller. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Older pushrod engines did not have timing chain tensioners. In these engines, there are several ways of checking a timing chain for excessive stretch. When an engine with no chain tensioner has a camshaft-driven distributor, observe the dwell section of an ignition scope pattern with the engine running to see if it jumps around as the engine idles. The timing mark will also move around during an ignition timing check.

You can also check for chain slack while the engine is in the car. Because the camshaft drives most distributors, you can use this method to check for chain slack.

First, remove the distributor cap. Then turn the vibration damper in one direction until the distributor rotor begins to turn. Next, turn the crank in the opposite direction until the rotor moves again while observing how far the damper moves. The engine may still run acceptably with 10° to 15° of chain slack. But, ideally, movement should be less than 5° at the crank.

Timing Chain Stretch

The timing chain or belt is the weakest link in an engine's long life. It is realistic to replace it whenever it has been removed. As an engine ages, its timing chain stretches. This can result in retarded valve and ignition timing.

Timing chains have a drive, or tension, side and a side where slack accumulates. **Figure 9.62** compares chain slack on timing sets for two cam-in-block engines. One of them has a chain tensioner to compensate for slack as the chain stretches.

After removing the timing cover during engine disassembly, you can check the timing chain for wear by first turning the crank in one direction, which tightens up one side of the chain. Then measure the amount of slack in the chain (**Figure 9.63**).

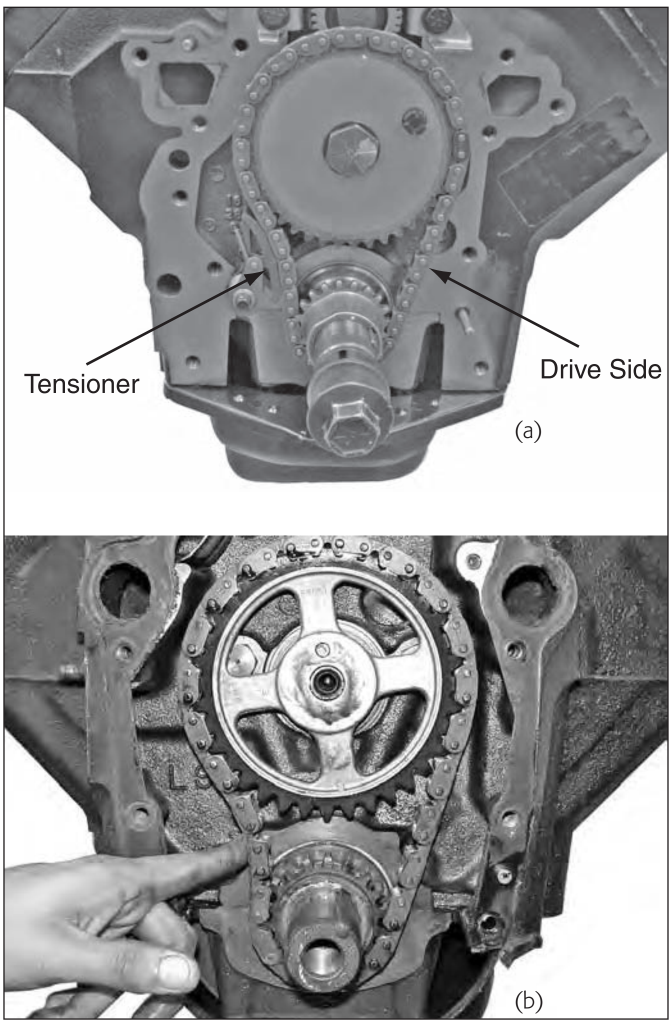


FIGURE 9.62 (a) A newer pushrod timing chain with a tensioner. (b) This timing chain from an older pushrod engine has no chain tensioner. The chain is badly worn. *(Courtesy of Tim Gilles)*

SHOP TIP

Before installing a new timing chain, soak it in oil.

Timing Chain Tensioners

Long chains like those used on OHC engines always use chain tensioners (**Figure 9.64**). When a timing chain is replaced, common practice is to replace the chain guides, both sprockets, and the tensioner as well.

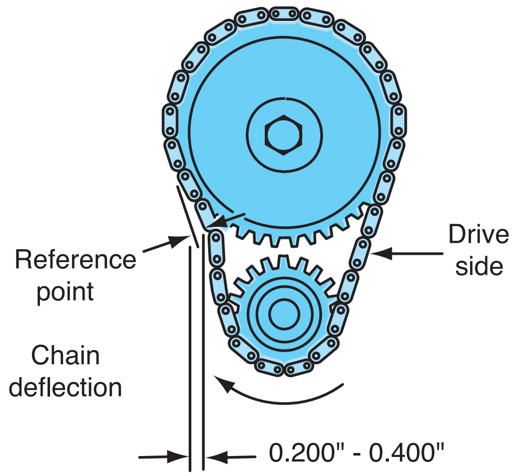


FIGURE 9.63 Measuring chain slack.

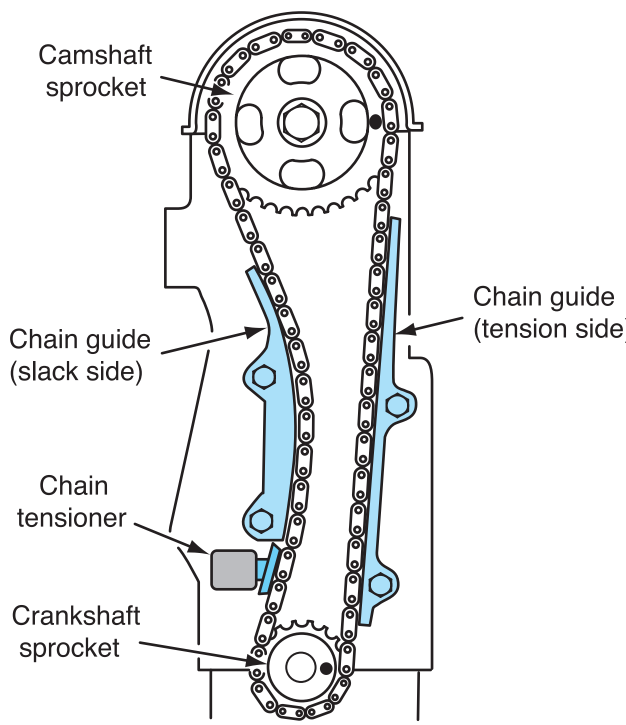


FIGURE 9.64 Parts of an OHC chain-driven assembly.

SHOP TIP

Some timing chain tensioners are spring-loaded and do not lock against the chain until applied by oil pressure when the engine runs. Do not rotate the crankshaft backward on these engines while the engine is off. Some of these types of tensioners can allow the chain to skip off correct valve timing (**Figure 9.65**).

Some chain tensioners are loaded against a ratchet to prevent the situation mentioned in the Shop Tip from occurring. To install these tensioners, release the ratchet mechanism with a pocket screwdriver (**Figure 9.66**). Then slide a small punch or Allen wrench into the hole to hold the tensioner in its retracted position while you reinstall it on the engine.

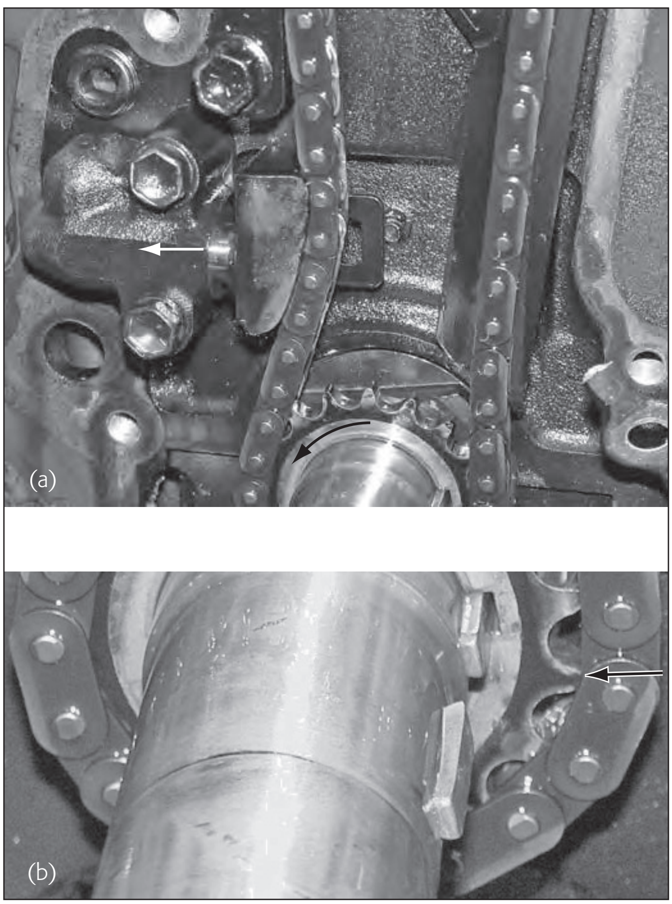


FIGURE 9.65 (a) Turning this crankshaft backward will pull the tensioner in, allowing chain slack to accumulate at the bottom of the crank sprocket. (b) The slack that results can allow the chain to skip a tooth. *(Courtesy of Tim Gilles)*

Timing Chain Guides

Long chains have chain guides with surfaces that wear. **Figure 9.67** shows typical chain guide and tensioner wear. **Figure 9.68** shows severe tensioner wear with the synthetic rubber surface worn totally away and the aluminum backing worn almost totally away.

CASE HISTORY

A customer had a noisy engine in a Toyota pickup with 200,000 miles on the odometer. On some high-mileage engines, the timing chain guide suffers excess wear before finally breaking. With the valve cover removed on the engine shown in Figure 9.69, wear was evident on the inside of the timing cover. When the timing cover was removed, a broken timing chain guide was found. The customer had complained of noise, which resulted as the unrestrained chain pounded against the timing cover.

TIMING THE CAM TO THE CRANK

Be sure to check the service literature before you install the chain or belt. The camshaft can be timed to the crankshaft in any of a number of ways, depending on the manufacturer. When most of the engines were cam-in-block, it was common for sprockets to be properly timed when the marks faced each other. The majority of engines manufactured today are OHC, however, and there are a variety of options available. These are covered in the rest of this chapter.

Chain Drive Timing Marks

When the engine has a timing chain, there are several ways that manufacturers label cam and crank sprocket timing. Here are some of the available options:

- Some manufacturers specify a certain number of chain links between the marks (**Figure 9.70**).
- Sometimes chains have colored links that must align with the marks on the sprockets (**Figure 9.71**).

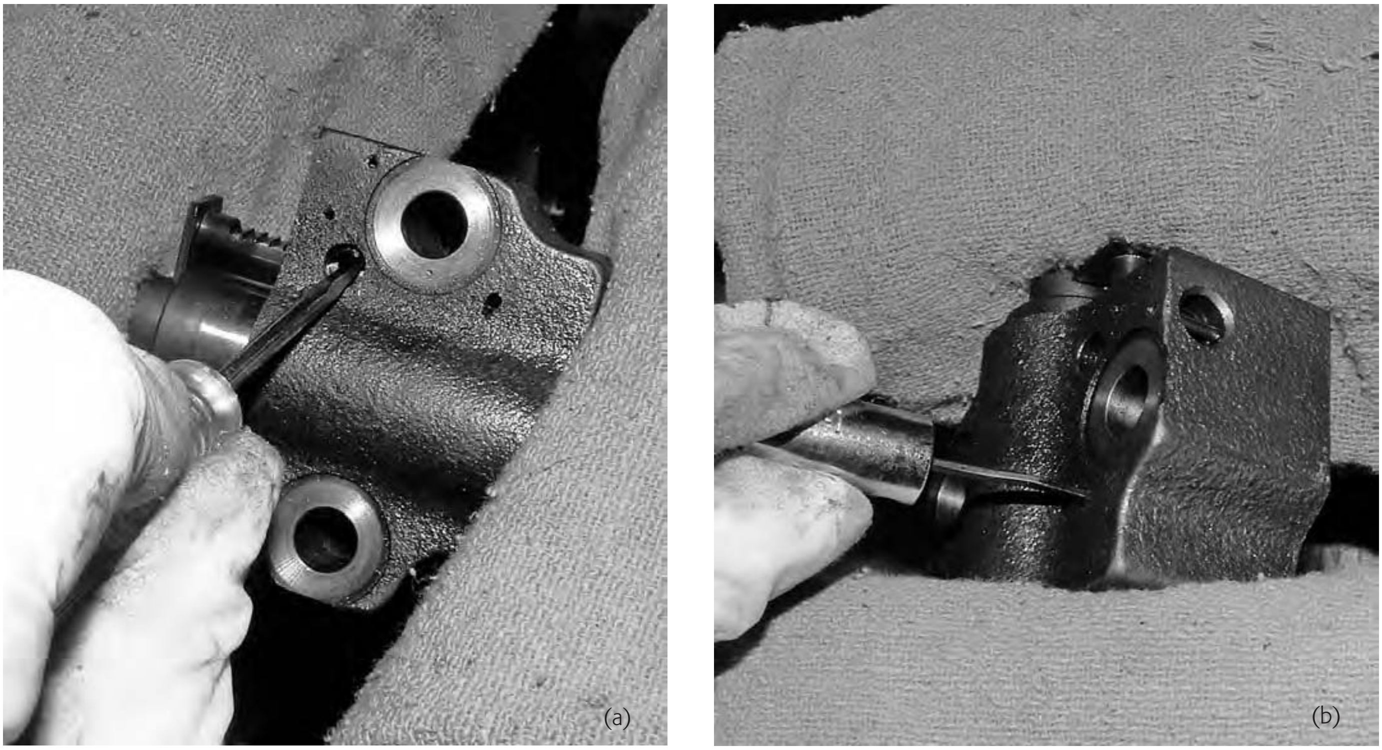


FIGURE 9.66 Use a small pocket screwdriver to release the ratchet mechanism. Then install a small punch or Allen wrench into the hole to hold the tensioner in the retracted position during installation.

FIGURE 9.67 Typical wear to a high-mileage timing chain guide and tensioner. The contact surfaces were smooth when new. *(Courtesy of Tim Gilles)*

FIGURE 9.68 This chain guide has worn almost all the way through its metal backing. *(Courtesy of Tim Gilles)*

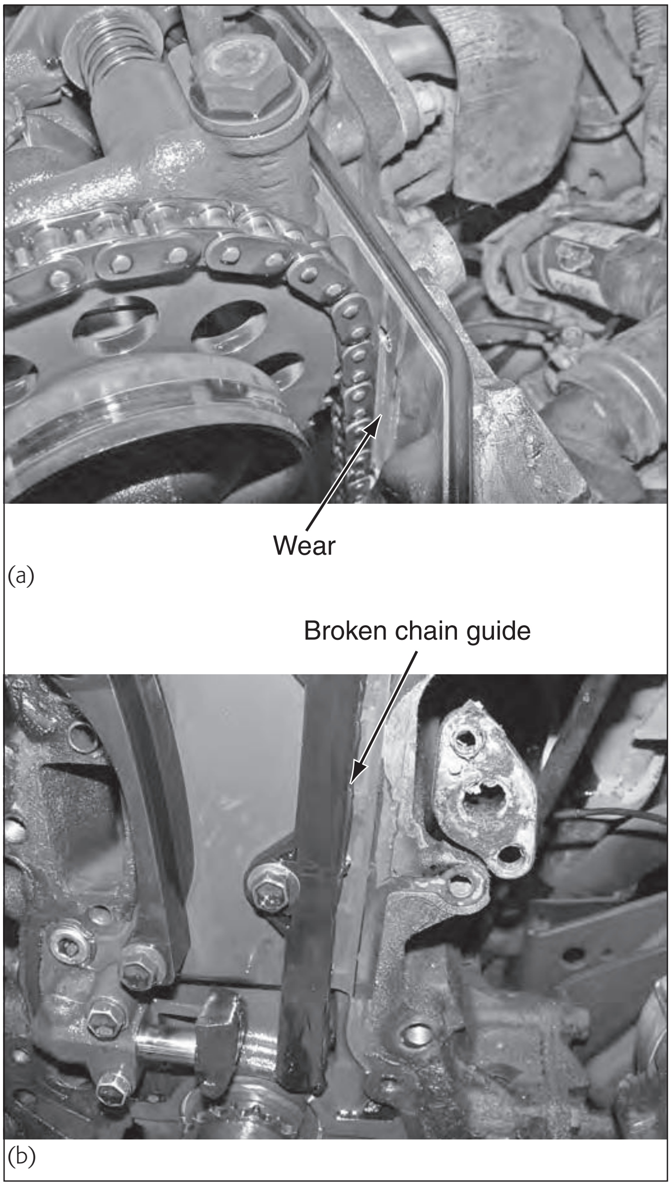


FIGURE 9.69 This engine made lots of noise. The cause turned out to be a broken timing chain guide and a loose, worn chain. *(Courtesy of Tim Gilles)*

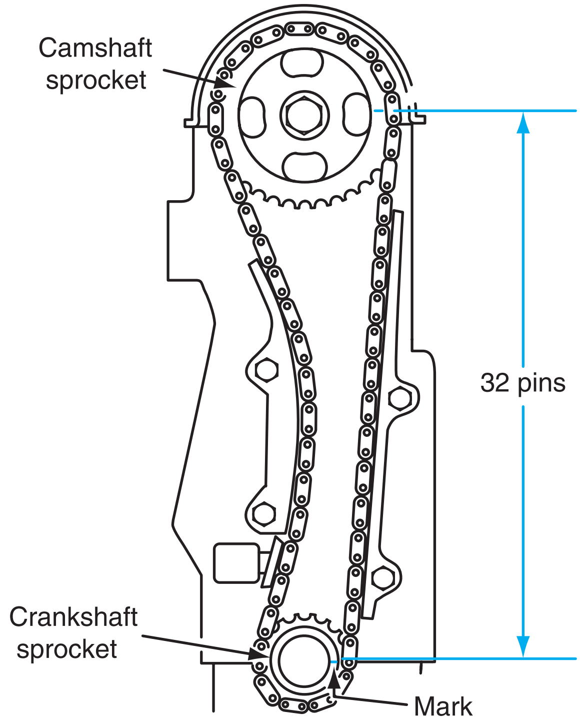


FIGURE 9.70 Some manufacturers specify a certain number of chain pins between the timing marks. In this case, 32 pins are counted.

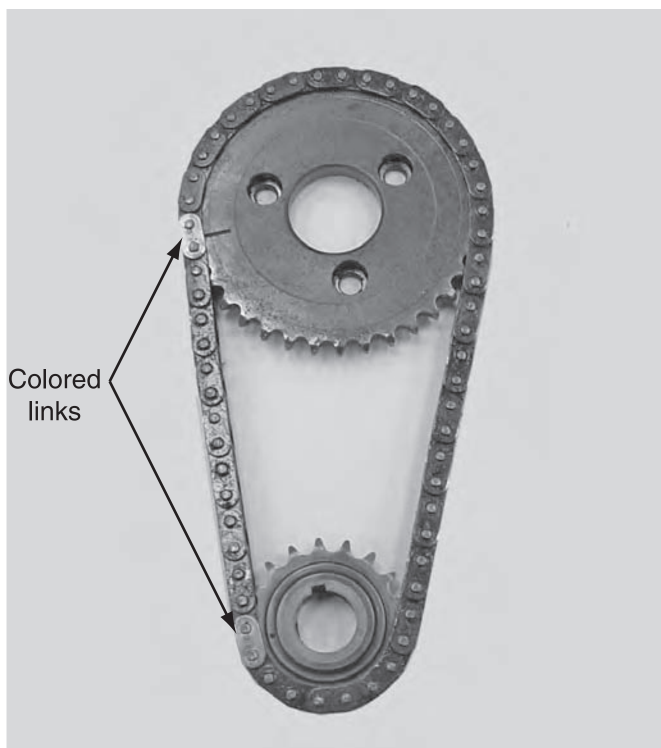


FIGURE 9.71 This timing chain has colored links that align with the timing marks. Check the service literature to verify whether the links go on the left or right side of the sprocket teeth.

- Some OHC engines have a mark on the cam sprocket that lines up with a mark on the cylinder head when the timing mark on the crank sprocket is at the TDC mark (**Figure 9.72**).
- OHC engines sometimes have one crankshaft-driven chain with one or two auxiliary chains to the cams on the cylinder heads (**Figure 9.73**). These can have several timing marks.
- Some DOHC engines have one camshaft driven by a chain and that camshaft turns the other one by a gear drive.

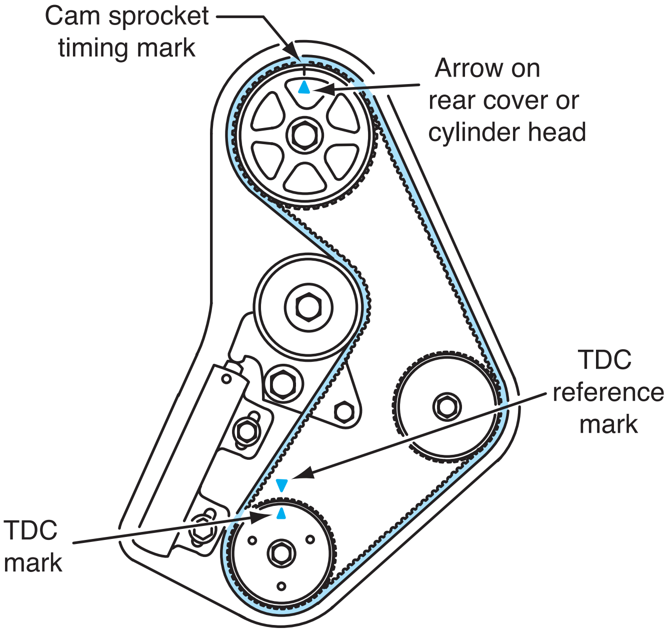


FIGURE 9.72 A mark on the cam sprocket aligns with a mark on the cylinder head when the crank sprocket is at TDC.

- Some engines use a balance shaft (see Chapter 12). It is crucial that the balance shaft be timed correctly. **Figure 9.74** shows typical balance shaft timing marks.

Locating TDC

Whether you are installing a timing chain or a timing belt, you need to position the number one piston at TDC. A small amount of engine theory knowledge will help you verify the TDC position without having to refer to service literature. For instance, when the cam lobes are in the valve overlap position on an OHC engine with bucket cam followers, the cam lobes face down toward the head. **Figure 9.75** shows the cam lobe positions in relation to a valve timing chart. **Figure 9.76** shows SOHC lobe positions at TDC at the beginning of the intake and power strokes. When the number one piston and its companion piston are at TDC, the cam lobes should be in one of these positions. More information on positioning the cam and crank sprockets correctly is provided later in this chapter.

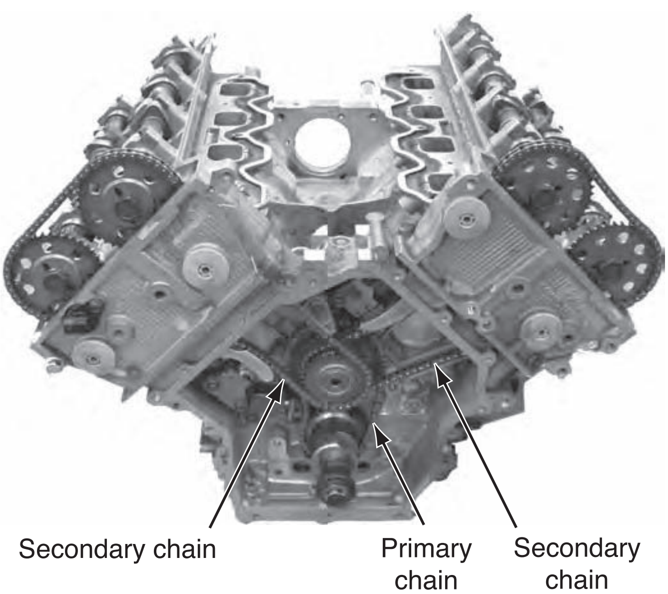


FIGURE 9.73 This Cadillac Northstar DOHC engine has a primary drive chain and two secondary chains. *(Courtesy of Tim Gilles)*

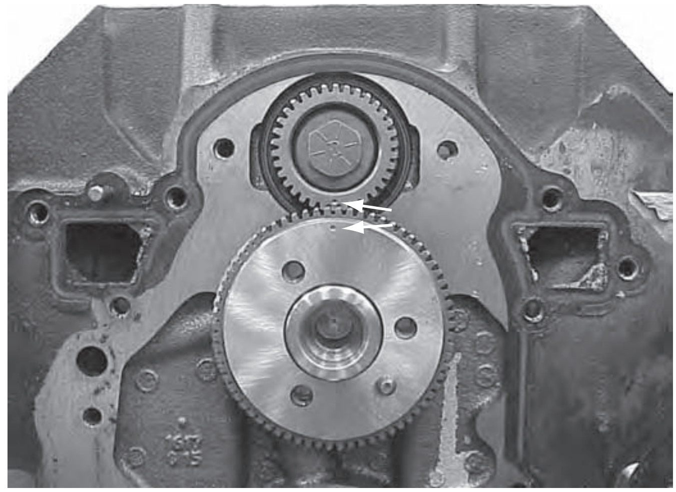


FIGURE 9.74 Typical balance shaft timing marks. The timing chain and sprockets are phased to this shaft. *(Courtesy of Tim Gilles)*

TIMING BELTS

Camshafts on many OHC engines are driven by a timing belt (**Figure 9.77**). Timing belts were introduced in the 1960s. Compared to timing chains, they are quieter, do not require lubrication, are more efficient, and resist stretching. Timing belts are remarkably strong and durable with a very strong fiberglass cord structure and rubber impregnated molded teeth (**Figure 9.78**). Both the inner cogged surface and the outer flat surface can drive accessories (**Figure 9.79**). Timing belts sometimes drive a coolant pump, an oil pump, and/or a balance shaft.

Timing Belt Inspection and Replacement

Timing belt replacement recommendations vary for each engine. Be sure to refer to the service

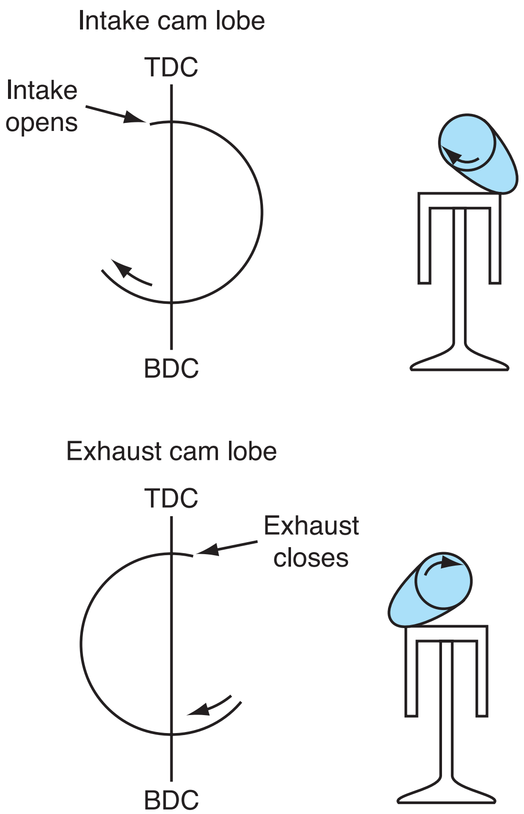


FIGURE 9.75 Position of intake and exhaust cam lobes when the number one piston is at TDC at the beginning of the four stroke cycle. This is when the timing marks should align. You can apply this same information to the individual cam lobes if you are timing a DOHC engine.

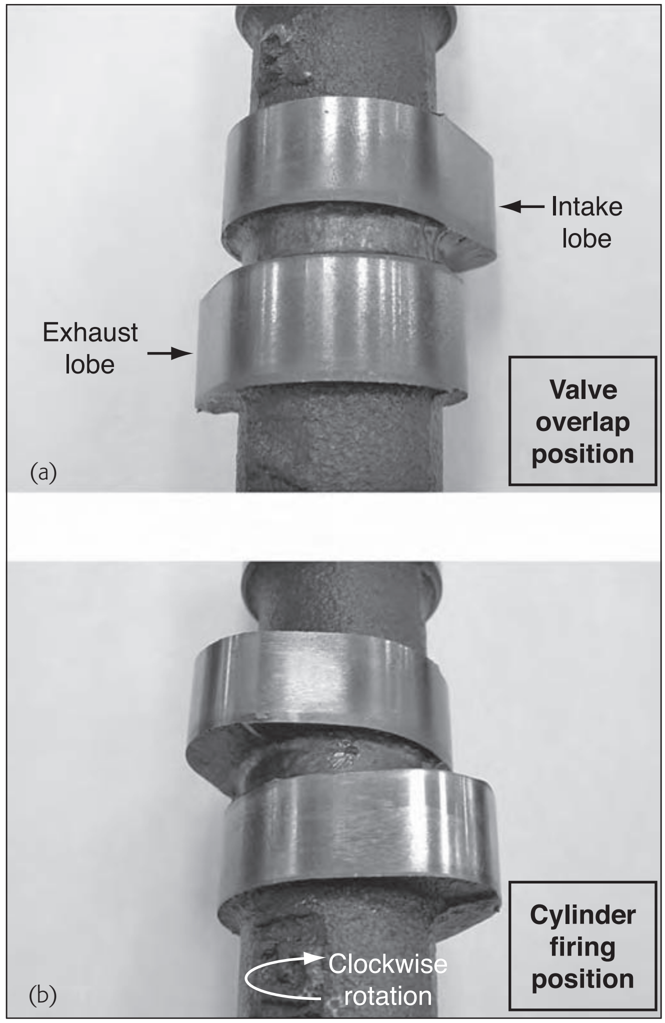


FIGURE 9.76 Position of SOHC cam lobes at TDC (with bucket cam followers). (a) Valve overlap. (b) Cylinder firing position. *(Courtesy of Tim Gilles)*

literature before beginning the job. There are service manuals dedicated solely to timing belt replacement (**Figure 9.80**).

Timing Belt Replacement Interval

It is important for a vehicle owner to follow the manufacturer's timing belt replacement interval recommendation. With an interference engine, a failed timing belt can result in piston-to-valve interference and serious engine damage. Some aftermarket belt manufacturers recommend that timing belts be replaced at 40,000 to 50,000 miles or every 4 years. Due to improvements in belt quality, some OE manufacturer recommendations now exceed 100,000 miles.

Timing Belt Material

Timing belts suffer virtually no stretch, although belt materials deteriorate with time and exposure to ozone, oils, and fuels. Artificial rubber materials are usually high-temperature neoprene or highly saturated nitrile (HSN). HSN is a superior material for high-performance applications. A comparison of belt materials by the Gates Rubber Company gives the following estimation of belt life at sustained high temperatures:

Neoprene—200 hours
High-temperature neoprene—500 hours
HSN—1500 hours

Timing Belt Storage, Handling, and Inspection

Fiberglass cords used in timing belts are stronger than polyester cords found in accessory drive belts, although they are more fragile. Bending

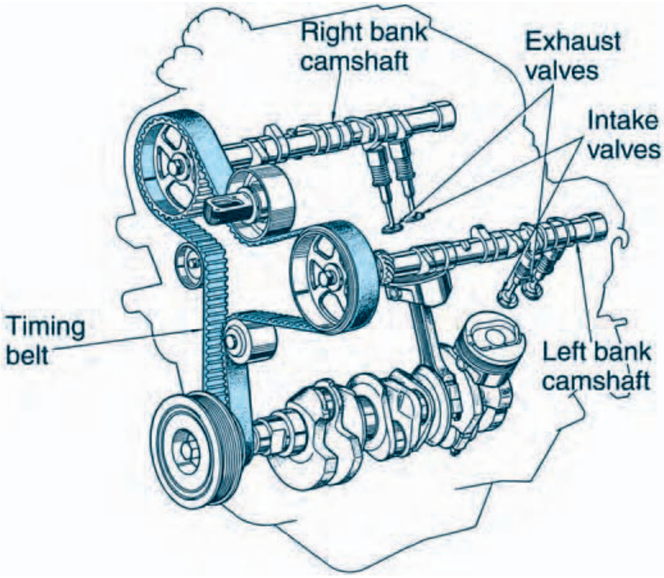


FIGURE 9.77 A V-type engine timing belt drive. *(Courtesy of Toyota Motor Sales, U.S.A., Inc.)*

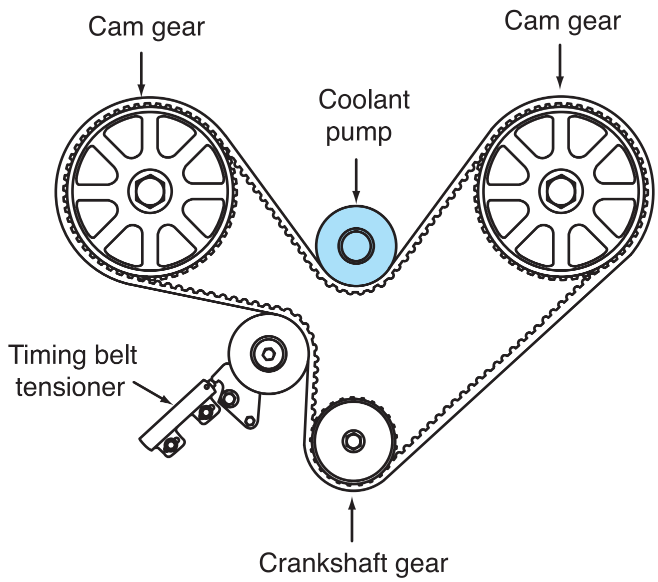


FIGURE 9.79 Both sides of a timing belt can drive accessories.

timing belts in any direction can cause them to break. Do not twist them more than 90°, and do not coil them up or hang them for storage.

- Inspect belts for fraying, cracks at the base of a tooth, or loose fibers.
- Rotate the engine slowly as you inspect the belt.
- Do not twist the belt.
- Wear on one side of a tooth indicates a misalignment problem.
- Remember that oil leaks can damage a belt.

Timing Belt Teeth

The spacing of the teeth on a timing belt must match the cogs on the cam and crank sprockets

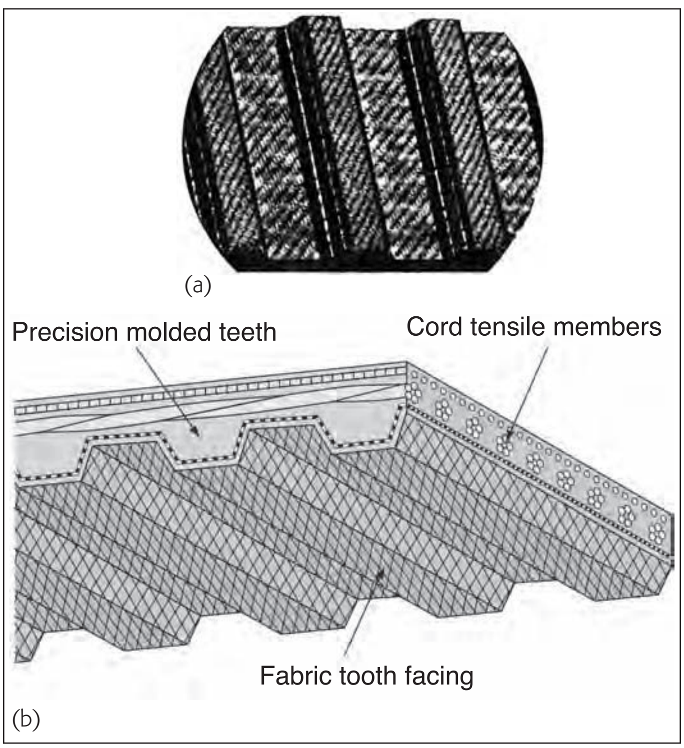


FIGURE 9.78 Parts of a timing belt. *(Courtesy of Gates Corporation)*

FIGURE 9.80 A timing belt replacement manual.

exactly. Carefully compare an old belt to its replacement for belt width and for tooth shape and spacing. Belts have different tooth rib profiles. Some have round ribs, whereas others are square. Be certain of an exact match.

Timing Belt Cover

Because timing belts are not lubricated, there are no sealing gaskets on the timing cover. A belt's service life can be affected by contact with foreign material, oil, mud, smog, or even ice. Timing covers for belts are designed to *thoroughly* cover the belt (**Figure 9.81**). If a foreign object gets into the belt area, damage to the tensile cord can result in belt failure. The cover is important, especially during bad weather. Snow can blow in on the warm engine of a parked vehicle, where it melts and then freezes up again on the timing sprocket.

> **CASE HISTORY**
>
> **A family traveled 200 miles on a ski trip. Upon arrival at their rented condo, the driver parked his vehicle outside for the night. During the night there was a snowstorm with heavy winds. When he attempted to start his car in the morning, the engine would not turn over. His son had replaced the timing belt and the timing cover had not been properly reinstalled. Snow that blew into the space between the sprocket and belt melted on the hot engine and then froze again during the night.**

TIMING BELT REPLACEMENT

Timing belts are replaced on a preventive maintenance basis or when they fail. When a timing belt is old or has been used beyond its replacement recommendation, cogs can strip off the belt, resulting in serious engine damage (**Figure 9.82**). If the flange behind the camshaft sprocket is damaged, this can also result in belt failure when it cuts the belt.

Before installing the belt on the sprockets, be certain that the camshaft and crankshaft timing marks are aligned correctly. Check the service literature for the correct positions of the marks. They

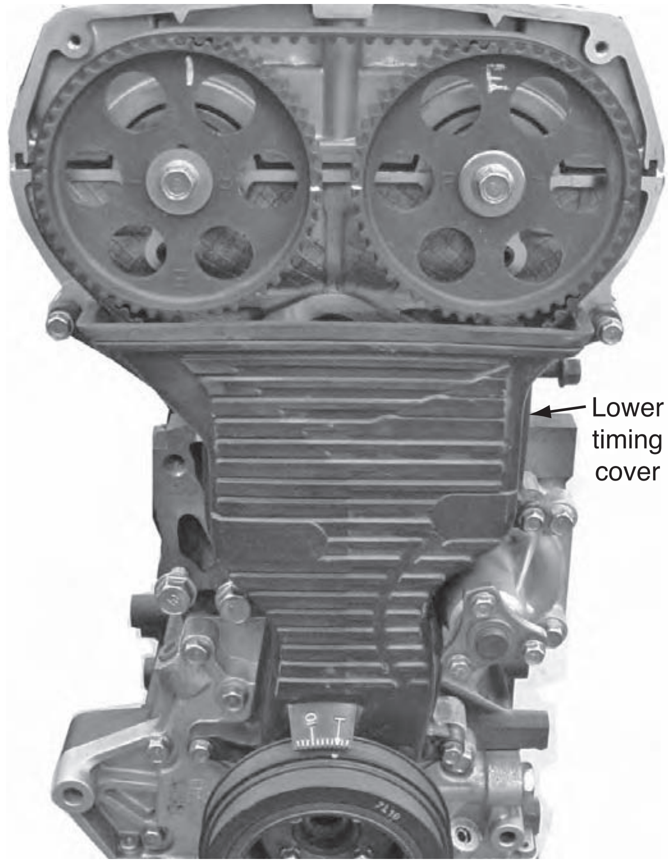


FIGURE 9.81 This engine has a two-piece timing cover. The upper piece has been removed. *(Courtesy of Tim Gilles)*

vary among manufacturers. Verify the correct cam lobe position at TDC as described earlier.

There are several precautions to take when replacing a timing belt:

- Use a non-petroleum-based solvent to clean the sprockets.

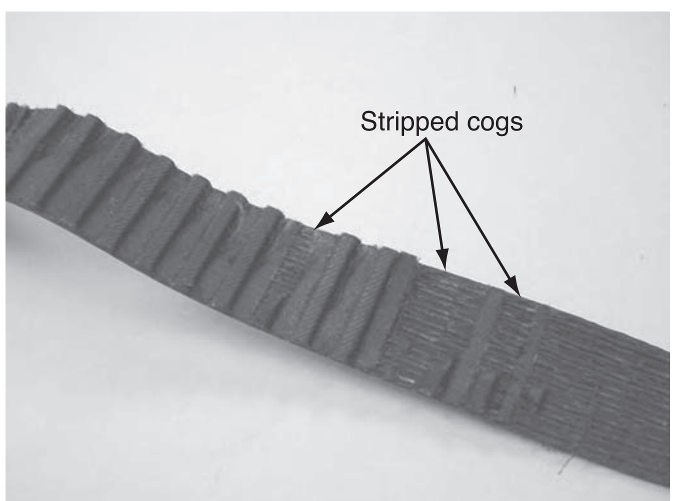


FIGURE 9.82 Some of the teeth are missing from this timing belt.

- Inspect the sprockets to see that wear on them will not cause wear on the timing belt teeth. Replace a sprocket that shows any kind of wear (see **Figure 9.59**).
- An OHC head with a timing belt has a camshaft oil seal (**Figure 9.83**), and some have an O-ring behind the cam sprocket. To avoid a future oil leak, it is good insurance to replace these during routine replacement of a timing belt.
- Belt tension is adjusted according to the manufacturer's specifications.
- Place a sticker on the valve cover or door post, listing the mileage when the belt was installed.

Belt Tensioner Replacement

Timing belt drives have one or more tensioner bearing assemblies (**Figure 9.84**). Rotate each belt tensioner carefully, feeling for any sign of roughness or tightness in the bearing. When in doubt, the best policy is to replace the bearing assembly. Failing to replace a defective bearing can result in serious damage to the engine.

NOTE

Defective timing belt and accessory drive belt tensioner bearings can cause OBD II engines (those built since 1996) to set a misfire diagnostic code.

Some timing belts have tension on the belt maintained by the coolant pump (**Figure 9.85**). Experienced technicians realize that it is advisable to replace the coolant pump whenever a timing belt that drives the pump is replaced.

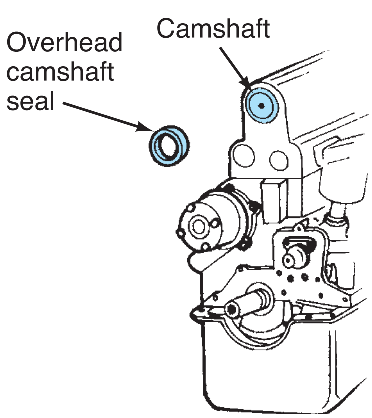


FIGURE 9.83 Replace the seal behind the cam sprocket on an OHC engine during a timing belt replacement.

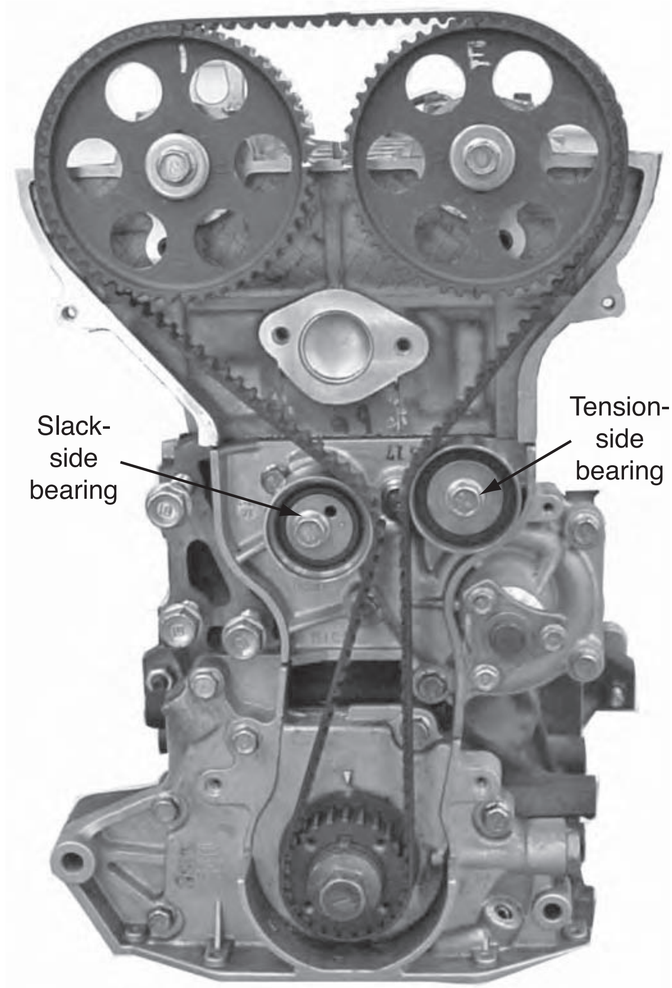


FIGURE 9.84 Replace any questionable tensioner bearing assemblies. This timing belt uses two. *(Courtesy of Tim Gilles)*

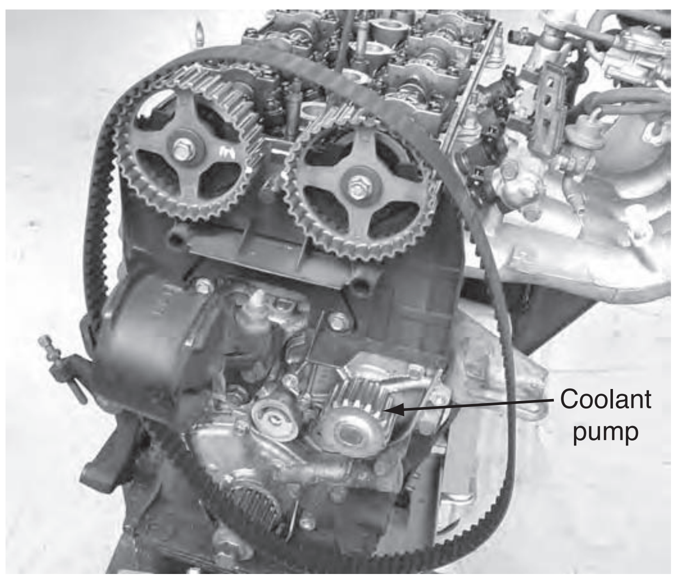


FIGURE 9.85 This coolant pump serves as an idler bearing for the timing belt. *(Courtesy of Tim Gilles)*

CASE HISTORY

A young woman purchased a 1988 Honda Civic. Although the car was 12 years old at the time of purchase, it had only 40,000 original miles on it. Because of the age of the vehicle, her mechanic suggested that she have the timing belt and other rubber parts, like drive belts and hoses, replaced. She told him to go ahead and replace all of those parts as well as the timing belt.

Following the belt replacement, the car ran for about 5000 miles without incident. Then, while on the freeway on a long trip, her engine suddenly stopped running and she had the car towed in for repair. The technician discovered a stripped timing belt. Typically, a few of the teeth are stripped off a belt when it fails. But on this belt, all of the teeth were stripped off (Figure 9.86). Further investigation showed that her coolant pump, which was driven by the timing belt, had failed.

Setting Cam Phasing/Valve Timing

Crankshaft and camshaft sprockets have timing marks that need to be correctly aligned. There are many ways that manufacturers mark their sprockets. Some marks are obvious and easy to understand; others are more difficult. **Figure 9.87** shows two typical crankshaft timing marks. Notice that

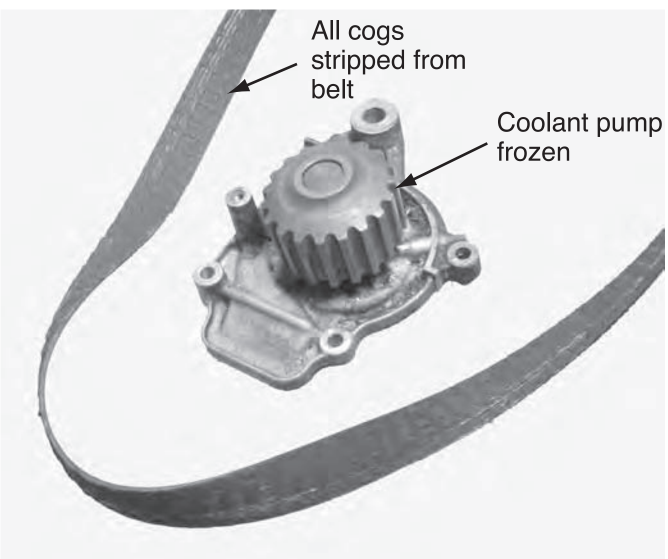


FIGURE 9.86 This belt was stripped of its teeth when the coolant pump froze. *(Courtesy of Tim Gilles)*

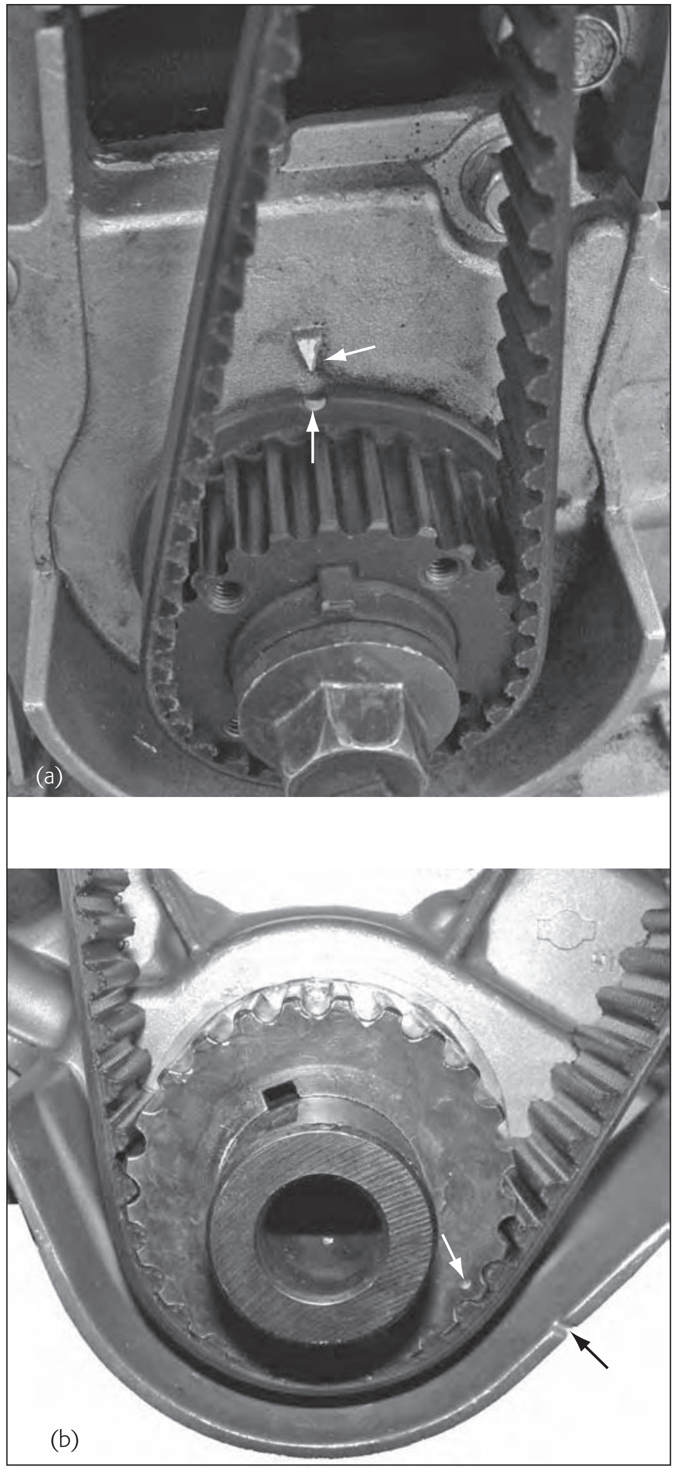


FIGURE 9.87 The timing mark in the top photo faces the twelve o'clock position when aligned correctly. The timing mark in the lower photo is at four o'clock. *(Courtesy of Tim Gilles)*

they point in different places; one faces directly up and the other faces the four o'clock position. Both of these indicate the TDC position for the number one piston and its companion. **Figure 9.88** shows the timing marks on an engine with an auxiliary shaft. There is also a mark on the crankshaft pulley because the timing belt can be replaced on this engine without removing the pulley.

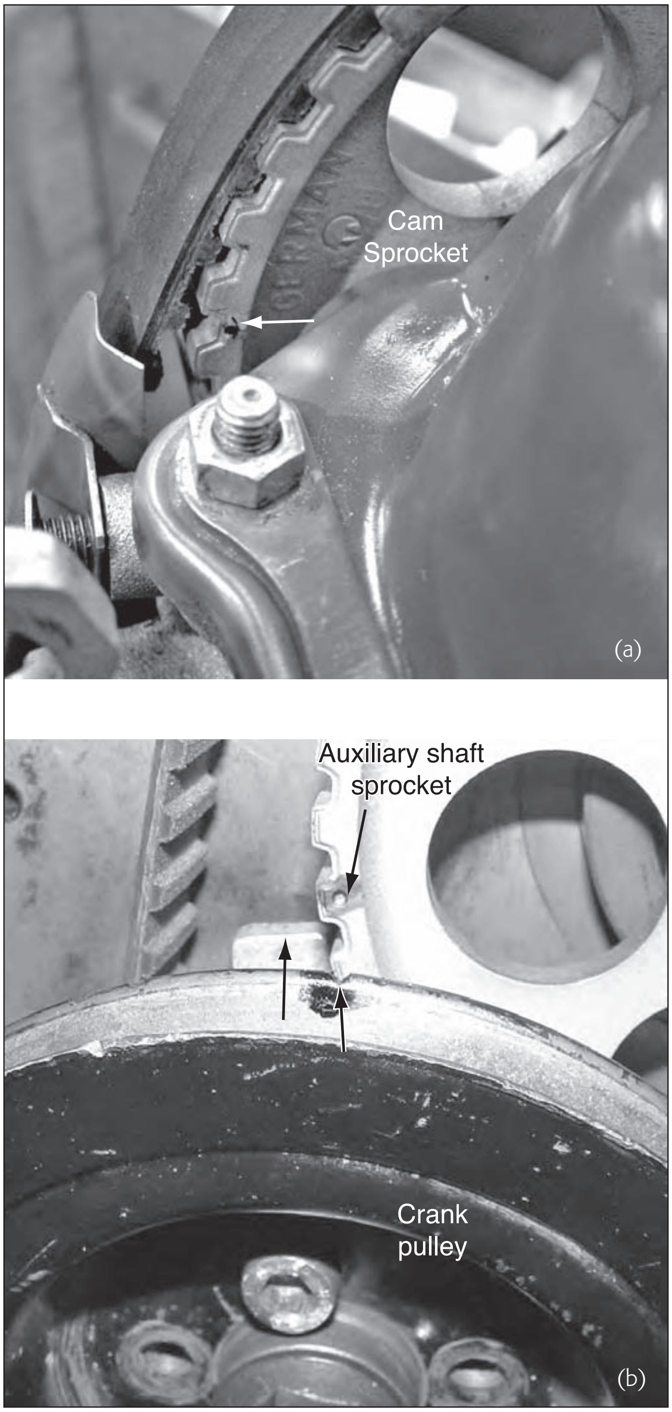


FIGURE 9.88 The top photo shows a mark on the back side of the sprocket that aligns with a mark on the cylinder head. The lower photo shows marks on the crank pulley and balance shaft. The pulley on this engine would have to be removed to replace the timing belt. *(Courtesy of Tim Gilles)*

Figure 9.89 shows a typical belt-driven OHC cam timing sprocket mark. On DOHCs, the sprockets are sometimes labeled for intake and exhaust. **Figure 9.90** shows typical markings on DOHC sprockets.

Turning the Camshaft(s)

With an interference engine, there are some cautions that need to be observed when turning the

FIGURE 9.89 A typical timing mark on a belt-driven cam sprocket. *(Courtesy of Tim Gilles)*

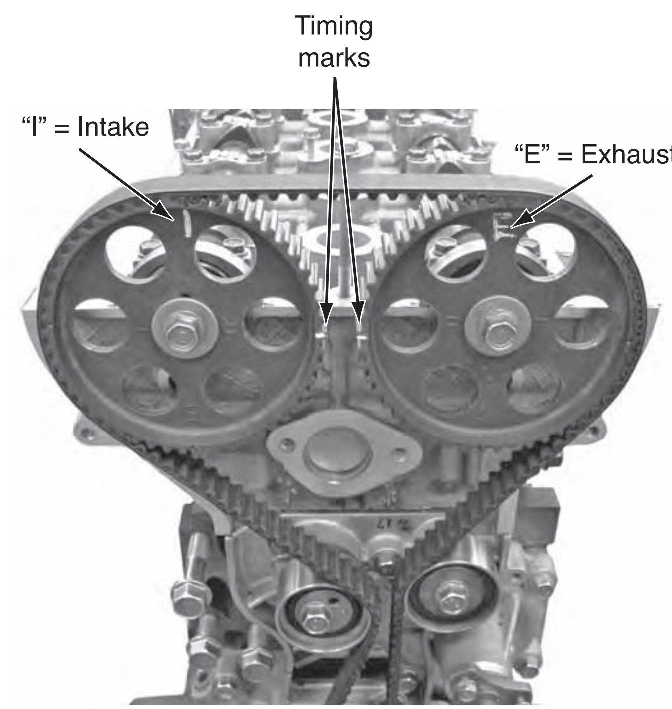


FIGURE 9.90 Markings on typical dual overhead cam sprockets. *(Courtesy of Tim Gilles)*

camshaft(s). When the head has been removed and is to be reinstalled, the camshaft can be turned to the correctly timed position prior to reinstalling the head. Align the timing marks to the TDC position and move the number one piston to TDC before installing the head on the block. If the head is already installed and you want to rotate the camshaft to a different position during belt installation, you might have to move the pistons partway down in their bores in order for the valves to clear the pistons.

The camshaft can be turned using a wrench, large pliers, or a special tool. Camshafts often have a hex casting to accommodate a wrench (**Figure 9.91**). When there is no hex on the camshaft, large pliers can be used between the cam lobes. The special tool shown in **Figure 9.92** fits into holes in the camshaft sprocket.

SHOP TIPS

- Use the tool to hold the camshaft while torquing the sprocket screw (**Figure 9.93**). A loose camshaft sprocket can result in catastrophic engine failure. Tightening with an impact wrench can break the snout off the front of the camshaft.
- A strap wrench can also be used to turn or hold the camshaft sprocket (**Figure 9.94**). This is a good tool to use for holding a crankshaft pulley also, because it will not damage a pulley groove or sprocket tooth (see **Figure 9.103**).

FIGURE 9.91 Camshafts often have a hex casting to accommodate a wrench for turning the camshaft. *(Courtesy of Tim Gilles)*

FIGURE 9.92 This tool for turning the camshaft fits into holes in the camshaft sprocket.

FIGURE 9.93 Hold the camshaft sprocket while tightening it to specification. *(Courtesy of Tim Gilles)*

FIGURE 9.94 A strap wrench can be used to hold or turn a camshaft sprocket. *(Courtesy of Tim Gilles)*

To help prevent timing errors, some timing belts come with lines marking the timing points on the outside of the belt (**Figure 9.95**). It can be difficult to hold dual overhead camshafts in the correct position while installing the timing belt; special tools make the job easier. **Figure 9.96** shows the right and wrong ways to use one such tool.

Adjust Timing Belt Tension

Many engines have a spring-loaded belt-tensioning feature (**Figure 9.97**).

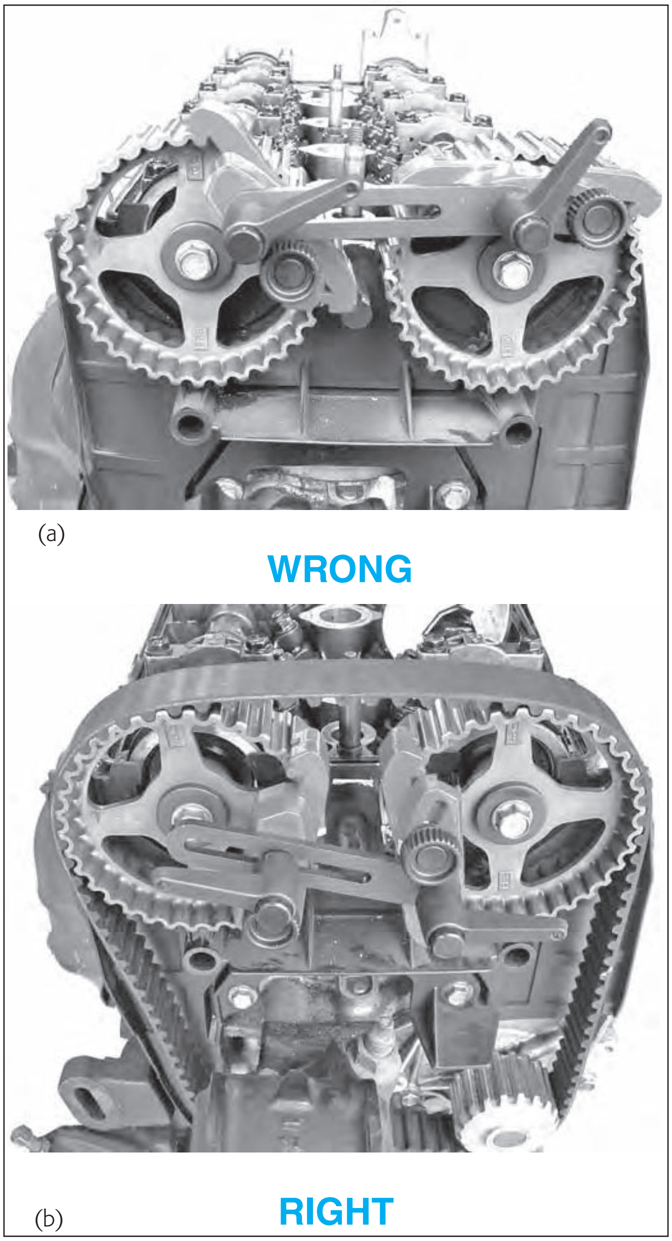


FIGURE 9.95 Camshaft positioning tool. (a) Installing the tool like this would prevent the belt from fitting onto the sprockets. (b) This is the correct way to install the tool. The belt can fit on the sprockets. *(Courtesy of Tim Gilles)*

FIGURE 9.96 Some timing belts have lines on the outside marking the timing points to help prevent errors in installation. *(Courtesy of Tim Gilles)*

When installing the belt:

- First, make sure that the drive side of the belt is tight between the crank and cam sprockets (**Figure 9.98a**).
- Next loosen the tensioner to allow the spring to force the tensioner roller against the belt (**Figure 9.98b**).
- Then tighten the tensioner screw and crank the engine over at least ten times. Tension on the

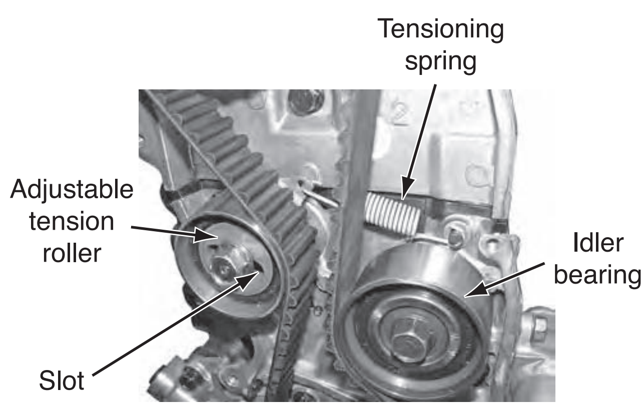


FIGURE 9.97 When the adjustment screw is loosened, the spring pulls the adjustable tension roller tight against the timing belt. *(Courtesy of Tim Gilles)*

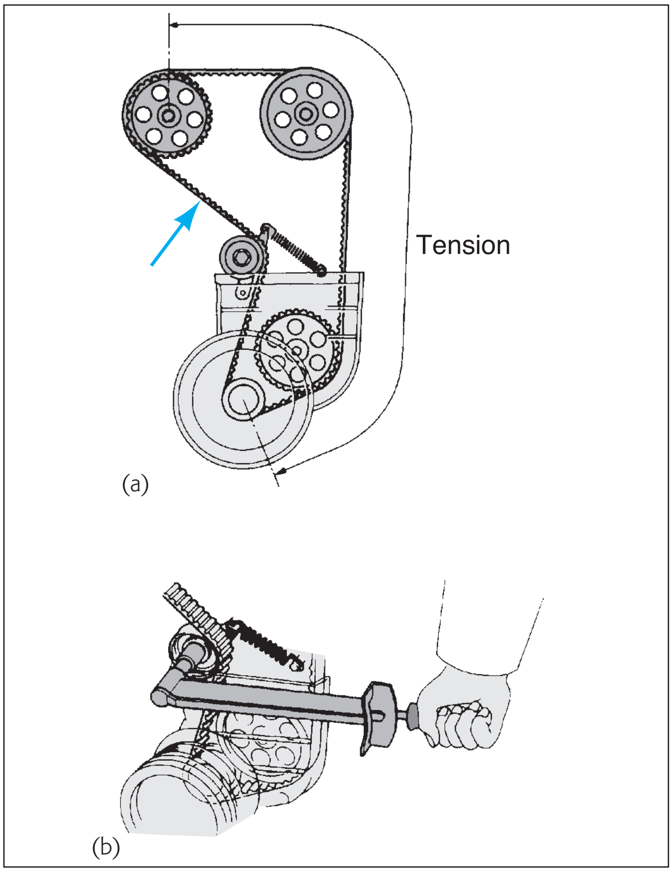


FIGURE 9.98 (a) Loosen the tensioner and let the spring pull the roller against the belt. See that the belt is tight in the area noted here. (b) Tighten the tensioner.

belt will drop as it seats into the timing sprocket.

- Loosen and retighten the tensioner-adjusting screw to complete the job.

NOTE

Do not adjust timing belt tension on a hot engine. The result will be a belt that is too tight, which can cause a broken camshaft.

Automatic Belt Tensioners

Some engines use automatic tensioners for the timing belt.

- The engine shown in **Figure 9.99a** uses a spring-loaded tensioner that must be unloaded before the belt can be installed. The spring is compressed in a vise while a pin is put into place to hold it compressed during installation (**Figure 9.99b**).
- Some tensioners have a specified adjustable clearance measurement, which is measured by a feeler gauge. The tensioner shown in **Figure 9.100** is an example of this. Be sure to check the service literature for instructions.
- Some vintage engines require the use of a belt tension gauge to set timing belt tension.

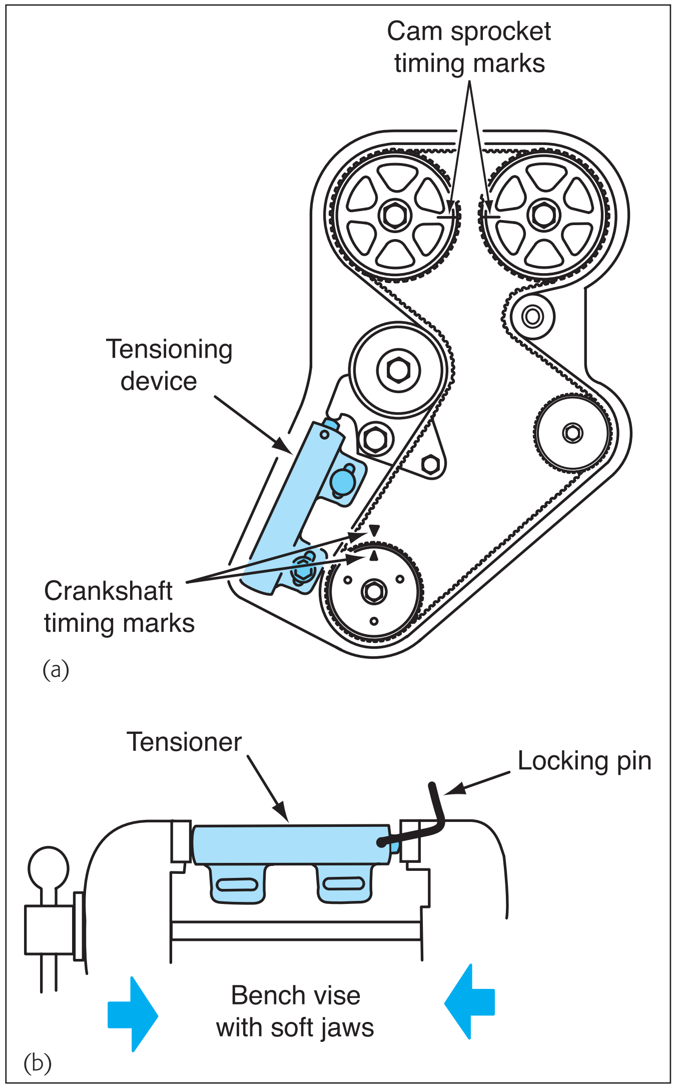


FIGURE 9.99 (a) A timing belt tensioning device on an OHC engine. (b) The spring is compressed in a vise while a pin is put into place to hold it compressed during installation.

NOTE

A V-belt tension gauge is not the correct gauge to use on timing belts or multiple ribbed belts. Use a click-type gauge instead (see Chapter 15).

Tightening the Damper Bolt

When replacing a timing belt, a very important consideration is to tighten the front pulley bolt correctly. Crankshafts vibrate; a loose pulley bolt will allow the pulley to shake back and forth on the crankshaft snout.

CASE HISTORY

A customer complained of hearing an intermittent knocking sound in the passenger compartment. The technician listened carefully with a stethoscope at several locations along the driveline. The noise seemed to be coming from the torque converter, but replacing the torque converter did not solve the problem. The technician decided to remove the oil pan and inspect the crankshaft. As he loosened the front crankshaft pulley bolt, he noticed that it did not seem to be as tight as it should be. These bolts are usually extremely tight. After removing the damper, he found the damaged woodruff key groove shown in Figure 9.101. A new timing belt had been installed 15,000 miles previously. The torque specification for the damper was in the neighborhood of 200 ft.-lb, but the bolt had not been tightened correctly. The result was a vibration that transmitted noise along the crankshaft where it was heard as a torque converter noise. A perfectly good torque converter was replaced before the true cause of the problem was found. A new crankshaft key and a bolt tightened to the correct specification solved the problem.

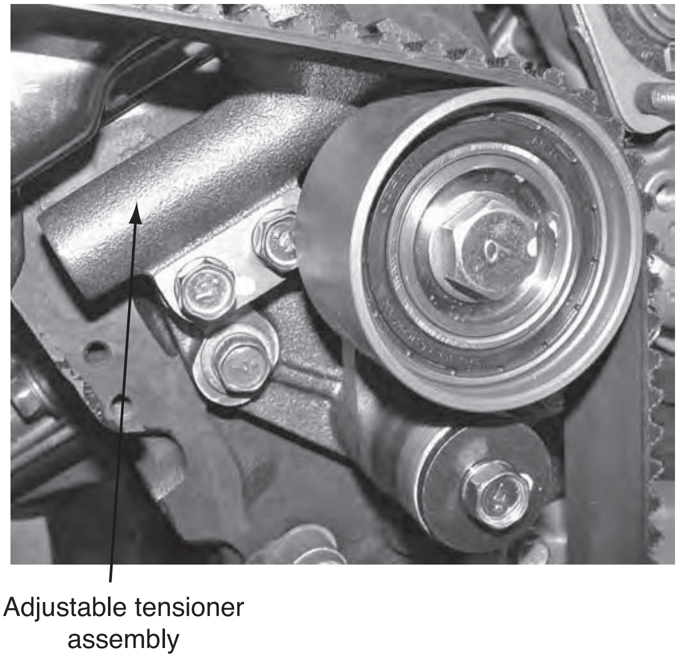


FIGURE 9.100 This Nissan automatic tensioner has an adjustable clearance. *(Courtesy of Tim Gilles)*

Sometimes a customer is not as lucky as the one in the case history. A loose pulley damaged the crankshaft shown in Figure 9.101. The crankshaft was removed from the vehicle for repair. A

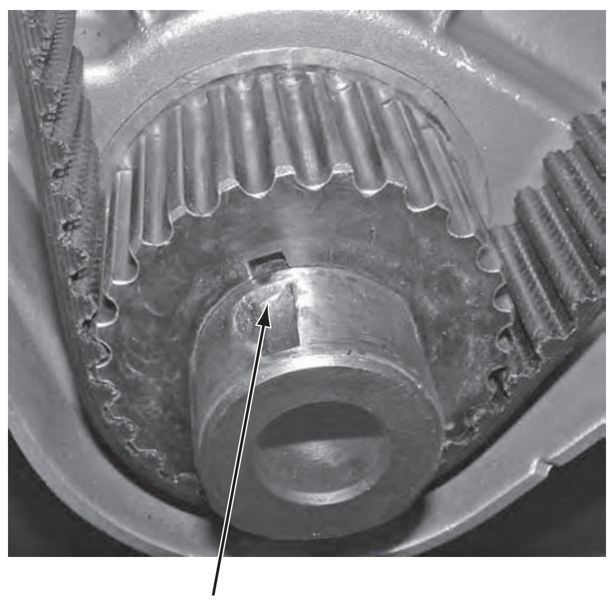


FIGURE 9.101 The groove in this crankshaft was damaged by a loose crank pulley bolt. *(Courtesy of Tim Gilles)*

FIGURE 9.102 A new pulley groove was machined into the crankshaft snout to replace the damaged pulley groove. The engine's ignition timing was not read from the crank pulley, so this did not pose a problem. The preferred procedure would be to repair the damaged pulley groove. *(Courtesy of Tim Gilles)*

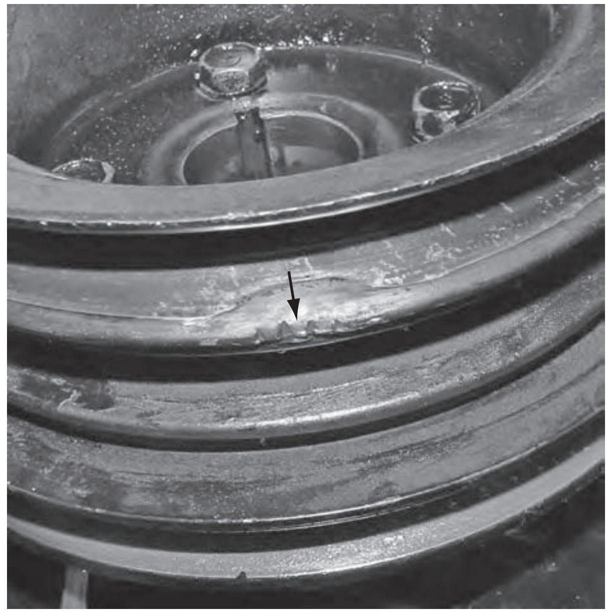


FIGURE 9.104 This pulley was damaged when the technician put too much pressure to a weak area of the pulley using a chain wrench. *(Courtesy of Tim Gilles)*

machine shop milled a new keyway into the opposite side of the crankshaft as a remedy for the problem (**Figure 9.102**). This would not be an acceptable fix if the outer ring of the crankshaft pulley has an ignition timing mark indicator groove. On these crankshafts, a piece of carbon is inserted into the crank keyway and the area surrounding the keyway is welded. Then the crank snout is reground to size. The area where the carbon was inserted is cleaned out to provide a new keyway in the old location. In any event, removing the crankshaft to complete this repair is a costly solution to the problem.

Torquing the damper bolt to a high tension is not easily achievable without holding the crankshaft firmly. Some technicians like to use a chain wrench to hold the pulley to keep it from turning (**Figure 9.103**). If you are not careful where you put the chain, you can damage the pulley (**Figure 9.104**).

SHOP TIP

When clamping a chain wrench to the crankshaft pulley, you will need to protect the pulley grooves from damage. A good trick is to wrap a piece of a serpentine belt around the pulley grooves before installing the chain wrench. A strap wrench like the one used in **Figure 9.94** is also a good alternative.

FIGURE 9.103 Holding the crankshaft pulley with a chain wrench. A piece of serpentine belt protects the pulley. *(Courtesy of Tim Gilles)*

Key Terms

backlash
CAFE
duration
edge loading
leak down
lift
valve overlap
zero lash

Study Questions

1. How many camshafts does a DOHC V6 have?
2. As the oil pump in a pushrod engine is turned, resistance to pumping the oil causes the cam to be forced toward the rear of the engine. What is this motion called?
3. To drive the oil pump and distributor, some overhead cam (OHC) engines use an extra shaft called a(n) _____ shaft that is driven by the crankshaft using an extra sprocket.
4. List two other names for valve lifters.
   a.
   b.
5. When there is no clearance between the valve stem and its actuator, this is known as _____.
6. What is the term for the pushrod engine hydraulic lifter adjustment accomplished simply by torquing the adjusting nut against a shoulder?
7. The _____ _____ is what the cam would be if there were no lobe.
8. The camshaft term for the number of degrees of crankshaft travel that the valve is off its seat is called _____.
9. On pushrod engines, why is the cam lobe tapered and the lifter off-center?
10. When a worn lifter face contacts the outside edge of the cam lobe causing severe wear, this is called _____.
11. When a cam lobe wears out, which will it most likely be?
    a. Intake
    b. Exhaust
12. What is the term for the period when the intake and exhaust valves are both open?
13. When there is too much valve lash on a mechanically adjusted valvetrain, the lifter or cam follower can miss the _____ ramp.
14. What name describes an engine that can have a collision between the piston and valve when the timing chain or belt breaks?
15. What part is replaced along with a timing belt when an engine does not have a tensioner bearing?

ASE-Style Review Questions

1. When there is a spiral gear on the camshaft of a pushrod engine, what is its purpose?
   a. It drives the distributor.
   b. It drives the oil pump.
   c. Both of the above
   d. Neither of the above
2. On a pushrod engine, all of the following are true *except*:
   a. Valve lash increases as pushrods and rocker arms wear.
   b. Valve lash increases as the valve and seat wear.

c. A decrease in lash can cause improper valve cooling and can lead to burned valves.

d. All of the above

3. The exhaust valves shown in the preceding photograph are from a four cylinder interference engine that has failed. All of the valves are bent an equal amount. Which of the following could be the cause?
   a. A broken timing belt
   b. Excessive chain slack
   c. Either of the above
   d. None of the above
4. Technician A says that it is necessary to keep flat tappets in order if the old cam and lifters are to be used again. Technician B says that used roller tappets should not be installed on a new camshaft. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that a valve lifter on a pushrod engine must be perfectly centered above its corresponding cam lobe. Technician B says a pushrod engine cam lobe is slightly tapered across its face. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that an incorrect camshaft thrust spacer can cause fluctuations in ignition timing. Technician B says that excessive timing chain slack can be verified on a pushrod engine with a distributor by turning the crankshaft by hand while watching to see if the distributor moves. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that valve lifters are sometimes called "tappets." Technician B says that hydraulic lifters should leak very slowly between the plunger and the lifter body. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Technician A says that excessive hydraulic lifter pump-up can occur if the valves float. Technician B says that hydraulic lifter valve adjustment on most engines positions the plunger at its center of travel in the lifter body. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. Technician A says that camshaft end thrust on a pushrod engine with a camshaft-driven oil pump results from resistance of oil being pumped by the oil pump. Technician B says that camshafts are usually inspected by visually checking the wear pattern on the lobes for edge loading. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. The cam lobes in the preceding photograph are for the number one cylinder and its companion of an in-line pushrod engine that rotates counter-clockwise when viewed from the rear. The lobes are positioned:
    a. At TDC at the beginning of the compression stroke
    b. At TDC at the beginning of the intake stroke
    c. None of the above

CHAPTER

10

Engine Power and Performance

CONTENTS

OBJECTIVES

Upon completion of this chapter, you should be able to:

- Describe the effects of the supercharger/turbocharger on engine performance.
- Describe how cam lobe profile affects high and low rpm engine performance.
- Advise a customer on high-performance options for his or her engine.

INTRODUCTION

Building high-performance engines has been a popular pastime for generations. In the 1930s and 1940s, when flathead engines were popular, hot rodders changed the compression ratio by milling the cylinder heads; bored cylinders oversized; and used special intake manifolds, carburetors, and headers. In the 1950s, 1960s, and 1970s, when "muscle cars" were popular, overhead valve pushrod engines were commonly modified to achieve high-end horsepower (**Figure 10.1**).

In today's era of the sport compact car, many four and six cylinder engines develop as much or more power as eight cylinder engines of the past. The smaller engines today use multiple valve combustion chambers, along with other modifications to increase breathing ability. This chapter deals with intake and exhaust manifolds, turbochargers and

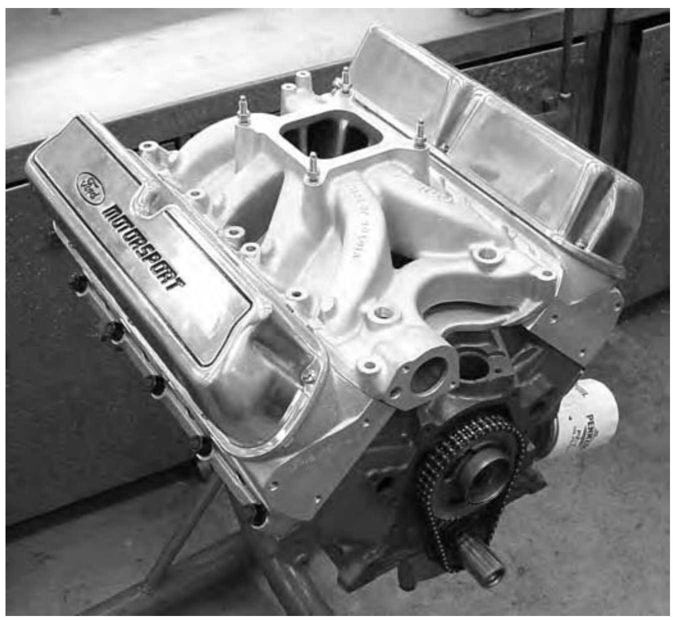


FIGURE 10.1 A high-performance pushrod engine. *(Courtesy of Tim Gilles)*

superchargers, engine performance, camshaft lobe designs, and variable valve timing. These items govern the performance of the engine.

Basically, an engine will produce more power when more of a correctly proportioned air-fuel mixture enters the cylinder. When an engine does not have a turbocharger or supercharger, it is referred to as *normally aspirated* or *naturally aspirated*. Engines equipped with turbochargers or superchargers can breathe more air and, therefore, produce more power.

An internal combustion engine is a big, self-driven *air pump*. The camshaft is the determining factor in how efficiently the engine pumps air while operating at various speeds. The overall performance of the engine is determined by the *grind*, or *profile*, of the cam. The size and shape of the intake and exhaust manifold runners and the valve ports also play a part in determining the engine's breathing ability.

NOTE

This chapter discusses real world situations that sometimes occur on customer vehicles. Aftermarket and high-performance issues are also covered, primarily because most shops have customers who can afford to spend money on their classic automobiles, and some customers own several of them. These select customers will expect you to know and understand this material, and if you are knowledgeable, the word will quickly spread. The aim of the material provided in this chapter is to "keep it simple." The objective is to put you in a position so you can easily understand the basics of engine performance. If you should decide to go further in making refinements on a manufacturer's design, you will need to do further study by reading more advanced publications on the topic of your choice.

INTAKE AND EXHAUST MANIFOLDS

The breathing system includes intake and exhaust manifolds that are carefully designed to provide a uniform flow to and from all cylinders. Manifold passages are known as runners. When a single manifold runner feeds two neighboring cylinders, these are known as "Siamese" ports (**Figure 10.2**).

Intake Manifolds

When an engine has throttle body fuel injection or a carburetor, the intake manifold is called a *wet manifold* because it flows both air and fuel. A wet manifold is designed to provide optimum flow for the air-fuel mixture and to reduce the chances of the vaporized fuel turning back into liquid fuel. Intake manifold runners on these engines have as few bends as possible.

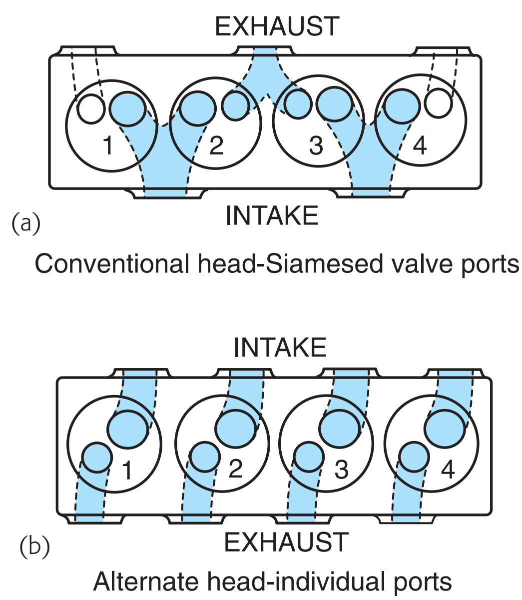
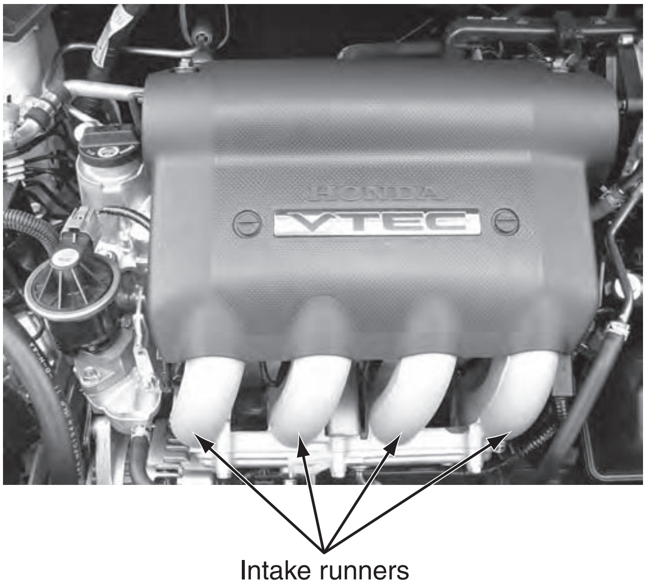


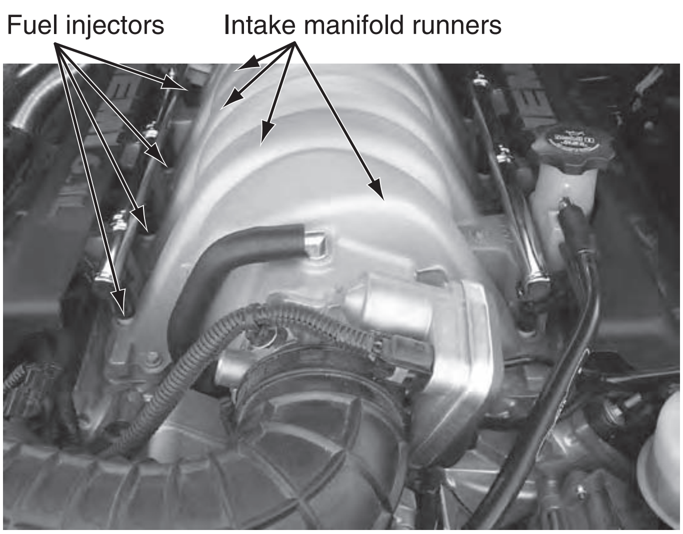
FIGURE 10.2 The top sketch (a) shows "Siamese" valve ports that share a manifold runner. The bottom sketch (b) shows individual ports.

VINTAGE ENGINES

By the mid-1980s, most manufacturers had replaced carburetors with fuel injection. But aftermarket carburetors and manifolds are still in demand on boats and vintage vehicles. Some race cars still use carburetors, too, due in part to the influence of NASCAR.



(a)



(b)

FIGURE 10.3 (a) These intake manifold runners for a four cylinder fuel injected engine are short, large, and relatively straight. (b) An intake manifold on a late model. *(Courtesy of Tim Gilles)*

Port fuel injection systems inject fuel directly above the intake valve. The intake manifold is designed for airflow only because fuel does not travel through the manifold. Port fuel injection manifolds can be designed with larger runners than wet manifolds. The runners can also have sharper bends, because these manifolds do not have to keep fuel suspended in air. **Figure 10.3** shows an intake manifold from a fuel injected four cylinder OHC engine.

Carbureted Manifolds

Intake manifold design is crucial to engine operation in much the same way as camshaft design. Parts are engineered to match and each combination is a compromise. Breathing parts must be correctly matched to each other. For instance, purchasing a high-performance manifold without buying matching components will probably hurt engine performance.

NOTE

In general, better performance at high rpm results in worse performance at low rpm.

Intake manifolds that flow air and fuel are designed to keep the fuel suspended in the air in fine droplets like fog. By the time the mixture reaches the combustion chamber, most of the fuel should be evaporated so it can burn easily. If the speed of the mixture drops too low, droplets of raw fuel can fall out of the mixture.

Manifold runner sizes are a compromise. Large-diameter runners flow well at high speeds, but the fuel separates from the air at lower speeds. Throughout the average rpm range of a passenger car, smaller-diameter manifolds work well to provide enough flow and keep the fuel in suspension.

Plenum. The air space in the manifold below a carburetor or throttle body is known as the *plenum*. The plenum floor is flat and often has ridges cast into it to catch fuel that drops out of the mixture. This makes it easier for the fuel to evaporate or to rejoin the moving air-fuel mixture as it flows through the manifold.

Dual- and Single-Plane Manifolds

On an eight cylinder engine with a dual-plane *two-barrel* manifold, each "barrel" supplies fuel to four cylinders (**Figure 10.4**). Manifold runners are designed to be nearly the same length so they will flow an equal amount of air and fuel. One barrel supplies air and fuel to both of the *inner* two cylinders on the opposite side of the engine and the *outer* two cylinders on its own side. This knowledge is

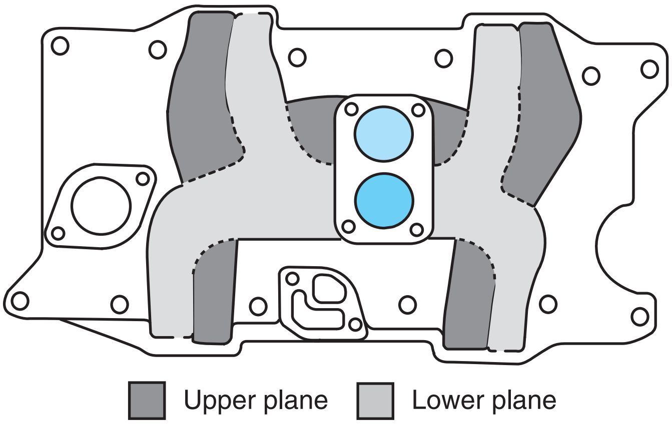


FIGURE 10.4 A closed-type two-barrel dual plane manifold. The arrows show that each carburetor barrel supplies fuel to four cylinders, two on each bank. This pattern is also the same on some four-barrel intake manifolds.

handy when troubleshooting vacuum leaks or carburetor failure if the problem is found to be only in those cylinders served by one barrel.

Figure 10.5 compares dual-plane and single-plane intake manifolds. The dual-plane manifold (**Figure 10.5a**) has smaller runners and is better suited to lower rpm use. A single-plane manifold, in which both barrels serve all eight cylinders, is more suited for high-speed use and is not street legal (**Figure 10.5b**).

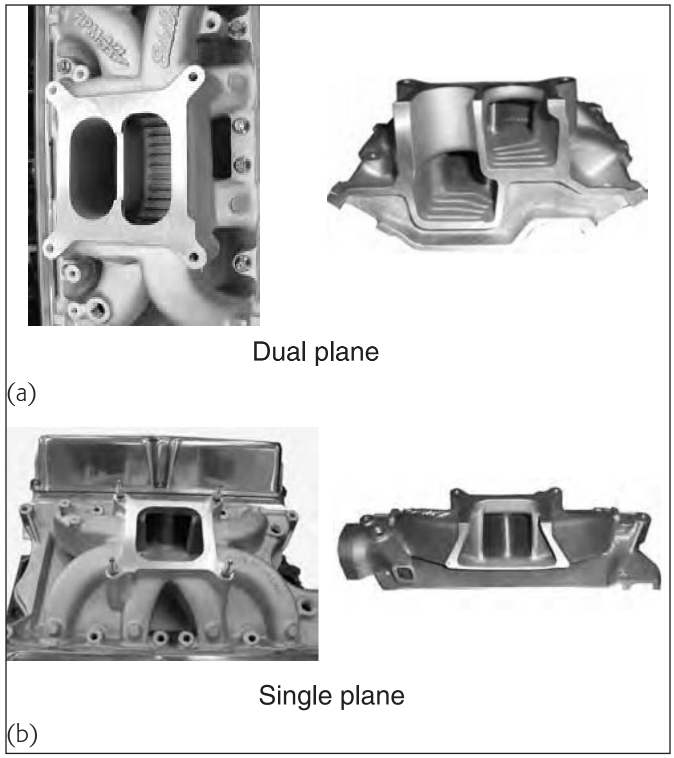


FIGURE 10.5 Comparison of dual-plane and single-plane intake manifolds. (a) Cutaway of a dual-plane manifold. (b) Cutaway of a single-plane manifold. *(Courtesy of Tim Gilles)*

Intake Manifold Coolant Passage

The intake manifold on a V-type engine has a coolant passage that connects the heads and provides the coolant outlet where the thermostat is located.

NOTE

A crack in the coolant passage can cause a leak that can be difficult to diagnose.

Intake Manifold Tuning

Intake manifolds are designed for either low-speed or high-speed use. Drawing air through the engine so it moves at sufficient speed is the key to effective engine breathing. For comparison purposes, imagine trying to suck a drink into your mouth, first through a very small diameter straw and then through a very large straw. Sucking softly through the small straw works very well, but if you suck too hard no more liquid will flow through the straw. With the large straw, you must suck harder to raise the liquid toward your mouth. But if you suck too hard, you will choke on too much liquid.

VINTAGE ENGINES

V-type engine intake manifolds are either "open" or "closed." Older V8s sometimes used an open manifold, which was lighter and less costly to manufacture, but it required a valley cover made of sheet metal to seal off the lifter valley. Today's engines use a closed manifold, which quiets engine noise.

VINTAGE ENGINES

Older engines with carburetors had a manifold heat control valve located at the bottom of the exhaust manifold (**Figure 10.6**). This device, commonly known as a *heat riser*, consisted of a *butterfly valve* that fit between the exhaust manifold and exhaust pipe. When the engine was cold, the valve would direct part of the exhaust stream through a passage in the intake manifold, which was beneath the carburetor, to help vaporize the air-fuel mixture. In V-type engines, the heat riser restricted exhaust flow on one side of the engine only, diverting exhaust through a passage in the intake manifold (**Figure 10.7**) to the exhaust manifold on the other side of the engine.

Some heat risers were built into the manifold, whereas others were replaceable. The heat riser shown in Figure 10.6 has a large counterweight and a bimetal thermostatic spring that opens in response to heat. Later model heat risers were controlled by engine vacuum. Heat risers sometimes became stuck, often in the open position. But when they stuck closed the manifold could overheat, which could cause carbon buildup and sometimes crack the floor of the intake manifold. It was common practice to free up a stuck heat riser by tapping on its shaft with a hammer.

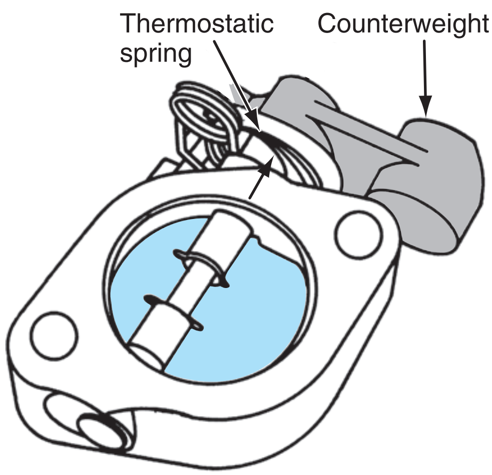


FIGURE 10.6 Vintage engines with carburetors often had a manifold heat control valve, often called a heat riser. This one is in the "heat on" position.

An engine needs to be able to maintain velocity and swirl at low speed, yet still be able to deliver a large volume of air flow at high speed. This can be accomplished with a butterfly control valve that changes airflow through the intake manifold by selecting a primary runner only or by adding a secondary runner (**Figure 10.8**).

Resonance Tuning. Resonance tuning is based on the Helmholtz Resonance Theory. Imagine a tuning

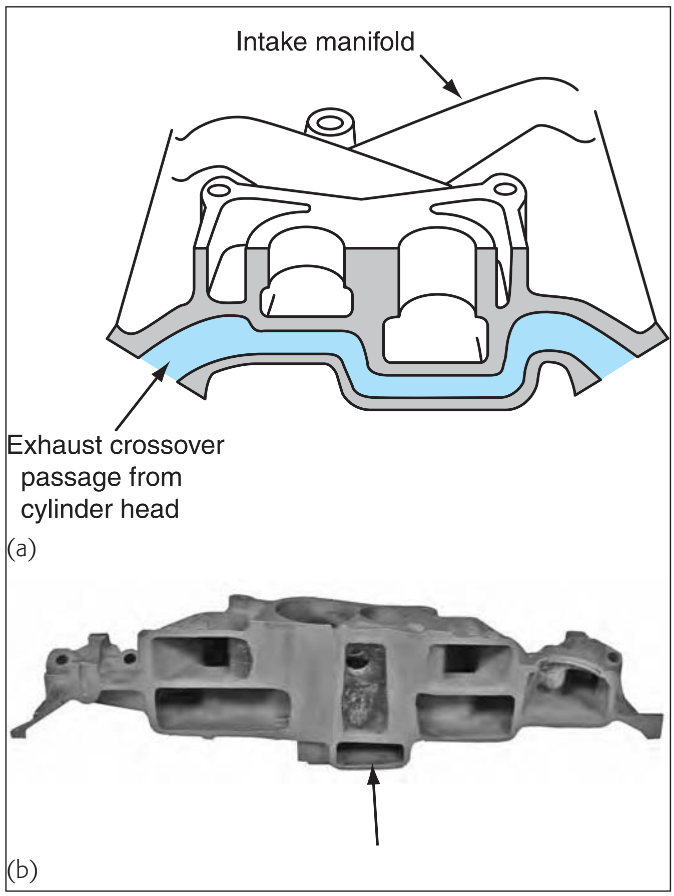


FIGURE 10.7 A vintage carbureted intake manifold side-to-side and lengthwise cutaways showing the exhaust crossover passage. (*Bottom: Courtesy of Tim Gilles*)

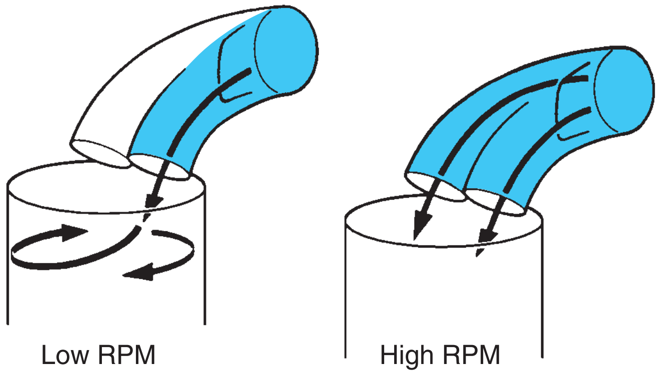


FIGURE 10.8 When an engine has computer controlled intake airflow for secondary runners, at low rpm, velocity and swirl are maintained. At high rpm, there is high flow.

fork held in front of a stereo speaker. If you use an audio signal generator to control speaker output, increasing the signal will cause the tuning fork to vibrate when it reaches its resonant point. As the signal is increased past the resonant frequency of the tuning fork, it will stop vibrating. A musical wind instrument illustrates a similar example of resonance. The natural frequency of the instrument varies when the length of the instrument's hollow tube is changed by covering holes, which alters the pitch of its sound.

The behaviors of sound in the preceding examples can be compared to the way air flows through the intake manifold of a running engine. As engine rpm increases, intake and exhaust valves open and close faster and the frequency of the pulses in the intake manifold varies. The resonant frequency of the air in the intake manifold is determined by the length and volume of its runners, as well as manifold pressure and temperature. Dense and low-pressure areas exist in vibrating air. A minor supercharging condition can be created if the resonance can be manipulated to time the pressure wave, called a standing wave, so its densest part reaches the valve just as the valve opens.

Variable Length Intake Manifolds

A variable length intake manifold (VLIM) takes advantage of resonance tuning, using runners of different lengths to provide a 10–15% torque gain. An engine's rpm constantly changes, but an intake manifold runner of fixed length has only one resonance point. A long runner has a low resonant frequency and a short runner has high resonant frequency.

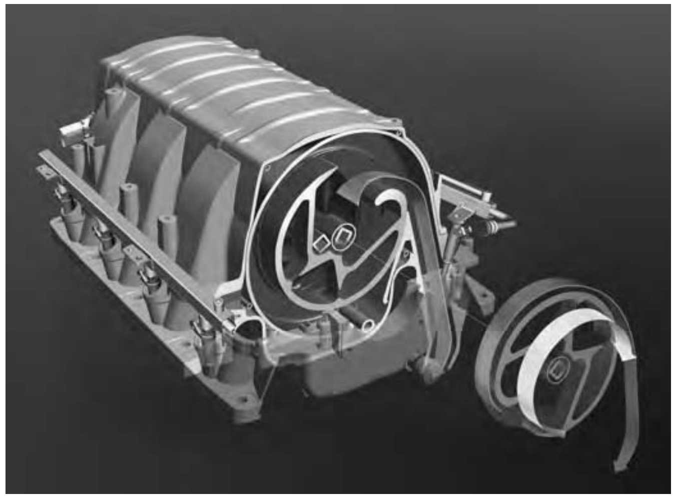


FIGURE 10.9 This port-injected intake manifold has long runners of varying length. *(Courtesy of BMW of North America, LLC)*

Manufacturers use different designs to provide variations in runner length. One example is shown in **Figure 10.9**. Another design uses butterfly valves to direct air through either a long runner or a short runner during differing windows of rpm change (**Figure 10.10**). The PCM (computer) looks at engine speed and load and moves the air valves accordingly.

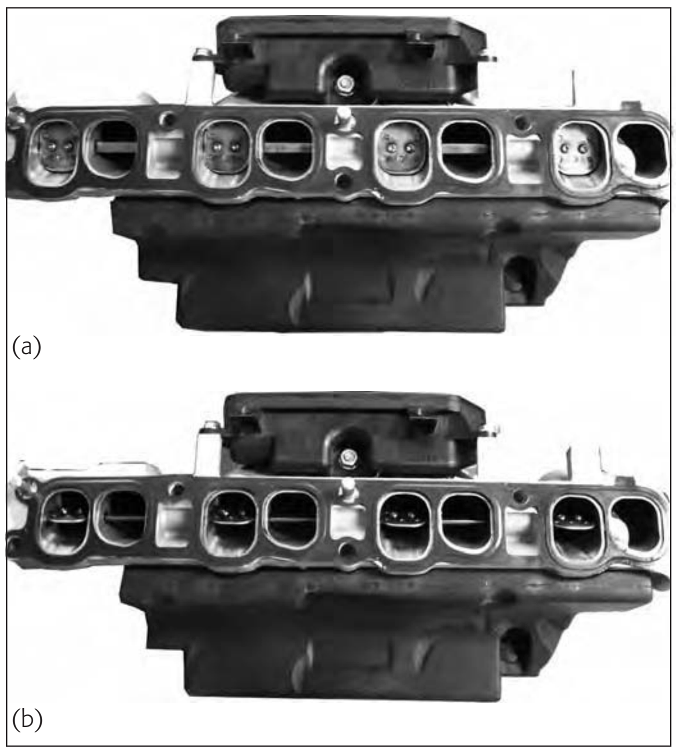


FIGURE 10.10 Butterfly valves control airflow between the short and long manifold runners based on engine requirements. *(Courtesy of Tim Gilles)*

At 6000 rpm, each valve opens and closes every 20 milliseconds (0.020 of a second). The cylinder cannot wait for air; it must be available when the valve opens. Air waves pulse through the intake and exhaust manifolds. During valve overlap, a pulsating pressure wave returning from the exhaust can go into the intake manifold. Tuned intake runners are designed to trap standing waves in the intake manifold, timing them so they are ready to be breathed when the intake valves open. Engine designers use several methods to get more than two resonant frequencies so more standing waves can be produced at various engine speeds.

NOTE

Some manufacturers recommend replacement of the intake manifold after a catastrophic engine failure. When an engine has blown up, exploded parts are sometimes coughed up into the runners of the intake manifold where metal parts can remain even after cleaning.

Cross-Flow Head

When intake and exhaust manifolds are on opposite sides of an in-line engine, the head is called a cross-flow head (**Figure 10.11**). This design improves breathing. Cross-flow heads have a coolant passage that provides the intake manifold with heat to help vaporize the fuel.

Cylinder Heads with Multiple Valves

Some high-performance late-model engines use three, four, or even five valves per cylinder

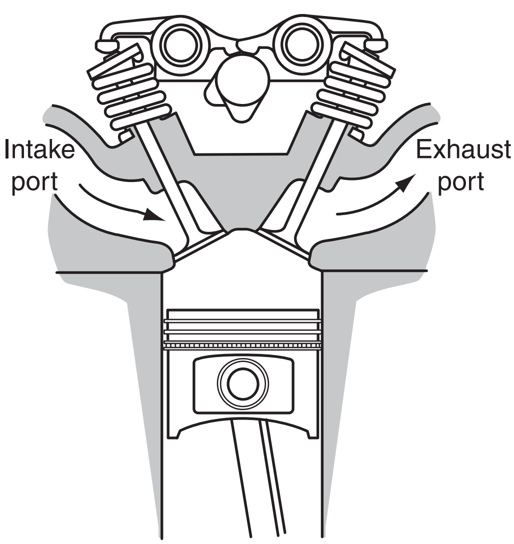


FIGURE 10.11 A cross-flow head.

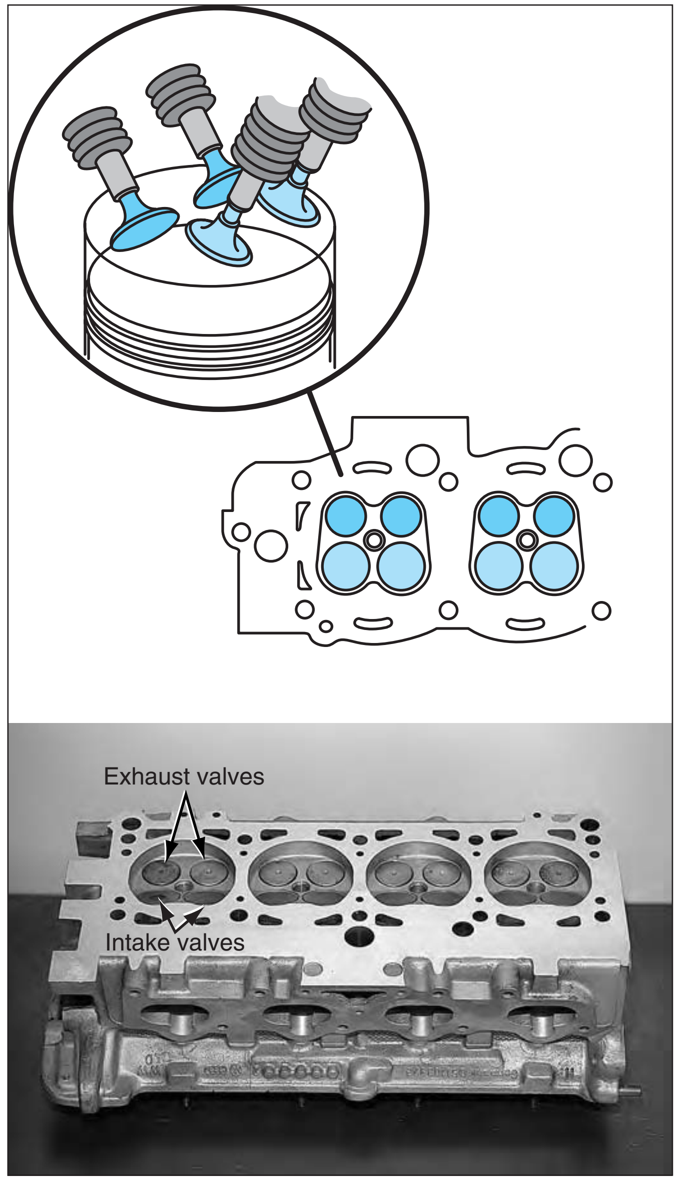


FIGURE 10.12 Four-valve combustion chamber. *(Courtesy of Tim Gilles)*

(**Figure 10.12**). These multiple valve designs have become popular due to improved higher rpm breathing. Compared to two valve heads, more flow area for a given amount of valve lift is possible. Multivalve combustion chambers can be made smaller with a more central spark plug location. This reduces the chances for an engine to knock, allowing higher compression ratios and, therefore, more power.

Very lean air-fuel mixtures are desirable, but they will not ignite unless the fuel is mixed well in the combustion chamber. At high engine rpm there is plenty of turbulence so this is not a problem. At low speeds, however, multivalve heads tend to allow fuel to fall out of the mixture. Some multivalve heads have controllers that open only one intake valve at low rpm and open another one at higher rpm. This helps maintain velocity and swirl at low speed and high flow at high speed (see Figure 10.8). Other multivalve heads use two intake manifold runners per cylinder that are variably tuned using a butterfly valve to control airflow.

ENGINE MODIFICATIONS TO IMPROVE BREATHING

There are several ways to improve engine breathing, but all of them have limitations. Opening an intake or exhaust valve too far, or for too long or short a time, can have an adverse effect on breathing. Intake or exhaust manifold flow can have a similar negative effect.

Valve Lift

Valve lift describes the distance a valve is opened. Increased valve lift allows more air and fuel flow. Unlike an increase in duration, which keeps valves open longer, valve lift does not cause a rough idle or ruin low end performance.

Do not confuse valve lift with lobe lift, which, depending on engine design, is sometimes a considerably smaller measurement. Measuring valve lift is discussed later in the chapter.

Limitations on Maximum Valve Lift

For performance purposes, why not lift the valves as high as possible and leave them open for as long as possible? Several considerations limit maximum lift. When valve lift reaches 25% of the port opening, the valve no longer interferes with air flow. Therefore, lifting the valve beyond this point will *not* increase air flow.

NOTE

A *curtain area* surrounds an open valve (**Figure 10.13**). When valve lift reaches 25% of the diameter of the valve port opening, this should approximately equal the curtain area. Lifting the valve beyond this point will provide no benefit.

Example:

- A 2" diameter valve opening has a radius of 1". Its area is 3.1416 (ΠR^2) $(1 \times 1 = 1)$.
- The circumference of the valve head laid out is 6.28" (ΠD).
- With ½" valve lift, the area of the lift area is $6.28 \times .5 = 3.14$. **Figure 10.14** describes how this works.

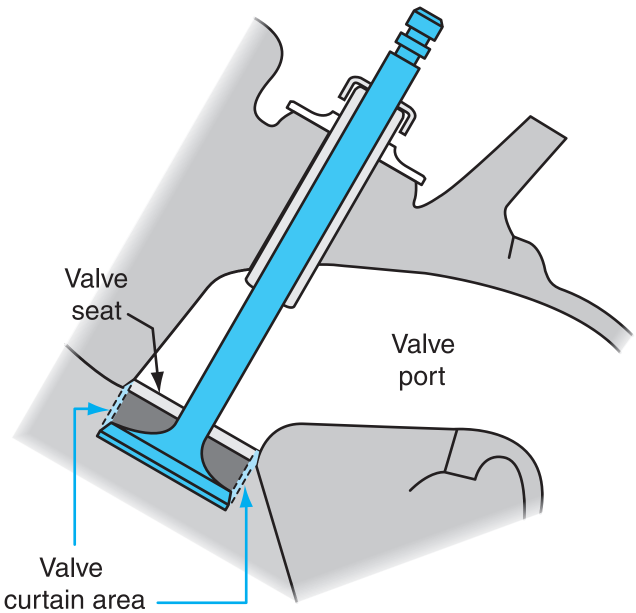


FIGURE 10.13 A curtain area surrounds an open valve. When valve lift reaches 25% of the diameter of the head of the valve, lifting the valve beyond this amount will not flow more air.

SHOP TIP

Do not make the mistake of installing larger valves that do not match the port opening. This will not serve a useful purpose if the port opening is too small. One machinist compared this to "a sewer lid flapping over a knot hole."

Engineers always have to make compromises. For instance:

- More lift can cause wear to valve guides, lifters, and rocker arms. To prevent excess wear, bronze guides are recommended with high lift cams as well as rocker arms with roller tips (**Figure 10.15**).
- Lifting a valve means compressing a valve spring. More lift calls for higher tension valve springs to prevent valve float. The more a spring is compressed, the higher pressure it exerts, resulting in excessive wear and decreased reliability.

Valve Spring Resonance

A valve spring is similar to a crystal water glass in that it has a resonant frequency or natural harmonic. If allowed to run undampened at the speed

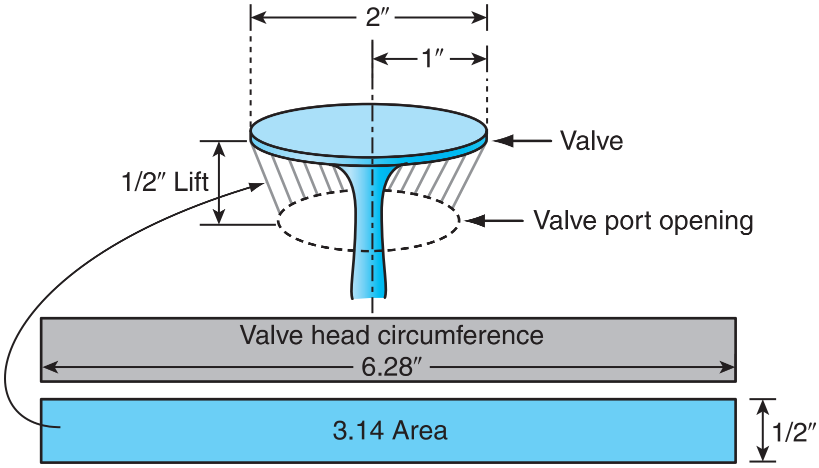


FIGURE 10.14 Figuring valve curtain area with a 2" diameter valve. Its area is 3.1416 (ΠR²) (1 × 1 = 1). Valve head circumference is 6.28" (ΠD). With ½" valve lift, the lift area is 6.28 × .5 = 3.14.

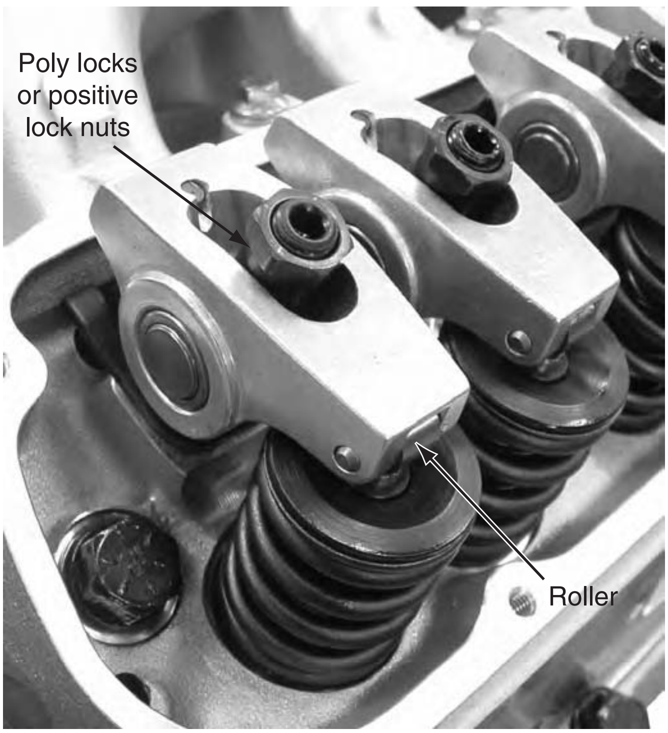


FIGURE 10.15 Roller tip rocker arms used with a high lift cam help reduce the friction required to rotate the engine. *(Courtesy of Tim Gilles)*

of its resonant frequency, the spring can either fail to control the action of the valve, or it can break. The valve springs on older vehicles usually had a resonant frequency that occurred at about 4500–5000 rpm, limiting the ultimate rpm when valves would begin to bounce. Today's springs are designed with a resonant frequency beyond the normal operating range of the engine.

NOTE

In restrictor plate racing, all engines must meet the same specifications and competition is extremely close. This is why you do not see "better" cars passing "at will" on the straightaways. A specially designed machine called a Spintron Laser Valve Tracking System (**Figure 10.16**) can spin an engine at up to 20,000 rpm to determine the rpm level where valves bounce or springs "jelly-roll." If an engine builder knows that the engine will not rev above 9000 rpm and the valve springs will not allow valve float until 10,000 rpm (in case the driver makes a mistake), the tested springs will allow more engine durability than springs that will not float until 12,000 rpm. Of course there are many other factors in winning races. For instance, there is always some valve bounce, but if that can be minimized by testing the valve springs very closely, a small difference in acceleration might result in that car winning the race.

An engine accelerating from idle to high speed goes through changes in spring dynamics two or three times. Raising its maximum operating range by as little as 200–300 rpm can put a race engine back into the range of spring resonance and valve float.

Valve Spring Coil Bind

A valve spring can be compressed only so far before the coils bind or stack up when the thickness of the spring results in the coils contacting one another (**Figure 10.17**). This is why double or triple springs with inner and outer coils are often used. At

FIGURE 10.16 A Spintron machine, which can rotate an engine up to 20,000 rpm, provides racing engine builders with a way to check for valve spring float and pushrod flex. (*Courtesy of Trend Performance, Inc. 23444 Schoenherr Road, Warren, MI 48089*)

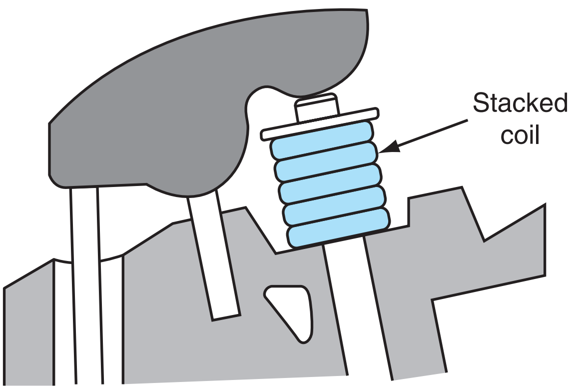


FIGURE 10.17 Too much valve lift can cause coil springs to bind.

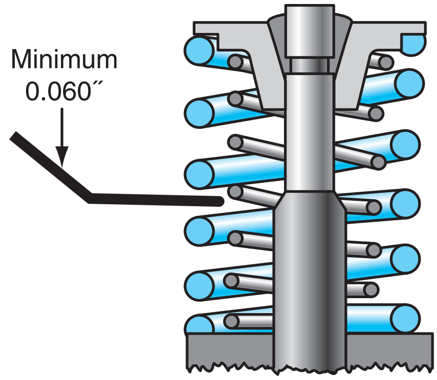


FIGURE 10.18 Check for coil spring bind at full valve lift, using a feeler gauge to check around the circumference of the center two coils.

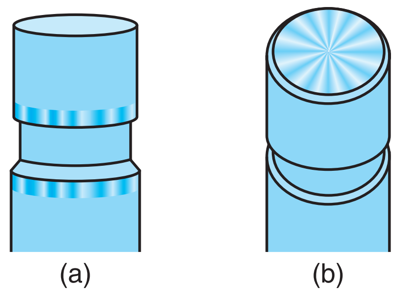


FIGURE 10.19 Indications of valve float. (a) Scuff marks on the valve stem above and below the keeper groove from valve lock scrubbing. (b) Multiple rocker arm contact areas on the valve tip.

very high rpm, if valve springs oscillate they will need some extra space between the coils. On high speed engines, at full valve lift there should be at least 0.060" clearance. Use a feeler gauge to check around the circumference of the center two coils (**Figure 10.18**).

Identifying Valve Float

How can you tell if a valve has been floating? There are several ways:

- If valve locks leave scuff marks on the valve stem both above and below the keeper groove, this indicates valve float.
- Another indicator of valve float is when there is evidence on the tip of the valve stem of multiple rocker arm contact areas (**Figure 10.19**). A nonrotating valve only rotates if it floats. The keepers (valve locks) clamp tightly to the stem of the valve and there is no contact between the center root of the keepers and the groove in the valve stem.
- Valve spring shims that are shiny are another possible indicator of valve float.
- During valve float, open exhaust valves sometimes contact pistons, leaving "witness marks" (**Figure 10.20**).

Most of today's heads are aluminum. Be sure to use hardened shims under the springs. At high speeds, intake valve springs tend to fail. Also, when valves float, springs tend to overheat and lose height and tension.

Titanium Valves

Heavy valves require stronger springs. Racing engines use lightweight titanium valves that are stronger and require less valve closed seat pressure from the spring, helping prevent valvetrain separation. High-end racing engine builders replace

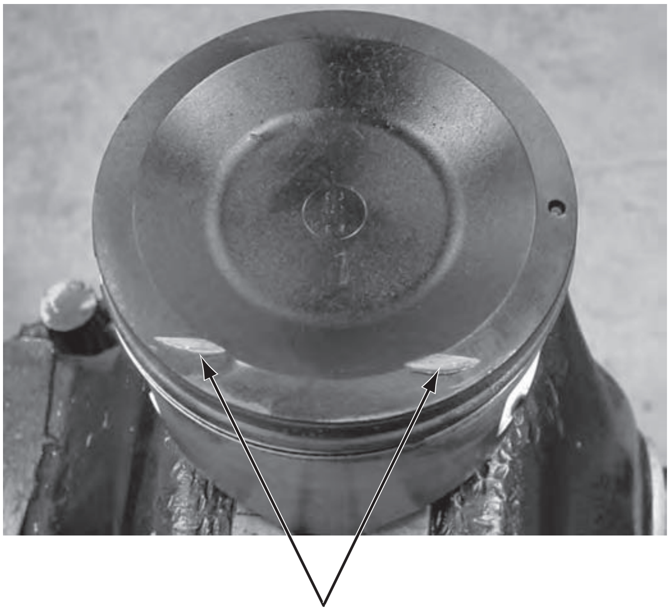


FIGURE 10.20 During valve float, open exhaust valves sometimes contact pistons, leaving "witness marks." (*Courtesy of Tim Gilles*)

titanium valves after every race because there is always some valve bounce, which more than doubles the load on the valve, drastically shortening its life expectancy.

Valve Spring Tension with Valves Closed and Open

With roller lifters, net horsepower remains the same with increased spring tension when the valve is closed. At first glance, it would seem that higher pressure valve springs would consume power when the valves are closed. However, as each valve opens and compresses it valve spring, another valve is closing, decreasing pressure as its spring reextends. This is known as the *regenerative characteristic*.

Valve Spring Open Pressure. Too much spring pressure when the valve is open reduces cam and lifter life and accelerates valve guide wear. It can also cause pushrods and rocker arms to flex; this can be observed using a Spintron machine.

Racing Springs

The quality of valve springs varies widely. Racing engine builders are known to order springs made of Swedish steel or rolled wire from Kobe, Japan. At speeds above 14,000 rpm, even the best valve springs do not work well. Formula One racing engines operate at speeds higher than this; they often use pneumatic valve closing mechanisms.

Porting and Polishing

Porting and polishing are cylinder head modifications that are done primarily to improve high rpm performance. The objective is to allow more air to flow at high speeds.

- Porting is when the size of a passageway is altered.
- Polishing smoothes the surfaces of the port.

Figure 10.21 shows a combustion chamber and valve ports in a head that has been ported and polished.

When the ports in a head are not aligned to match the ports in the manifold(s), high-speed airflow can be obstructed. Ports mismatched by more than 1⁄16" can be ground to help high-speed performance (**Figure 10.22**). This is called *match porting*.

Porting is not usually worthwhile for street cars because most factory ports flow 40% more air than can flow through the valve opening. Smaller ports can keep air flowing at a higher velocity; with larger ports at lower rpm, fuel tends to fall out of the air-fuel mixture.

Airflow Requirements

The amount of intake and exhaust that flows through manifold runners is measured in cubic feet per minute (**CFM**). Larger engines require bigger

FIGURE 10.21 A ported and polished combustion chamber and valve ports. (*Courtesy of Tim Gilles*)

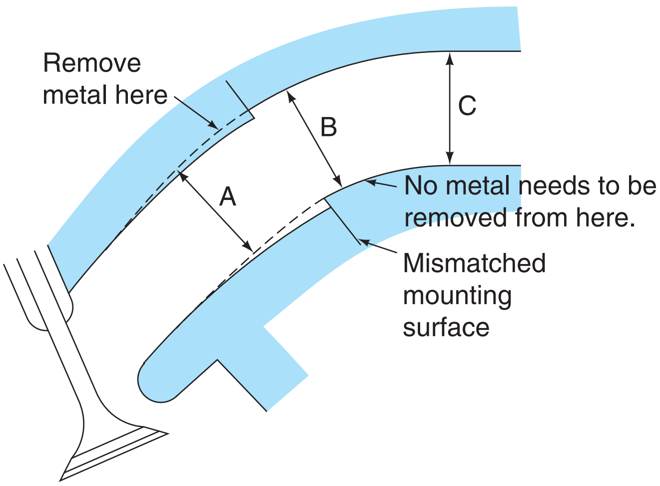


FIGURE 10.22 Matching the ports of the intake manifold and the cylinder head.

ports for adequate airflow. An engine of a certain size can only flow so much air.

NOTE

When someone wants to determine the CFM requirement for an engine at 100% **volumetric efficiency** (perfect breathing conditions), they use the following formula:

CID/2 × rpm/1728 × Volumetric Efficiency = CFM

- Divide the cubic inch displacement (CID) by 2.
- Multiply this figure by the maximum rpm, divided by 1728.
- Multiply this by the volumetric efficiency.

For instance, a 5-liter (302-cubic inch) engine can only flow 524 CFM of air at 6000 rpm. A 5.7-liter (350-cubic inch) engine will flow a maximum of 607 CFM of air at 6000 rpm. Would you want to install a 780 CFM carburetor and manifold on this engine if 6000 rpm was its red line? ("Red line" is the racer's term for the highest rpm point on the tach where the engine is shifted.)

Flowbench Testing

On racing engines, airflow though intake and exhaust passages is tested on a flowbench (**Figure 10.23**). Velocity is important. It is more efficient to keep air moving; at higher velocity more air can be pushed into the cylinder. Velocity is maintained by having the smallest port cross-sectional area that will deliver near maximum flow.

NOTE

One popular saying is "Pressure makes flow. Flow makes volume."

Certain shapes flow better than others. An engineer alters ports using a flowbench to improve flow through certain key areas, including the bend at the valve guide, the ridge around the valve seat, and the area of the valve seat where the air exits the seat. Airflow is restricted ½" above and below the valve seat because the air must turn 90° and expand. The upper part of the port only affects flow by 1–4%. The curved part of the port restricts about 12% and the area below the valve accounts for an average of 17–19% of the total restriction.

A flowbench compares the pressure drop flowing through a port or air cleaner with a pressure drop across an orifice. Vacuum motors pull air through the intake or exhaust and exhaust and airflow is calibrated based on known flow through an orifice of a specified size. A cylinder adapter the same size as the engine's cylinder bore simulates the shrouding of the cylinder. A switching valve is used when changing between intake and exhaust flow testing.

The flowbench uses two manometers, a vertical manometer and a horizontal incline manometer. The vertical manometer tells the base test pressure. It is important when comparing advertised test numbers to know at which base test pressure the test was conducted. The vertical manometer uses water as the test liquid; measurements are in *inches of water*. Adjusting the flow knob positions the vertical manometer at a certain level (28" of water, for instance). The incline manometer uses costly blue fluid ($80 per ounce) that has twice the specific gravity of water.

A dial indicator attachment is used to open the valve as flow is tested at different lift points (**Figure 10.24**). Pro-Stock engines can have about 1" of valve lift, whereas motorcycles have about 0.350". The percentage of flow is read on the incline manometer and converted using a scale (**Figure 10.25**). All valve lift points are tested at the same pressure. The flow on the vertical manometer is readjusted as lift points are changed.

Combustion Chamber Shape

Combustion chamber shape also restricts airflow. Wedge combustion chambers restrict flow

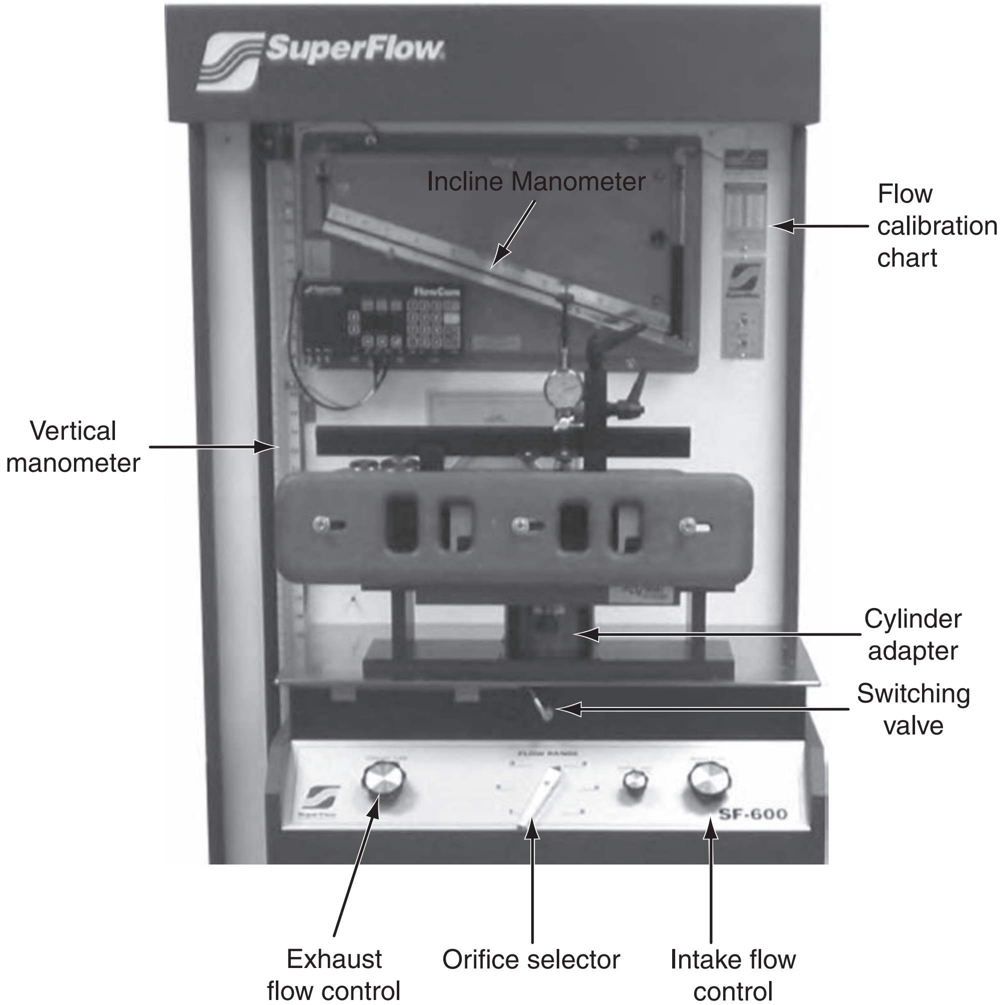


FIGURE 10.23 A flowbench for testing airflow. (*Courtesy of Tim Gilles*)

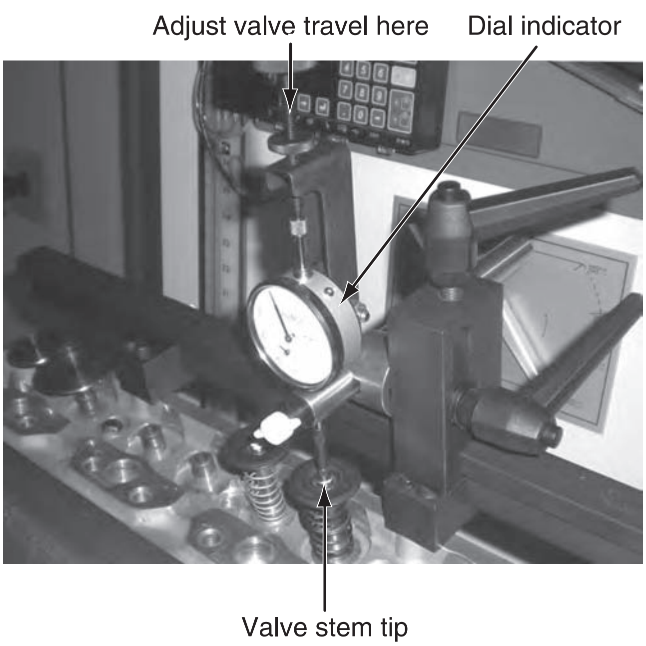
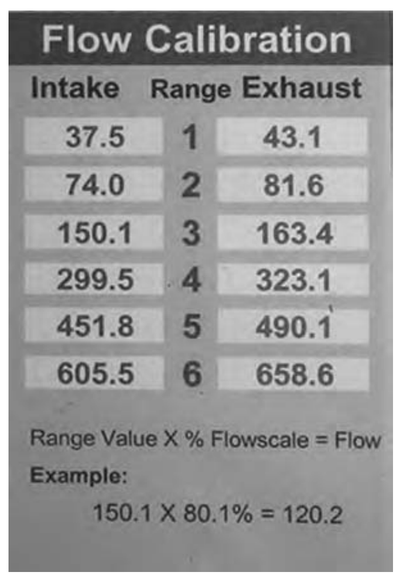


FIGURE 10.24 The valve is opened to test airflow at different valve lift points. (*Courtesy of Tim Gilles*)



Flow Calibration

Intake	Range	Exhaust
37.5	1	43.1
74.0	2	81.6
150.1	3	163.4
299.5	4	323.1
451.8	5	490.1
605.5	6	658.6

Range Value X % Flowscale = Flow

Example:

150.1 X 80.1% = 120.2

FIGURE 10.25 A flow calibration scale on a Superflow flowbench. In the above example, orifice #3 was selected to determine flow through the intake system. (*Courtesy of Tim Gilles*)

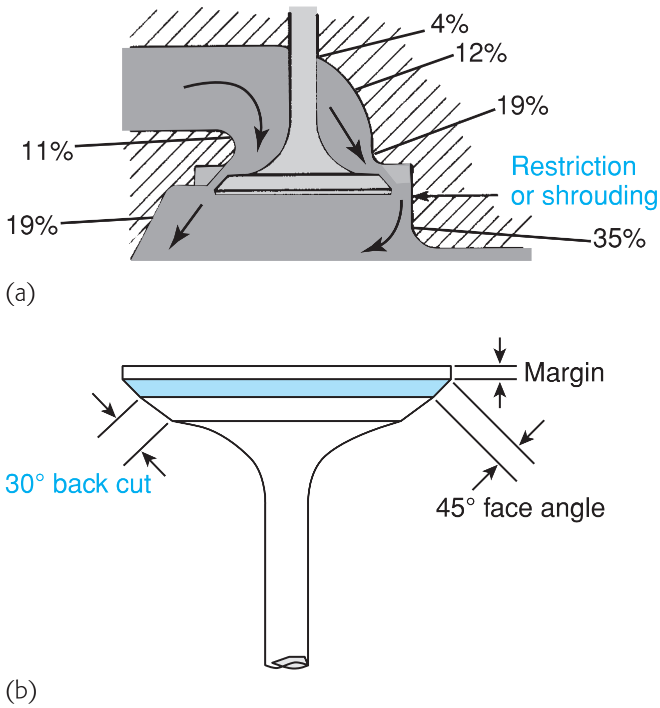


FIGURE 10.26 (a) Restrictions to airflow in the valve port and a wedge combustion chamber. (b) A 30° back-cut next to the face angle increases airflow at higher rpm.

because of **shrouding** (**Figure 10.26a**), which can restrict flow by about 35%. Hemispherical chambers allow air to flow more easily into the chamber because they lack the shrouded area.

Valve Size

Sometimes aspiring racers make the mistake of choosing the largest valve possible. This presents a few problems. For instance, with a larger valve flow is restricted by the shroud. Also, one side of the port will be closer to the cylinder wall, which restricts flow. Installing a larger valve also calls for more volume in the intake port and more work on the intake manifold. All of this must be done with a flowbench.

A large valve also weighs more. To close it, a stronger valve spring will be needed. Titanium valves are much lighter and can be used with lower tension valve springs. These springs are expensive, however, so they are mostly used in professional racing engines.

Porting

Racing professionally is very expensive. Some types of racing have certain requirements that all engines must meet. This sometimes includes a metered restriction to limit the amount of air that can enter the engine; this is called "restrictor plate racing." At this level of competition, providing an equal amount of air and fuel flowing to all cylinders can make the deciding difference in the outcome of a race.

Professional racers use heads that have been ported on computer numerical control (CNC) machines. Porting is done to one port and combustion chamber at a time with follow-up tests made on a flowbench to judge the results. When the combustion chamber and ports have been optimized for both intake and exhaust, their shape is "mapped" to digitize them for the CNC machine. The CNC machine can duplicate the contours of the intake and exhaust ports for the remaining seven intake ports and seven exhaust ports (on a V8) and the combustion chambers. For racers, the primary advantage to CNC porting is consistency.

When a port has been designed for a particular engine, it remains in the computer's memory and can be duplicated using the CNC machine on future sets of heads. Sometimes hand porting is attempted using a die grinder, but this process is time consuming and not very exact. Also, CNC machining has lowered the cost of CNC ported cast aluminum heads to the point where hand porting is no longer a realistic option.

Valve and Seat Angles

Airflow that is not directed becomes turbulent, which restricts airflow. Angles must be smooth and curves gradual. High-velocity air cannot make an abrupt change in direction. Three-angle valve seats and *back-cut valves* help achieve consistent airflow. An example of a **back-cut valve** is one with a 30° angle ground between the neck of the valve and its finished 45° face angle (**Figure 10.26b**). The back-cut on the valve should come to within approximately 0.015″ of the edge of the desired 45° face angle. The 30° angle reduces the width of the 45° face angle, so be careful not to remove too much.

A flatter angle results in a larger gap between the valve face and seat. For instance, at 0.100" valve lift, a 30° angle results in a 0.087" opening, whereas a 45° angle results in an opening of 0.071", and so on. Some machinists also vary the top angle of the valve seat. For example, with a 45° valve face and 30° back-cut, the machinist might use a seat top angle of from 35° to 38°.

EXHAUST MANIFOLDS

Exhaust manifolds (**Figure 10.27**) are often made of cast iron because of its ability to tolerate fast, severe temperature changes. Exhaust gas temperature is related to the amount of engine load; when the engine works hard, or when it has a lean air-fuel mixture, the exhaust manifold can run almost red hot.

Headers

Headers are exhaust manifolds made of steel tubing (**Figure 10.28**). Ordinary mild steel headers tend to have a shorter service life than cast iron manifolds, because they are thinner and can rust through. Stainless steel headers are more costly but can last as long as the vehicle.

Headers designed for maximum high rpm power are short with a large cross-sectional area. Headers do not improve performance at low rpm unless they are specifically tuned for low rpm use. Longer pipes make greater backpressure, which tends to improve low rpm performance.

Exhaust systems are not severely affected by bends in the pipe as long as the cross-sectional area of the pipe is not diminished (with a dent to clear the steering box, for instance). The primary header tube should be bigger than the port opening in the cylinder head. This creates a vacuum in the void between the header and valve port, preventing reversion. Reversion is discussed later in this chapter.

Small head hex screws are usually required so they can fit next to the header tubes. Notice the exhaust flange in Figure 10.28. A thick gasket is usually used with headers like this.

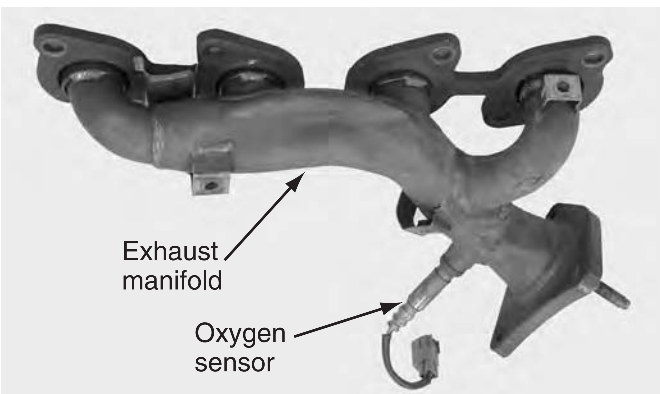


FIGURE 10.27 An exhaust manifold. (*Courtesy of Tim Gilles*)

FIGURE 10.28 A high performance exhaust header. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Older engines usually had cast iron cylinder heads. At the factory, exhaust manifolds were usually bolted to the heads with no gaskets because the newly machined surfaces were perfectly flat. In service, replacement gaskets are used to compensate for surface variations that have developed. If you disassemble an older engine and it does not have exhaust manifold gaskets, there is a good possibility it has never been disassembled before.

TURBOCHARGERS AND SUPERCHARGERS

A supercharger is an air pump designed to increase air density in the cylinder. Each cylinder of a four cylinder, 2-liter (2000 cc) engine has a displacement of 500 cubic centimeters. Therefore, if the piston is at BDC and the intake valve is open, the cylinder will fill with 500 cc of air. This is 100% volumetric efficiency, a theoretical value described later in the chapter. When the engine is running, atmospheric pressure is not a sufficient force to fill the cylinder completely with air and its volumetric efficiency will be less than 100%. Engine power output is directly related to its volumetric efficiency, and supercharging provides a means of filling the cylinder more completely. Racers call supercharging "a replacement for displacement." Original equipment engines today produce more than 1 horsepower per cubic inch. Adding 5 psi of boost to a typical inline six cylinder GM light truck engine results in about 70 additional horsepower.

NOTE

Normal atmospheric pressure is approximately 15 psi (14.7 psi at sea level). If a supercharger provides 15 psi of boost pressure, this effectively doubles the engine size.

There are two primary categories of automotive supercharging; the exhaust-driven *turbocharger* and the belt-driven *supercharger*. Electric superchargers are also available in the aftermarket.

Draw-Through or Blow-Through

Superchargers and turbochargers are either *draw-through* or *blow-through.* On carbureted engines, a *draw-through* system pressurizes the intake manifold *after* the carburetor and air cleaner (**Figure 10.29**). This is the only practical way to install a Roots-type blower (described later in this chapter). On fuel injected engines, air is pumped directly into the intake manifold.

A *blow-through* system pressurizes the air cleaner above the carburetor or fuel injection system (**Figure 10.30a**). These make easier aftermarket installations and will fit more easily under a low hood line (**Figure 10.30b**). Carbureted blow-through systems often use an enclosure box, called a *clamshell*, which surrounds the carburetor. This works well with a carburetor because when it is enclosed in a box, it operates like a normally aspirated carburetor.

When a blow-through system is used with a carburetor, the secondary jets are re-jetted richer and the float bowl vent tube must be within the top of the carburetor opening to allow for equal float bowl pressure. At high boost pressure, a brass carburetor float can be crushed, so solid foam floats are used. In addition, a fuel pressure regulator is used to keep pace with increases in supercharger pressure.

Turbochargers

Some engines have a turbocharger in the exhaust system (**Figure 10.31**), commonly referred to as a turbo. Turbochargers are available as original equipment on many cars and trucks. Retrofits are easier with electronic fuel injection than they were on carbureted engines of the past. Therefore, aftermarket turbocharging has become more popular in the high-performance marketplace with many options available. Knowledge of their operation and service will be important for you in dealing with your customers.

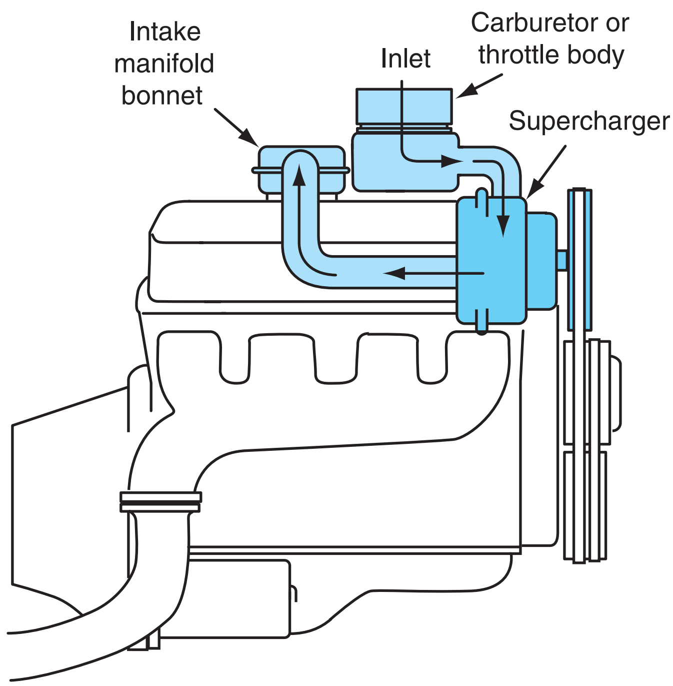


FIGURE 10.29 A draw-through supercharger.

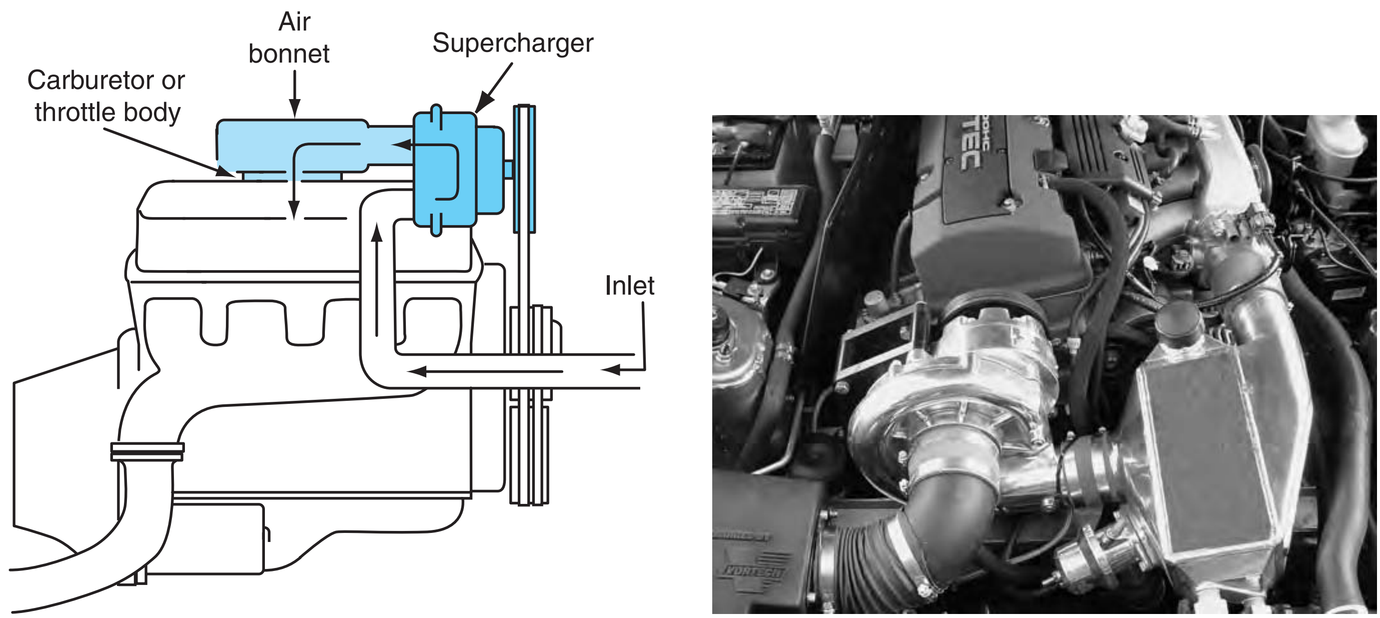


FIGURE 10.30 (a) A blow-through supercharger. (b) An aftermarket centrifugal belt-driven supercharger. It is a blow-through, fuel injected design. *(Courtesy of Tim Gilles)*

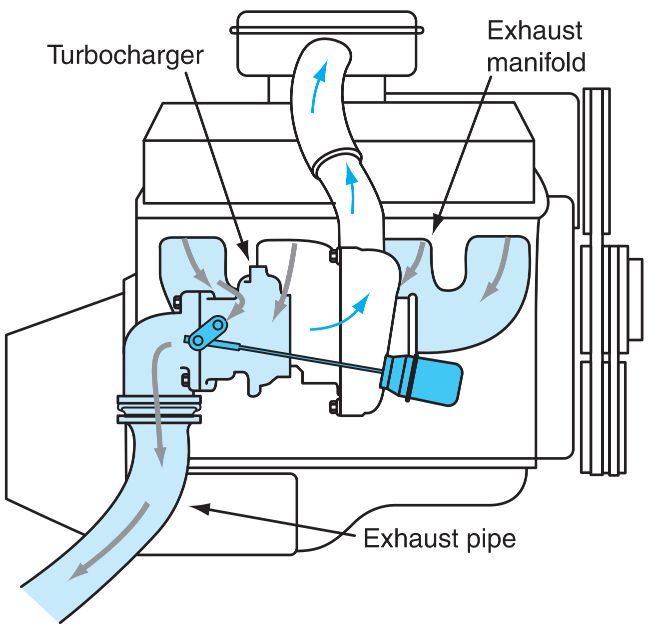


FIGURE 10.31 Components of a turbocharger system on a four cylinder engine.

A turbocharger is a gas turbine—a small, radial fan pump driven by energy from heat and pressure in the moving exhaust (**Figure 10.32**). It provides a smaller engine with approximately 40% more torque and horsepower over a stock **normally aspirated** engine. The engine does not use the turbo unless it is under load, so a smaller displacement engine can achieve better fuel economy than a larger, nonturbocharged engine of comparable power. One drawback is decreased engine life because the smaller the engine, the larger the percentage of time the turbo is used for accelerating and climbing hills. This results in a hotter running engine.

NOTE

A normally aspirated engine will lose 3% of its horsepower with every 1000-foot increase in altitude. But a turbocharged vehicle will not lose power when driven from low to higher altitude. The rpm of the turbine increases about 2% for every 1000-foot increase in altitude. This is especially advantageous for smaller turbocharged aircraft that use piston engines at higher altitudes.

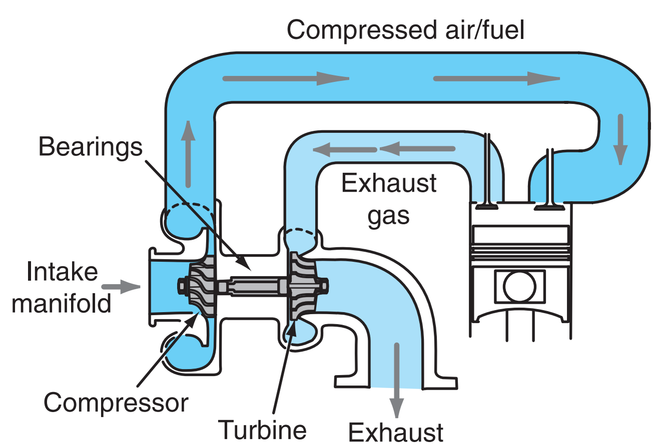


FIGURE 10.32 A turbocharger uses the energy of exhaust gas to force more air-fuel mixture into the cylinder to increase engine power.

Turbochargers are also very popular with diesel engines. Diesel fuel contains more energy than gasoline. Because it requires more air to burn completely, turbocharging is very helpful. Turbochargers are used on virtually all commercial diesel powered trucks as well as on most tractors.

Turbocharger Operation

A turbocharger is a *centrifugal* pump; centrifugal force takes the incoming exhaust and throws it through a snail-shaped outlet. The pump shaft has two wheels, a compressor and a turbine. The exhaust wheel is the turbine and the wheel that forces air into the intake manifold is the compressor (**Figure 10.33**). As exhaust pressure spins one wheel, the other wheel forces more combustible mixture past the intake valve and into the cylinder, increasing engine efficiency. **Figure 10.34** shows a blow-through turbocharger on a racing engine.

Two types of compressors are radial and axial. An axial compressor is like a jet engine. It draws air into the front and pushes it out the back in the same direction it is already moving. A turbocharger compressor uses a radial-type wheel, which means that air enters the leading edge of the wheel, called the *inducer*, parallel to the turbine shaft. It is then redirected 90° and exits the compressor housing perpendicular to the turbine shaft.

Turbocharger Airflow

The *diffuser* is the area between the parallel walls of the compressor cover and bearing housing where the air leaves the wheel. The *volute* is the curved funnel in the cover that increases in size from small to large. Air directed into the volute from the diffuser is slowed, which increases its pressure in the diffuser as the cover fills with static pressure. Air leaving the compressor wheel is unstable and erratic. The diameter of the cover is considerably larger than the compressor wheel to allow for a diffuser surface of sufficient diameter to accommodate this unstable air.

Before entering the engine the pressurized air moves from the compressor, either to a boost tube or through an aftercooler (covered later). Although a turbo takes advantage of the energy of exhaust gas movement to power its impeller, this is not simply free energy because the turbo itself restricts the exhaust stream.

Turbine and Compressor Size Matching

Engineers who design a turbocharger match the size of the turbine and the compressor to an engine's displacement, rpm, and volumetric efficiency. They call this "trimming" a turbo. Exhaust system flow is subjected to *backpressure*.

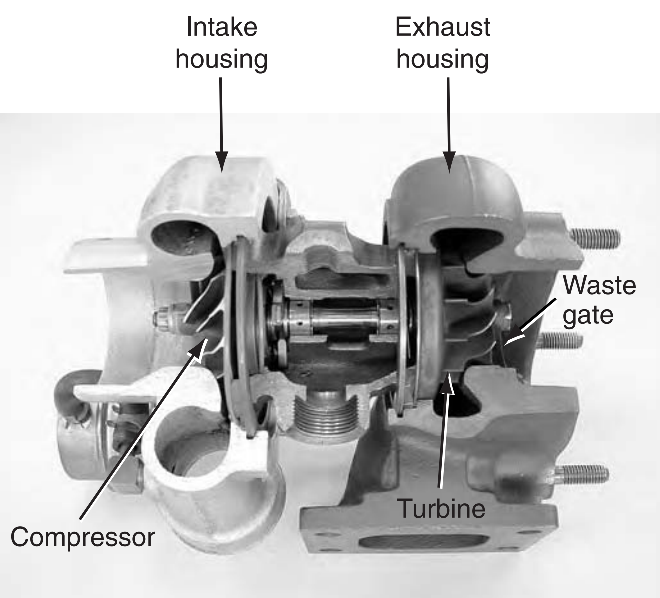


FIGURE 10.33 A turbocharger cutaway. *(Courtesy of Tim Gilles)*

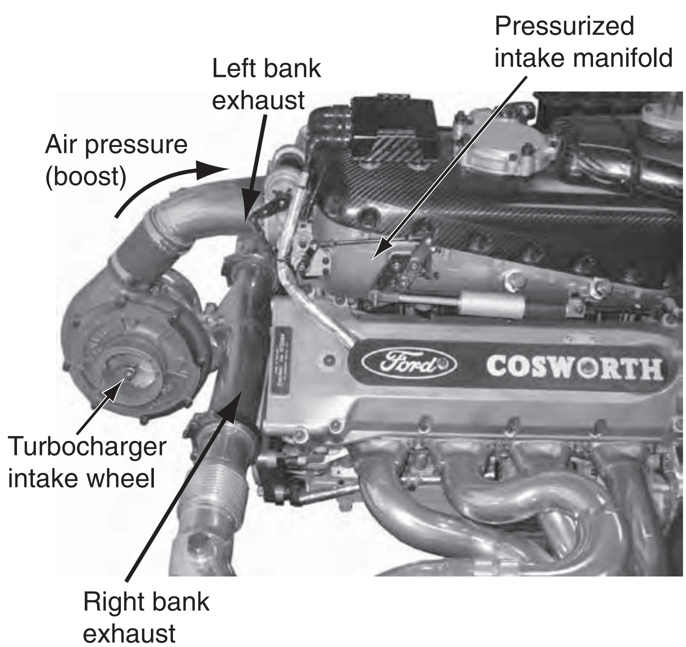


FIGURE 10.34 This turbocharged Cosworth is a blow-through design. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Turbo lag was more likely to occur in older vehicles. Lag was more pronounced when the throttle body or carburetor was too far away from the intake valve. Turbo lag is less of a problem with port fuel injection because the fuel injector is located directly above the intake valve.

Compare exhaust flow to a small stream of water flowing from the end of a garden hose. When you start to restrict flow by moving your thumb over the end of the hose, pressure builds and the water squirts out a greater distance. But if you continue closing off the opening, you cause too much backpressure and the distance of the flow drops off again.

The size of the turbine is matched to the engine's exhaust system based on the rpm where boost pressure will be applied. An understanding of pressure is important not only in the design of camshafts and intake and exhaust systems, but also in engineering the balance between the turbine and compressor ends of a turbocharger. This is similar to the way port size affects flow in intake and exhaust passageways at different engine speeds. Smaller turbines raise *more* boost pressure, but too small a turbine housing will choke off flow and cause excess backpressure.

NOTE

The maximum flow capacity of a turbo compressor is called "choke." When pressure reaches a certain point where flow stops, this is called surge or stall.

When a compressor is too large, it requires more power to spin; if it does not rotate fast enough, it will not compress the air sufficiently. With too small a compressor, the engine might need more air than the compressor can compress without overheating the air.

NOTE

When an engine produces sufficient exhaust flow to spin a supercharger or turbocharger enough to create boost, this is referred to as *spooling*.

Turbo Boost

The amount of air density a turbo can provide is known as **boost pressure**, or *boost*. The point where boost begins is called the **boost threshold**. This might be something like 1800 rpm, for instance.

Turbo Lag

When a turbo is spinning at low speed, little or no boost is produced. The time required to bring the turbo up to a speed where it can function effectively is called **turbo lag**—hesitation in throttle response when coming off idle.

Twin Turbos. Twin turbos are sometimes used with V-type engines. Exhaust power from half of the cylinders feeds two identical turbos, each matched to one-half of the engine's required airflow. This design is popular for road racing because the smaller wheels spool faster with less turbo lag (**Figure 10.35**).

NOTE

A twin turbo is not the same as a compound turbo; twin turbos are the same size and provide even pressure at the same time. Multistaged, compound turbos used in extreme duty performance applications, like tractor pulls, use one turbo to feed the next. Two, three, or four stages are used that sometimes reach boost pressures of 100–200 psi. These engines frequently blow up.

Turbochargers all have some lag. Smaller units have less, so they are often used in pairs.

To reduce turbo lag, some drag racers use a nitrous oxide system at low rpm, controlled to shut off by a pressure switch when a certain level of boost is sensed. Electronic controls allow another option for reducing lag. If timing is retarded while more fuel is injected (only when the throttle is open a small amount), the excess fuel burns in front of the turbo, making more heat to cause it to spin.

Supercharger Pressure Control

Supercharged systems use different ways to control excess pressure in the exhaust and intake sides. A fixed geometry turbocharger, like the type used in many heavy-duty diesel engines requires no pressure relief because it runs with predictable boost within a narrow rpm band. An automotive engine, however, must run at widely varying speeds so a wastegate is commonly used to control the speed of the turbine.

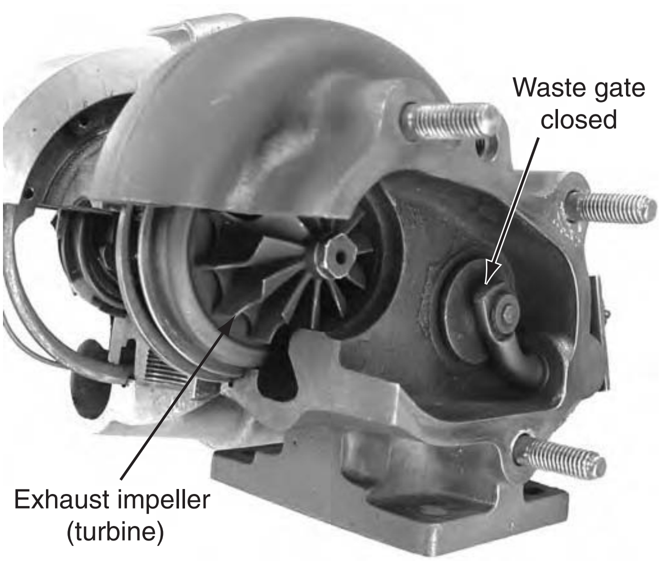
FIGURE 10.35 Twin turbos are sometimes used with V-type engines. *(Courtesy of BMW of North America, LLC)*

Wastegate

Without a *wastegate*, a turbo could provide so much power that the engine could destroy itself. Smaller turbines are used in automotive turbochargers because they are better at providing low-end boost and avoiding turbo lag. They work effectively, but if rpm climbs too high, the increasing exhaust flow can push the turbine too fast, building too much exhaust system backpressure. Boost pressure opens the wastegate when it reaches a specified point, relieving pressure by allowing exhaust flow to bypass the turbine, limiting its speed and output. **Figure 10.36** shows a wastegate in the open and closed positions. A redundant relief valve protects the system in case the wastegate becomes stuck.

The wastegate actuator is applied by air pressure supplied by a hose, which is tapped into boost pressure at the compressor discharge outlet. When boost pressure reaches the point in the actuator where it is higher than the opposing spring pressure, it opens the wastegate.

Internal and External Wastegates. A wastegate can be either internal or external. A turbo with an internal wastegate like the one shown in Figure 10.36 works fine for most street applications and is easier to install when doing an aftermarket installation. In high flow turbos, however, if the wastegate is not big enough to divert excessive boost, pressure will continue to rise. When an engine will have



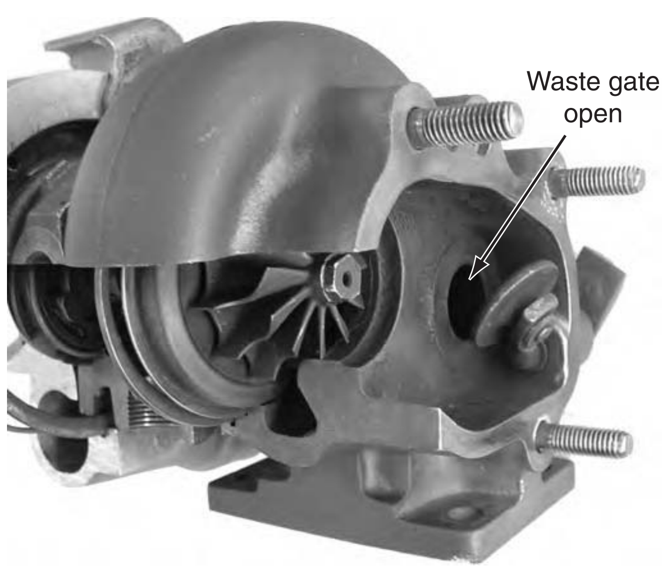


FIGURE 10.36 A wastegate in open and closed positions. *(Courtesy of Tim Gilles)*

more than double its original horsepower, an external wastegate with higher flow capacity can be used in combination with a turbocharger that lacks an internal wastegate.

An external wastegate is plumbed into the exhaust manifold, rather than the turbine housing, aimed into the manifold in the direction of exhaust flow. For the best flow, it is recommended that it be positioned 45° to the manifold with a smooth transition. If it is installed at 90° to the manifold, flow can be cut in half.

Changing Boost. The spring in an external wastegate can be changed to alter the amount of boost. Changing the amount of boost pressure is limited somewhat by the size of the turbo. If it was originally designed to work with 8 pounds of boost and you change the wastegate spring to provide 16 pounds of boost, the turbine will probably choke at full throttle and the intake air temperature can rise dramatically.

With an internal wastegate, boost pressure can be increased up to about 5 pounds by shortening the arm to the actuator. This applies more pressure to the actuator's internal spring.

Boost Controllers. A boost controller is a more sophisticated method of controlling the wastegate manually or by computer. It controls how much pressure is actually applied to the wastegate actuator. In racing, the controller can be mapped to electronically control boost, based on inputs like vehicle speed and transmission gear range.

Blow-Off Valve/Compressor Bypass Valve

Whereas a wastegate controls pressure in the exhaust side of the turbo, a compressor bypass valve controls pressure on the intake side of the turbo. Under high boost, when the throttle plate is closed quickly to decelerate, a condition known as *turbo surge* occurs. It develops as inertia continues to compress the air above the throttle plate. Surge is a back and forth movement of the air above the throttle plate that causes the compressor to stop making pressure. When air pressure builds above the throttle plate it reverses direction, flowing back toward the inlet of the compressor before bouncing back toward the throttle plate. This cycle repeats itself as the energy dissipates, creating surges in pressure that can cause the turbine shaft speed to be slowed faster than it normally would. Surge can sometimes result in damage to the turbo. A series of loud barks associated with turbo surge can sometimes be heard.

A compressor bypass valve installed between the aftercooler and the throttle plate prevents turbo surge by dumping boost pressure when the throttle is closed quickly, equalizing pressure between both sides of the turbo, allowing it to freewheel. The valve is opened by intake manifold vacuum, which rises when the throttle plate closes. This allows pressurized air trapped above the throttle plate to be relieved.

Blow-Off Valve. When a compressor bypass valve dumps air pressure into the atmosphere, it is usually called a *blow-off valve* (BOV). The sound of pressurized air dumping from a BOV is audible and is sometimes amplified by turbo enthusiasts who like the sound. Fuel injection systems that use a mass airflow (MAF) sensor can run rich when an externally vented BOV is used; however, systems using a manifold absolute pressure (MAP) sensor are unaffected.

Compressor Bypass Valve. A different style valve, called a *compressor bypass valve* (CBV), is quieter than a blow-off valve. It dumps pressure back into the fresh air intake instead of into the atmosphere. This is the type of valve commonly used in factory installations.

Variable Geometry Turbochargers

A wastegate is a simple way of varying turbocharger geometry. A more sophisticated way is to use a variable geometry turbine (VGT), also called variable nozzle or variable displacement turbine. One design has movable vanes in the turbine housing (**Figure 10.37**). A computer that has been *mapped* to manage changing engine conditions adjusts vane position, altering the nozzle opening to change the volume and pressure of the exhaust gas entering the turbine. Small openings work better at low rpm, whereas wide openings work best at high rpm. With no need for a wastegate, the VGT provides better energy efficiency. Another VGT design uses fixed vanes that are covered or uncovered by a sliding nozzle ring.

VINTAGE ENGINES

Intercooler is a term that originated when turbocharger cooling of automotive and aircraft engines had multiple stages of superchargers and the cooling device was installed between them. Today, many people refer to intercoolers as aftercoolers, because they are located *after* the supercharger or turbocharger.

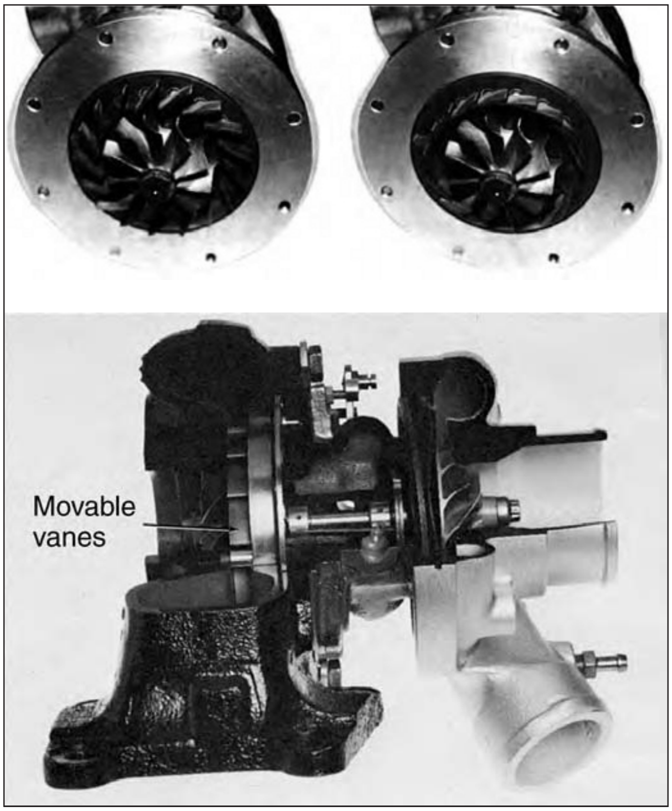


FIGURE 10.37 A variable nozzle turbo. The top photo shows how the vanes move.

Variable geometry turbines for gasoline engines are relatively expensive due to the expensive materials required for durability.

Aftercooler/Intercooler

An *aftercooler*, also called an *intercooler* or *charge air cooler*, is often installed with a turbocharger (**Figure 10.38**). A turbocharged engine operating at sea level with 7 psi boost should theoretically have about 1½ times the power of a normally aspirated engine. However, when air is compressed, it becomes hotter, so fewer air molecules can enter the engine. Pressure produced by the turbo can cause fuel to detonate in the cylinder. Incoming air at 90°F will become 276°F when compressed at 14 psi boost. An aftercooler is a sophisticated and expensive air cooler installed at a point after air has been compressed. **Figure 10.39** shows an aftermarket air-to-air aftercooler.

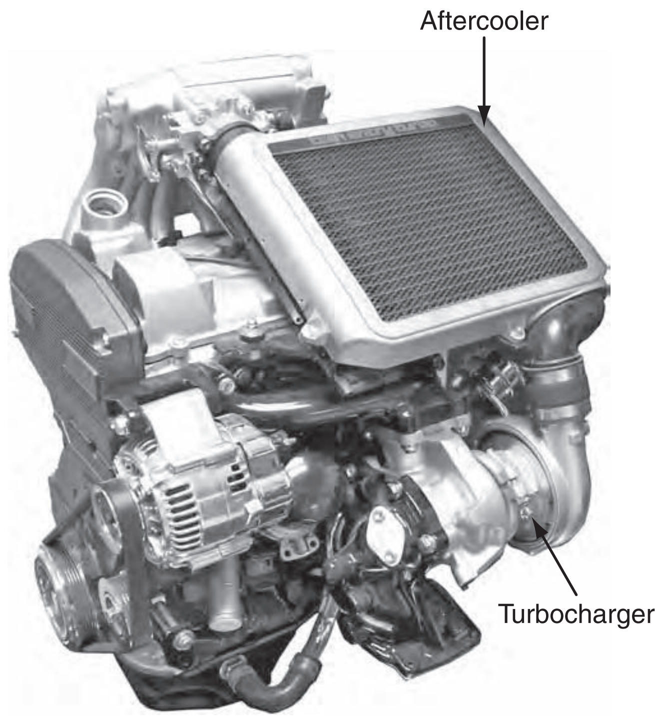


FIGURE 10.38 An OE aftercooler on a Toyota. *(Courtesy of Tim Gilles)*

NOTE

For every 10°F the air-fuel mixture is cooled, a power gain of about 1% is achieved. Aftercoolers cool supercharged air by about 100°F before it enters the engine, providing about 10% more power output.

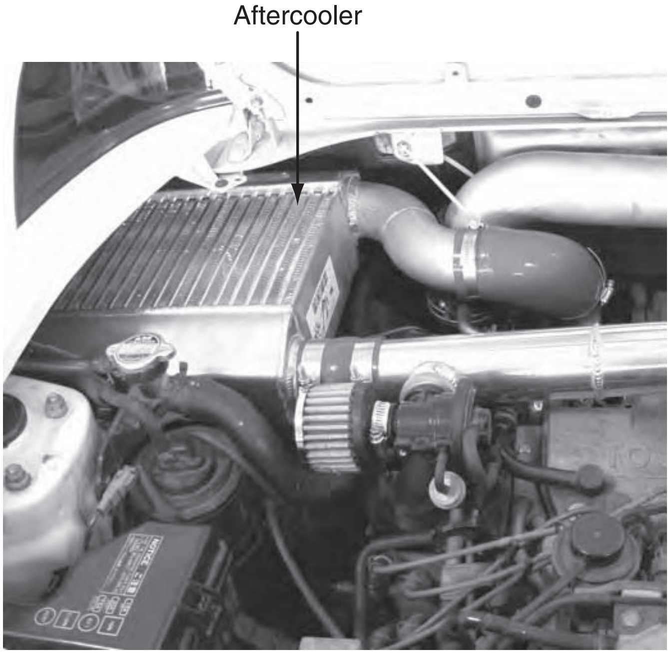


FIGURE 10.39 An aftermarket aftercooler. *(Courtesy of Tim Gilles)*

Aftercoolers are relatively trouble free. They are cooled by either air (**Figure 10.40**) or water (**Figure 10.41**). Air cooled aftercoolers are known as *air-to-air*. Most production engines run 6 or 7 psi boost so that they can live a long life on available low-octane fuels; 7 psi is about half of atmospheric pressure (14.7 psi).

Turbocharger Thrust/Boost Differential

End thrust, or side-to-side pressure, on the turbine shaft occurs when pressure is higher in either the turbine or the compressor. This is known as *boost differential*. Too much pressure difference between the turbine and compressor causes a parasitic load that robs horsepower and can result in turbo failure. Positive boost differential is when pressure is higher in the compressor housing, and negative boost differential is when pressure is higher in the turbine. Positive differential is best for performance, but negative differential occurs at wide-open throttle when boost cannot keep pace with rising turbine pressure.

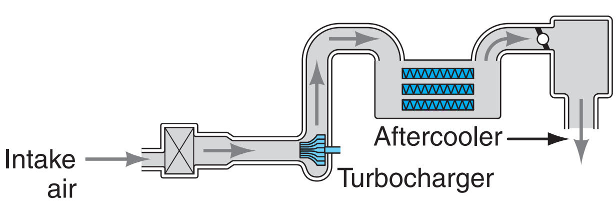


FIGURE 10.40 An air-cooled (air-to-air) aftercooler/intercooler.

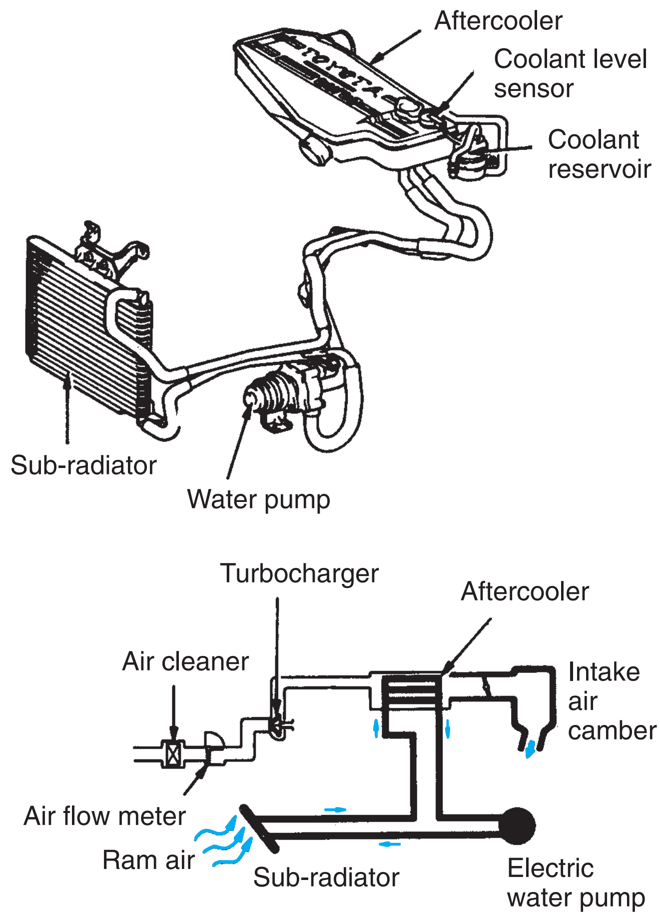


FIGURE 10.41 A water-cooled aftercooler.

Parts of a Turbocharger

Turbocharger parts include the bearings, turbine shaft, and compressor and turbine wheels and housings. The turbine wheel and shaft assembled with the compressor wheel is called the *rotor*.

Turbocharger Bearings. Turbocharger bearings sometimes operate under extreme conditions, like high temperatures and very high rotational speeds. There are also radial and thrust (axial) loads that vary as the exhaust pulsates. Most turbocharger bearings are a three-piece bronze set that includes two full-floating journal bearings and a flat thrust bearing. Full-floating journal bearings rotate in their housings, typically at about one-third the speed of the turbine shaft. Bearing embeddability is an important bearing attribute because the most common cause of turbocharger failure is contaminated oil.

Turbo Thrust Bearing. Hardened steel thrust rings fit in a bore in the bearing housing, positioned on both sides of a stationary thrust bearing surface in the housing (**Figure 10.42**). The thrust bearing assembly is fed with oil through an oil gallery from the center to reliefs in the thrust surfaces. Oil is thrown from the thrust rings at very high speed so an oil deflector shrouds them at the outside edge to redirect the oil to the oil drain cavity in the housing.

Turbo Ball Bearings. Ball bearing cartridges are expensive, but they offer a better option for extreme racing conditions. Although traditional three-piece thrust bearings are adequate for most applications, ball bearings eliminate the need for a thrust bearing. Nearly half of the rotor drag on a three-bearing assembly is due to the thrust bearing, and eliminating this drag can reduce turbo lag by up to about 15%. In racing, with all other things equal, a ball bearing turbo could make a significant difference.

When a ball bearing cartridge is used, less oil flow is required so there will be an orifice to restrict oil flow.

Compressor Wheel Design. Most compressor wheels are cast aluminum, although some very expensive racing wheels are machined from a titanium billet for use under very high boost pressures. Several wheel designs are used in turbochargers, depending on the application. A stationary industrial engine that runs with little variation in rpm uses a straight radial wheel. However, this design does not work well throughout the wide rpm band of automotive engines. Automotive engines usually use a *splitter blade wheel*, which has alternating blades of short and full lengths and can take a bigger gulp of air. The most commonly used automotive wheel has a backward curved impeller (BCI), which is more efficient through a wider rpm band. Air moving through this wheel begins to diffuse even before entering the diffuser.

Turbine Wheel and Shaft. The turbine wheel and shaft assembly, called the turbine shaft, is the most expensive part of the turbo. Turbine wheels used for aviation are required to be one piece with the shaft, but a typical automotive turbine shaft is made of forged steel that is friction welded to the cast turbine wheel. The shaft has rolled threads and is induction hardened where the bearings ride. Cast turbine wheels are sometimes made of a very hard austenitic nickel-chromium-iron alloy called Inconel, or Inco. Inco is used for turbine wheels in diesels and some high-performance gasoline turbos because it is more resistant to high temperatures.

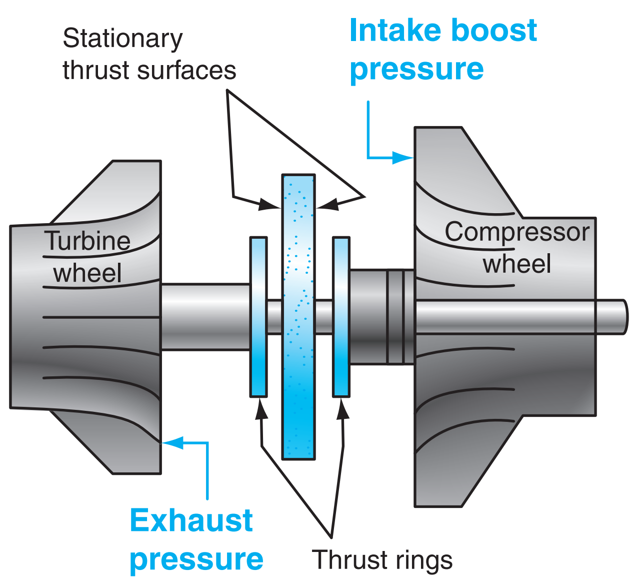


FIGURE 10.42 Thrust rings are positioned on both sides of a stationary thrust member in the housing. When boost and exhaust pressures are unequal, end thrust results.

The turbine housing is either divided or open. Open housings are better for high-speed gasoline engines. A divided housing provides more torque in the low to mid rpm range and is, therefore, popular with diesels.

Bearing Housing. The bearing housing, which is usually cast iron, seals gas and controls oil. It is cooled by oil, coolant, or air. After engine shutdown, it also insulates turbine heat from the lube oil.

When installing an aftermarket turbocharger, be sure the oil drain in the compressor housing is within 20° of vertical.

Turbocharger Oil Control. Today's turbos have metal rings similar to piston compression rings on the ends of both the compressor and the turbine. They seal exhaust pressure and boost pressure from the turbo oil drain area. Pressure leaking into this area would pressurize the crankcase, causing internal oil consumption and external oil leaks.

Turbochargers deflect oil, rather than using seals for oil control. Oil does not enter either the compressor or turbine when there is boost pressure in either side.

Temperature and Pressure Gauges

Turbochargers and superchargers often have temperature and pressure gauges in the intake manifold. The pressure gauge shows the amount of boost pressure in the intake manifold, whereas the temperature gauge indicates how well the intercooler is working. A boost gauge displays pressure in psig (the *g* means "gauge"). It measures the pressure in the manifold and compares it to atmospheric pressure. Therefore, 10 psig is actually 14.7 + 10, or 24.7 psi absolute pressure in the manifold.

Turbocharger Lubrication

Lubrication is crucial to turbochargers; therefore it is recommended to change the oil more frequently. Turbo bearings can get extremely hot during a shutdown when the engine is shut off immediately after the turbo is used. Engine oil burns at about 430°F (221°C); when the engine is shut off after a period of acceleration, the bearing on the exhaust side of the turbo can reach temperatures in excess of that. Some turbochargers have water-cooled rear bearings to help solve this problem. Synthetic oil burns at a higher temperature so it is the oil of choice for use with a turbocharger.

SHOP TIP

Following an oil change, disable the ignition system and crank the engine for 30 seconds to supply oil to the turbo. If you forget to do this, the turbo will run without oil when the engine is started. This can damage an expensive turbo.

Turbocharger Care

Heat is potentially damaging to a turbocharger. Its oil flow is only about 8% of the total oil flow through the engine. Yet the turbo heats the oil 40% more than engine bearings do. Following high output use, a driver should be advised to drive slowly for about 1000 yards (1.10 kilometers) to allow the turbo to resupply with cool oil before shutting the engine down. Some of today's turbos have special lubrication and cooling features that function even after shutdown.

VINTAGE ENGINES

Turbochargers on carbureted draw-through systems had carbon faced positive oil seals because the compressor was sometimes under manifold vacuum.

CASE HISTORY

Early turbochargers in the late 1970s were mounted in the rear of the engine compartment and, therefore, ran hotter. "After-lube" was extra important for these units. A driver of a turbo car was testing out his engine in a remote area when he was stopped by the police for speeding. He pulled over and shut off his engine. While the engine was off, the oil solidified in the oil return. This resulted in excessive oil smoke from the car's exhaust.

SHOP TIP

Following an extended period of storage, disable the fuel injectors and crank the engine for 30 seconds to prelube a turbo until oil pressure registers on the dash light or gauge.

Turbocharger Balance

Turbos spin in excess of 100,000 rpm and are balanced to run in excess of 150,000 rpm, 25 times the maximum rpm of most engines. Compare this to the speed of an alternator, which spins at about 20,000 rpm. Balancing on the turbine wheel is done in two planes like dynamic tire balancing or crankshaft balancing on the nose and on the back face of the wheel. High-volume turbo manufacturers and rebuilders typically balance the assembled turbocharger in two planes with a balancing machine by scallop grinding the compressor nose or nut. There are also very high-speed balancers available that balance in a single plane.

Turbocharger Replacement

Turbocharger rebuilding is not usually attempted in repair shops. Part of the balancing procedure includes grinding a scallop into the turbine shaft nut. When this nut is removed, balance, which is critical, is upset. Unless a large number of turbos are rebuilt, it is not economical for a repair shop to rebuild them. Shops will often order a new or rebuilt turbo cartridge to install in the old compressor housing.

NOTE

It is usually necessary to remove the compressor housing from the intake manifold before it is possible to remove the turbo cartridge. Attempting a shortcut can result in a bent impeller blade, which can cause the turbo to howl and, ultimately, cause bearing failure.

SHOP TIP

Full-floating plain bearings are used in most turbos. Because they have oil clearance on both sides, they have double the normal clearance. Therefore, the shaft will feel "loose," which is normal.

Typical clearance between the compressor wheel and cover is only about 0.009–0.012". When inspecting a turbo, a rule of thumb is: *If the wheel rubs the housing, the turbo needs to be replaced*. Do not try to make it rub; simply see if it has been rubbing in service.

Contact between the cover and the end of the wheel can sometimes be felt when the wheel is turned by hand. When there is oil pressure, however, the parts will correctly center.

Turbocharger Troubleshooting

A turbocharger operates in a difficult environment with high rpm and extreme heat. It is bathed in hot exhaust gas of about 1800–1950°F (982–1066°C). This is more severe than the environment of the engine's stainless steel exhaust valves, which are cooled much of the time by contact with their valve seats.

The primary cause of a turbocharger failure can be overlooked, resulting in failure of a second turbo. Blockages, leaks, and foreign object damage are common failures. Before getting into turbo troubleshooting, diagnose problems as if the engine did *not* have a turbo.

A high number of turbo warranty returns are what manufacturers refer to as "NCFR—No Cause for Removal." The leading cause of these unnecessary warranty returns is blowby, which can result in oil in the turbo housing. Compression-type rings seal the turbo shaft to keep exhaust pressure out of the center housing. A restriction in the oil return (**Figure 10.43**) will cause pressure, resulting in oil

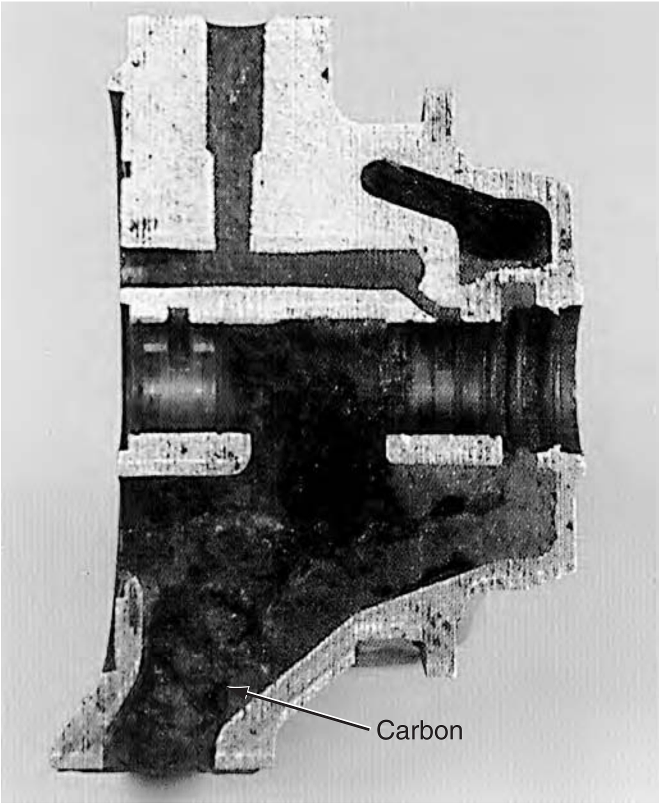


FIGURE 10.43 A turbo oil return can become plugged with carbon.

consumption and smoke. If a crimped or plugged drain line is not repaired when a new turbo cartridge is installed, the oil consumption complaint will not be addressed.

SHOP TIP

Avoid Teflon tape when sealing lubrication line threads. The tape can accidentally tear off and block oil flow to a critical place.

The PCV valve should close when the intake side of the turbo is under boost. If it does not, the crankcase can be pressurized through the PCV system. This can result in oil entering the intake side of the turbo from the now pressurized center housing. Be sure that the correct PCV valve is used and it is in good operating condition.

"Slobber" is a condition when water and carbon run from the exhaust ports. This can sometimes be traced to long periods of idle.

An engine with worn or broken piston rings or a piston damaged from detonation or preignition will have excessive blowby. This will pressurize the center housing and cause oil consumption to become even worse. Following engine repair, the turbocharger should still be cleaned and reused.

NOTE

A turbocharger troubleshooting chart is in the appendix at the back of the book.

Diagnosing Damage to a Turbo

When the turbo has been damaged by a foreign object, look at the wheel to determine from which direction the damage came.

Turbine damage. Any engine failure where parts enter the exhaust can damage the turbine. This includes broken piston rings, valves, or pistons.

Compressor damage. Damage to the compressor wheel results from objects entering the intake (**Figure 10.44**).

When contaminated oil damages a full-floating turbo bearing, heavy particles will tend to damage the outside of the bearing.

Thrust Bearing Failure

Thrust bearings do not normally fail. They are designed to withstand up to 20 pounds of boost differential. During an aftermarket turbo installation, sometimes too small a turbine is installed. If it is allowed to make too much boost, thrust bearing failure can result.

When a thrust bearing has failed, the following will help you solve the problem. Pressure is exerted on the back face of either wheel, which pulls the wheels apart (see Figure 10.42). The compressor thrust surface is the one closest to the turbine, and the turbine's thrust surface is the one closest to the compressor.

FIGURE 10.44 Damaged compressor wheels.

BELT-DRIVEN SUPERCHARGERS/ BLOWERS

Superchargers are air pumps, commonly called *blowers*. They can easily produce 50% more power than a normally aspirated engine of the same size. The crankshaft usually drives the supercharger with a belt, but it is sometimes driven by a chain or gears. **Figure 10.45** shows a cutaway of an original equipment passenger car supercharger. Belt-driven superchargers spin at 10,000 to 15,000 rpm, which is much slower than turbochargers.

Because it is belt driven, a supercharger provides more torque at lower speeds than a turbocharger. It also has a quicker response (no turbo lag). There are several kinds of supercharger pumps, including centrifugal, Roots, vane (Judson), Lysholm twin screw, rotary (Wankel), and axial flow fan (like a jet turbine). The most common ones in automotive use are the centrifugal and the Roots types (**Figure 10.46**). A belt-driven Roots blower is the one commonly seen on dragster engines (**Figure 10.47**).

FIGURE 10.45 Cutaway of an original equipment supercharger. *(Courtesy of Tim Gilles)*

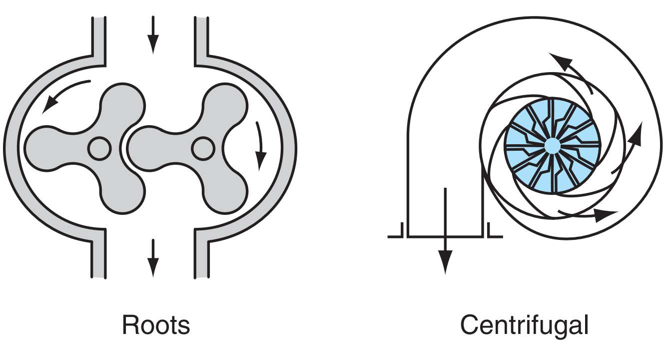


FIGURE 10.46 The most common automotive supercharging pumps are the Roots and the Centrifugal.

FIGURE 10.47 This funny car engine has a Roots-type blower. The belt arrangement over the top is to provide protection if it explodes (as they sometimes do). *(Courtesy of Tim Gilles)*

There are two groups of superchargers: the positive displacement and the dynamic.

Positive Displacement Superchargers

A positive displacement pump delivers the same amount of air with each revolution regardless of the speed. Therefore, the faster it turns the more air it pumps. Because there is no lag with these blowers, they provide a remarkable increase in torque right off idle. A big blown engine will come off the line extremely fast when the throttle goes wide open. In fact, when these engines have carburetors they are mounted sideways so fuel will not surge against the main jets.

Belt slippage and heating is a problem with positive displacement blowers. Serpentine belt-driven Roots blowers are available with optional pulleys of 8, 10, and even 12 ribs. Heavy boost blowers use a 2" or wider cogged belt to eliminate slippage altogether. Some of these engines use two keyways in the crankshaft snout to prevent the cogged pulley from shearing a single key. One advantage to using a cogged blower drive belt is that it takes the place of a vibration damper.

The most popular positive displacement supercharger is the *Roots type*, called a lobe-type supercharger. Roots-type blowers are used on top-fuel dragster engines because they are the only type of forced induction permitted in that class of drag racing. Meshing rotors pump and compress air when they are rotated. Air is forced against the sides of the blower instead of into the center. **Figure 10.48** shows the airflow through a lobe-type supercharger. Sometimes lobes are *helical* (twisted), and other times they are *straight cut* (**Figure 10.49**).

Lobe superchargers tend to pulse at low speeds, but a helical rotor tends to smooth these pulses out. A three-lobe rotor tends to pulse less than a two-lobe rotor. Eaton, which makes the vast majority of Roots-type compressors, uses a 60° twist and three lobes to increase the efficiency of the Roots blower.

When the engine is not under a heavy load, intake manifold vacuum turns the rotors like a windmill, thereby using less power. Unlike turbos, however, blowers consume horsepower as they are driven. A Ford blower uses 60 horsepower at 5000 rpm but only uses ½ horsepower when cruising on the highway.

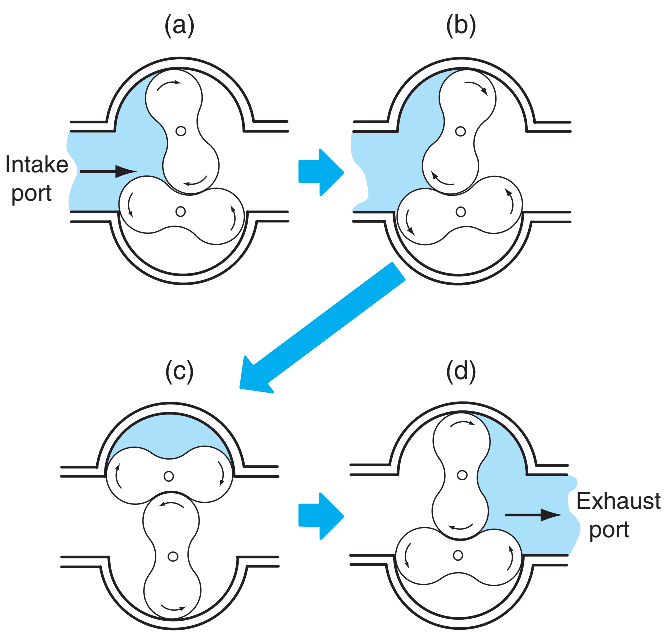


FIGURE 10.48 Lobe supercharger airflow.

Blower Lubrication

Because exhaust gases do not drive superchargers, they do not get hot. Therefore, lubrication is not the big problem it is with turbochargers. In fact, the Roots-type units are lubricated with their own supply of SAE 90 gear oil, which has no specified oil change interval. There is a sight plug on the blower to verify oil level (**Figure 10.50**).

Pressure Relief Valves

There are different designs and purposes for pressure relief valves in forced air induction systems. As with turbochargers, some supercharger systems divert air back into the supercharger inlet (bypass or recirculating) and others divert air to the atmosphere (open atmosphere). Most superchargers for street use do not blow off air into the atmosphere; they use a standard bypass valve to recirculate air back into the supercharger inlet. Standard bypass valves are used when boost is less than 12 psi. High boost racing engines (over 12 psi) use a blow-off-type valve that diverts a larger volume of air to the atmosphere. One example of a high boost blower pop-off valve on a drag race engine, shown in **Figure 10.51**, can prevent damage when there is a fuel explosion or when the throttle is backed off, but the supercharger is still pressurizing air. **Figure 10.52** shows an aftermarket pop-off valve. Valves that divert pressure to the atmosphere are not usually needed when there is

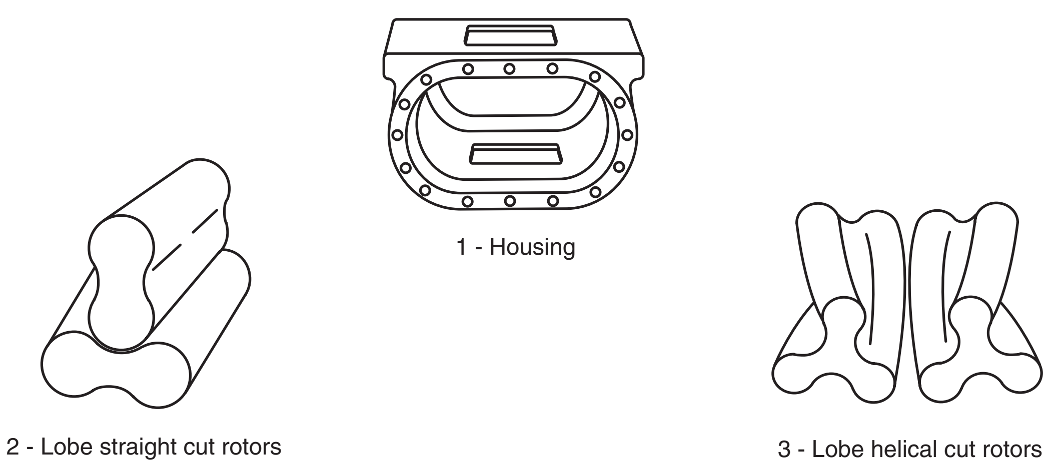


FIGURE 10.49 Variations of a supercharger rotor design.

less than 8 psi of boost, but they are recommended at levels higher than that.

A bypass valve prevents unnecessary air from being forced into the engine or against the throttle plate. There are times when a supercharger is forcing air into the engine but the engine cannot take more air. Perhaps an intake valve is closing or there is an air pulse moving in the opposite direction in the intake manifold. As conditions quickly change,

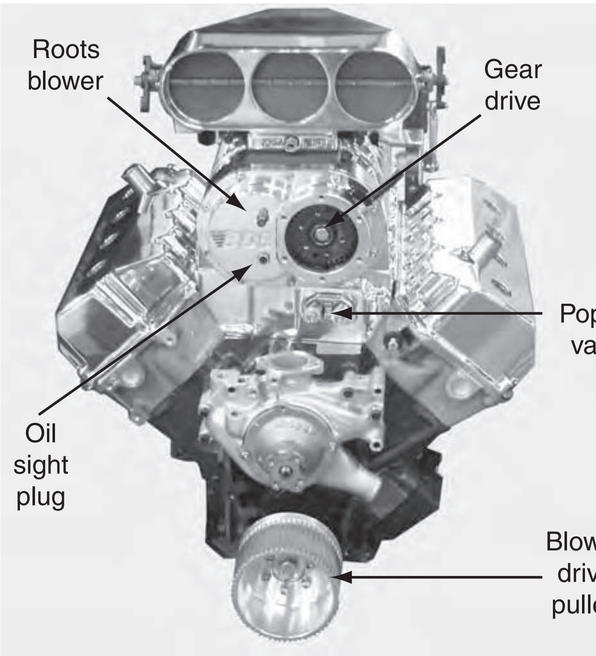


FIGURE 10.50 Parts of a blower. The pop-off valve controls excess pressure and the gear drive allows for an easier change in blower output. *(Courtesy of Tim Gilles)*

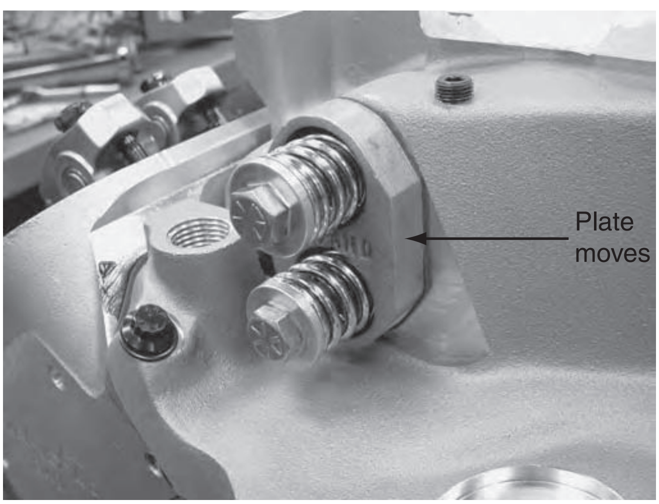


FIGURE 10.51 A high boost blower pop-off valve for a drag racing engine. *(Courtesy of Tim Gilles)*

FIGURE 10.52 An aftermarket pop-off valve. *(Courtesy of Tim Gilles)*

however, air will be required immediately. The bypass valve allows air in the manifold to be maintained at a predetermined pressure, waiting for an opportunity to flow. Airflow from a supercharger increases on an equal basis with rpm change; it is not otherwise regulated during these milliseconds when there is no room for the forced air.

A few superchargers use a clutch to cycle off and on; air is bypassed when the supercharger is not spinning. The air bypass valve also becomes a blow-off valve when boost rises above about 8 psi.

Other Supercharger Types. Volkswagen's scroll-type G-lader is so called because *lader* means "charger," and the shape of its chambers resembles the letter "G." The displacer inside its housing moves in an off-center circular motion like a hula-hoop. Another positive displacement blower is the vane type, which compresses air inside its housing before forcing it through its outlet. Electrical axial flow fan-type superchargers draw high amperage and are used most often on small engines with high boost. When installed correctly, they operate only at full throttle so they do not wear out the brushes in the electric motor.

Dynamic Superchargers

The three types of dynamic superchargers are the centrifugal, the axial flow, and the pressure wave.

Centrifugal superchargers are popular in the aftermarket because they can be fit under the hood of many vehicles. A centrifugal supercharger is similar in design to a turbocharger. However, it is crankshaft driven, rather than exhaust driven so there is no exhaust impeller. It has only one wheel, a belt-driven turbine. Whereas positive displacement blowers run at lower speeds, centrifugal supercharger speed is typically about 7 times the speed of the crankshaft. The crank overdrives the blower pulley, which is overdriven by gears to the impeller.

When accelerating from idle, a centrifugal blower only produces from 0 to 1 psi of boost, unlike a Roots blower, which gets full boost immediately off idle. With a centrifugal supercharger, blower rpm and engine rpm move together in synch.

Centrifugal supercharger oiling is often supplied by the engine's lubrication system, although some have an independent system that uses ATF as a lubricant.

The axial flow pump is not often found, because of its expense to manufacture.

The pressure wave pump is used mostly for two-stroke diesels. A dynamic supercharger is like a turbocharger in that its output increases as the square of engine speed. If the engine turns twice as fast, boost output is quadrupled, so this pump operates best at high speeds but produces less boost pressure off idle.

NOTE

When comparing dynamic superchargers with positive displacement blowers and turbochargers, maximum engine power is not the governing factor. A better means of testing is to compare the power throughout the entire power curves of the three different designs. Street cars operate mostly below 4000 rpm, so this will be a consideration in deciding on the best type of blower to use.

NOTE

Because aluminum heads dissipate heat better than cast iron, they are the head of choice when used with a supercharger or turbocharger.

Blower Problems

Blowers are very dependable but dirt is a prime enemy to them. Vacuum leaks on the intake side suck in dust that can ruin the unit. Exhaust side air leaks (boost side) hurt performance. Vacuum leaks can also fool the computer, causing the engine to run lean. A leak on the boost side, on the other hand, will cause a rich condition. The oxygen sensor and computer manages the air-fuel mixture based on what is sensed in the vehicle's exhaust, but it will only make relatively minor corrections to the mixture. It cannot compensate for major leaks. Leaks are usually accompanied by a whistling sound that can be easily located by listening for its source.

CAMSHAFT AND ENGINE PERFORMANCE

When a performance camshaft is installed, additional new breathing system parts are often required as well. These might include a new intake manifold and exhaust system, a new carburetor or fuel injectors, and altered computer mapping (**Figure 10.53**). All parts need to be matched. Camshaft manufacturers will provide information about their cams on request and will recommend specific combinations.

The cam designer can fine-tune an engine’s performance by changing the point of valve opening or

VINTAGE ENGINES

The Roots blower, the oldest supercharger design, used by GM, Ford, and Toyota, was originally developed by the Roots brothers in 1854 to blow a constant supply of air for cupolas in foundries. In the mining industry, a giant blower was used to blow air through mine shafts. The scroll-type supercharger, used by Volkswagen, was invented in France in 1905, and the Lysholm twin-screw compressor was invented in the late 1930s.

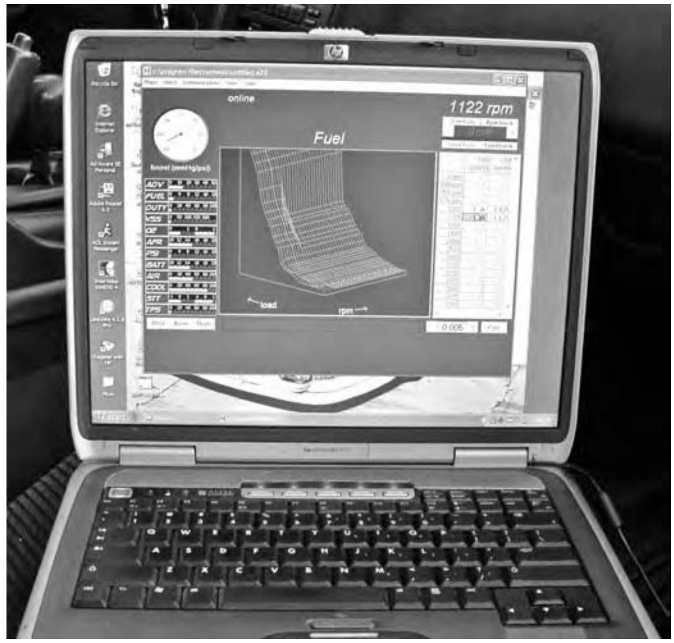


FIGURE 10.53 An aftermarket computer is programmed with a personal computer. Fuel system functions and ignition timing are mapped. *(Courtesy of Tim Gilles)*

closing. These are called valve timing "events." Chapter 9 includes a basic discussion using a valve timing chart, showing the relationship between crankshaft position and valve opening. The following discussion delves into this in more detail. The point at which the intake and exhaust valves close can have a major effect on the operation of the engine. Refer to **Figure 10.54** to clarify the following events. The overall objective is to maximize cylinder filling. Remember that the timing of the camshaft events is listed in *crankshaft* degrees.

Intake Valve Opening

The intake valve must already be open before TDC, before the piston begins moving down on its intake stroke. If the valve was closed, the piston would drag against the resistance presented by the unopened valve port, especially at higher speed. The specification for intake opening for stock applications is listed in most service literature.

The piston must start and stop at the beginning and the end of each stroke. During the intake stroke the connecting rod spins, whipping the piston down into the bore. At higher speeds the piston accelerates very quickly, causing a big gulp of air when it reaches its maximum velocity at 90° of rod angle.

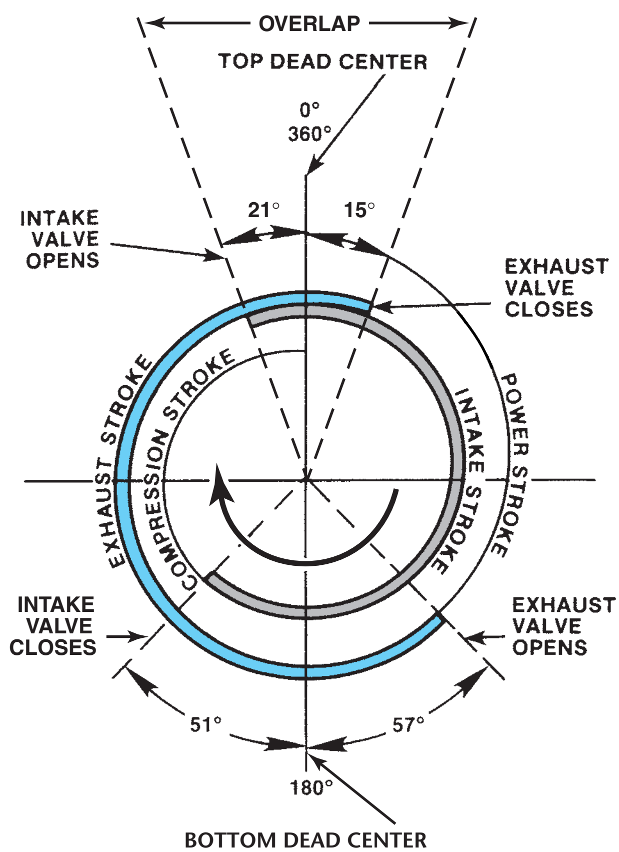


FIGURE 10.54 This chart shows the opening and closing points of the intake and exhaust valves in crankshaft degrees. Valve overlap is 36°.

NOTE

Piston velocity governs engine speed. A short stroke engine can reach higher crankshaft rpm than a long stroke engine. Formula One racing engines have very short crankshaft strokes. Compare their very high rpm operating range with that of very low rpm large diesel engines used in 40- to 50-foot boats. These engines have very long crankshaft strokes and run at about 2200 rpm top speed; normal speed is about 1800 rpm. The propeller is what limits the speed of these engines. If the propeller or its drive shaft breaks, the engine will overspeed and blow up.

Intake Valve Closing

The intake valve remains open long after the piston reaches the bottom of the stroke (BDC) and changes direction into the compression stroke. This takes advantage of the velocity of the incoming gases, helping to continue filling the cylinder with additional air-fuel mixture even though the piston is moving back up the cylinder.

The closing of the intake valve is a very important factor in how the engine operates:

- It controls the rpm range of the engine. Closing the intake valve later allows more fuel and air to enter the cylinder. Therefore, higher rpm is possible.
- The point at which the intake valve closes governs the *effective compression* ratio of the engine. Closing the intake valve later lowers the effective compression ratio. This is not the same as the static compression ratio of the engine, which is the measured difference in combustion chamber volumes between TDC and BDC. Static and effective compression ratios are discussed later in this chapter. Having a higher static compression ratio allows longer intake valve duration.
- Closing the intake valve too soon can increase detonation.

Exhaust Valve Opening and Blowdown

The exhaust valve must open well before the end of the power stroke. *Blowdown* is a term describing the part of the power stroke between when the exhaust valve opens and the piston arrives at BDC. The pressure of expanding gases in the cylinder must be bled off during the blowdown period before the piston changes direction and moves up on the exhaust stroke. Most of the power of the burning gases has been delivered to the piston by about halfway through the power stroke so opening the exhaust valve at this point does not harm an engine's power output. The exhaust valve should be nearly wide open by the time the piston reaches maximum velocity. This prevents resistance to flow caused by exhaust gas pressure, which would result in a pumping loss. *Pumping losses* are the work needed to move air into and out of the cylinder. Another pumping loss occurs when the throttle plate impedes the flow of air into the cylinder.

When the blowdown period begins too late, this results in high pressure on the exhaust stroke and can cause intake reversion at lower speeds.

NOTE

The EGR valve actually increases engine efficiency. Late-model computer-controlled engine management systems use the EGR valve to add inert exhaust gas to the air-fuel charge. Because the air-fuel charge does not contain as much energy, the driver must open the throttle further to maintain the desired power. Opening the throttle plate further reduces pumping losses.

VINTAGE ENGINES

In the 1970s, an exhaust gas recirculation (EGR) valve was installed on many engines to control NOx emissions. In their early years, these valves were primitive. A popular tune-up trick was to disable the EGR valve, increasing engine performance and economy.

Exhaust Valve Closing

The timing of the closing of the exhaust valve is important for maintaining high intake manifold vacuum. When the piston has reached the top of the exhaust stroke, the cam lobe holds the exhaust valve open past TDC. At higher speeds, the inertia of the moving exhaust gas leaving the cylinder results in lower pressure behind it. This vacuum condition sucks more exhaust from the cylinder (called *scavenging*) and helps draw in more fresh air-fuel mixture during valve overlap, increasing power **(Figure 10.55)**. The inertia of the incoming air provides additional help in filling the cylinder.

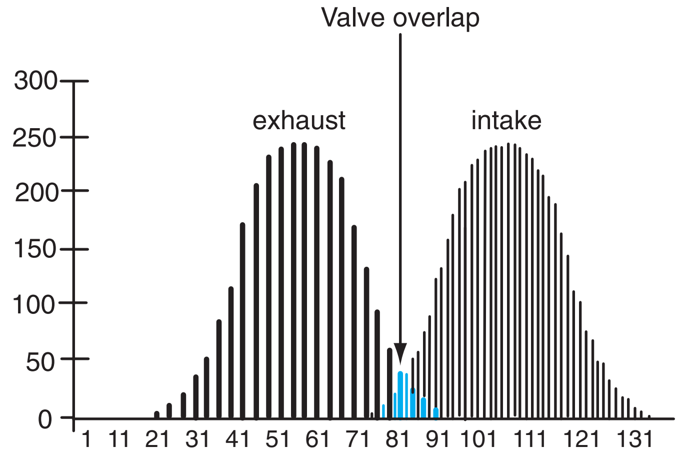


FIGURE 10.56 During valve overlap both valves are open at the same time. (*Courtesy of Dimitri Elgin, D. Elgin Cams*)

Valve Overlap and Engine Performance

Valve overlap occurs at the top of the intake stroke when the intake valve is already open and the exhaust valve has not yet finished closing (**Figure 10.56**). Stock engines have overlap of 15–30 crankshaft degrees. In the example in Figure 10.54, the amount of overlap is 36°. High duration racing cams can have overlap of from 60° to 100°. Additional overlap provides more efficient cylinder filling at high rpm but causes lower engine vacuum and worsened low-end performance, idle quality, and low-speed fuel economy.

Maximum piston velocity on the intake stroke occurs before maximum valve lift is reached, so opening the valve earlier can improve engine breathing. However, if the intake valve opens too soon, idle quality suffers while higher end performance does not improve much. The timing of the closing of the exhaust valve is the valve overlap factor that affects high-speed performance. In fact, increasing the size of the exhaust valve and port is not commonly seen as beneficial to power output because the flow from the cylinder is limited more by the exhaust valve as it is closing. Cam designers try to minimize valve overlap while attempting to maximize high-speed performance. Variable valve timing takes advantage of this knowledge and is covered later in this chapter.

A high overlap camshaft designed for high-performance, high rpm use can have high valve *lift*, too. Overlap is what gives these engines their distinctive "lope" at idle. But low intake manifold vacuum associated with this lope can lead to problems such as inconsistent vacuum power brake applications. This is why auxiliary vacuum reservoirs are sometimes needed.

High valve overlap can also lead to clearance problems between the valves and pistons because both valves are partly open when the piston is at the top of the cylinder.

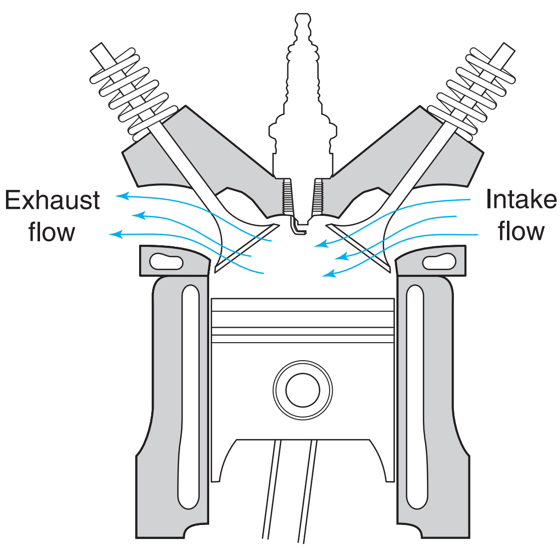


Figure 10.55 At higher rpm with more duration, increased exhaust flow pulls more air into the cylinder through the intake port.

NOTE

Excessive valve *lift* does not cause piston-to-valve interference because the piston is *down* in the cylinder when the valve is open to maximum lift.

VINTAGE ENGINES

Some smog control engines of the 1970s used small valves, low lift, and higher valve overlap to help cool peak combustion temperatures. At low speed, the open intake port is packed with exhaust gas as the piston completes its exhaust stroke. This dilutes the incoming mixture, lowering combustion temperatures and NOx emissions. Because the exhaust valve remains open into the intake stroke, some of the exhaust is drawn back into the cylinder at low speed, further diluting the mixture. This reversing of the direction of the exhaust is known as *reversion*. Using reversion is not practical at part throttle when control of NOx is most needed. Newer engines use EGR valves to lower combustion temperatures.

Less overlap results in more pressure in the cylinder at lower rpm. This results in greater torque at low rpm. The "RV" or "high gas mileage" cams fit this profile.

Excessive valve overlap can cause problems with turbochargers. A turbocharger operates on backpressure in the exhaust. If the turbo operates at too low an rpm, the backpressure can flow through the open exhaust valve into the intake air stream, limiting boost pressure into the cylinder. Camshaft designers can recommend the best camshaft to use with a turbocharger.

CHECKING CAMSHAFT TIMING

Cam timing can be verified with a dial indicator and degree wheel. The degree wheel is mounted on the front of the crankshaft. It is used with a pointer mounted to the block and adjusted so that it points to TDC (**Figure 10.57a**). Aftermarket crankshaft pulleys that have degree positions etched on their surfaces are also available (**Figure 10.57b**).

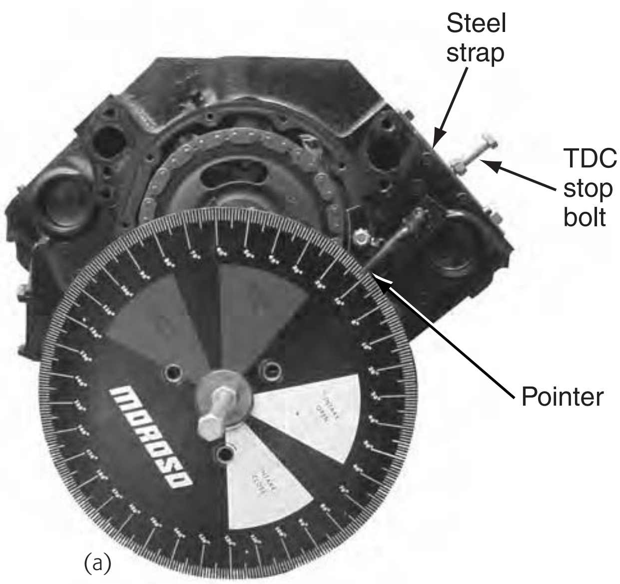


FIGURE 10.57 (a) A degree wheel installed on the crankshaft. (b) A crankshaft pulley with degree marks. *(Courtesy of Tim Gilles)*

Locating TDC

The exact location of TDC must be determined before the cam timing can be checked for accuracy. Simply having the piston at the top of its travel in the cylinder does not ensure that the crankshaft is exactly at TDC. The crankshaft can rotate through several degrees at TDC while the piston remains stationary at the top of the cylinder. This happens as the rod journal reaches the top of its arc between the time it stops moving up and starts moving down again (**Figure 10.58**). The exact position of TDC is located at the midpoint of this travel.

Locating TDC Using a Stop Bolt

TDC can be pinpointed using a stop bolt fixture. **Figure 10.59** shows one made of a steel plate fastened to the head bolt holes above the number one cylinder. A bolt threaded into the plate provides the "stop." On OHC engines with the spark plug located above the center section of the piston, a stop tool can be made using a spark plug cut on a lathe (**Figure 10.60**).

To find TDC, the crankshaft will be rotated first in one direction and then in the other until it comes up against the stop and cannot move further (**Figure 10.61**). TDC is the location exactly between the two stop points. With a degree wheel fastened to the crankshaft by its pulley bolt:

- Rotate the crankshaft until the number one piston runs into the stop bolt. Note the degree wheel reading at the pointer (**Figure 10.62a**).

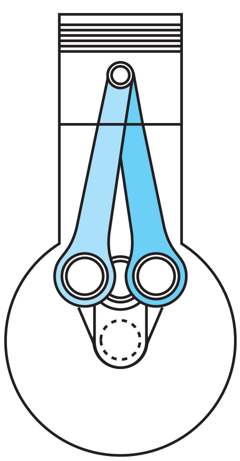


FIGURE 10.58 The crankshaft rotates through several degrees of travel while the piston is stopped at TDC.

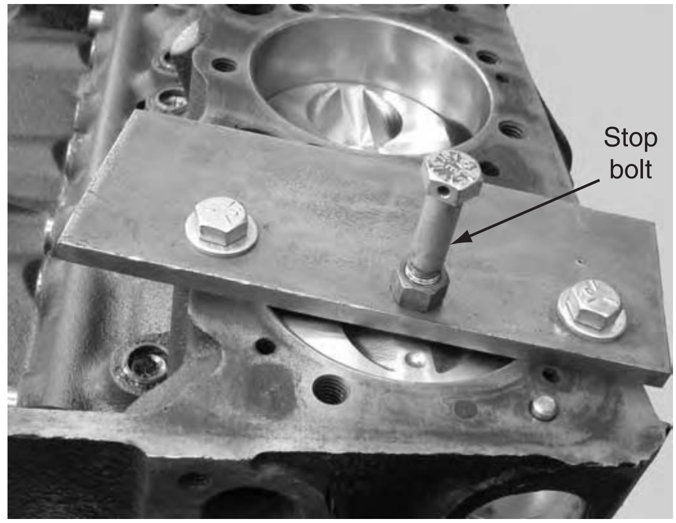


FIGURE 10.59 A stop bolt fixture used for locating exact TDC. *(Courtesy of Tim Gilles)*

- Rotate the crankshaft backward until the piston comes against the stop once again and note the degree reading (**Figure 10.62b**).
- TDC is located exactly between the two readings on the degree wheel. Add the two numbers together and divide them by 2. The resulting number is the number of degrees that the pointer is off of TDC. Let us say that the degree reading is 22° on one side and 18° on the other. The average of the two is 20°, so adjust the pointer so it aligns with 20° on the degree wheel. Then turn the crankshaft all the way against each stop once again. The degree settings should now be equal at 20°.
- Remove the stop plate and move the crankshaft until 0° on the degree wheel is aligned with the pointer. You have located TDC.

Locating TDC Using a Dial Indicator

The following describes how to pinpoint TDC using a dial indicator mounted to read off the top of the number one piston (**Figure 10.63**).

- Turn the crankshaft to move the piston up in its bore until the highest needle reading on the indicator is reached.
- Note the position of the timing pointer on the damper pulley.
- Continue rotating the crankshaft until the needle on the indicator begins to move back down. Note this position on the damper pulley. TDC is

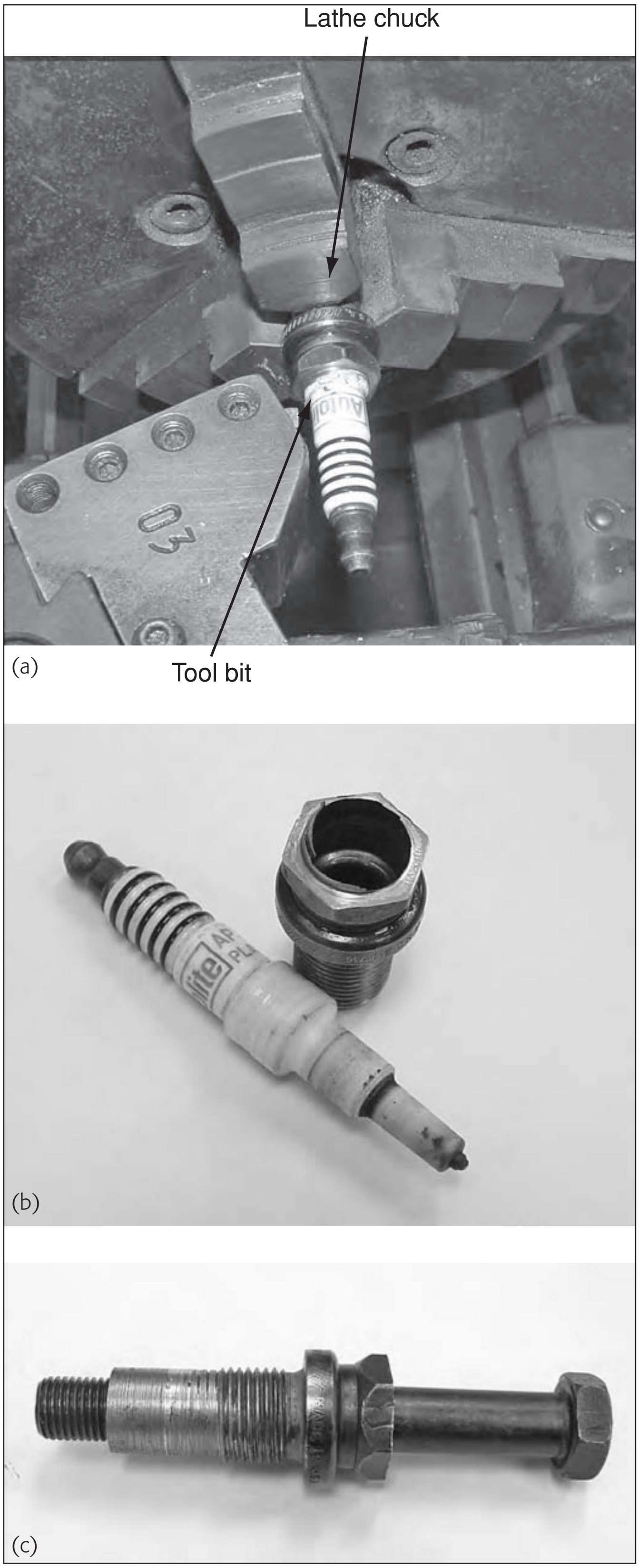


FIGURE 10.60 Making a stop bolt from a spark plug. (a) Cutting the steel shoulder using a lathe. (b) Separate the center of the spark plug from the outer shell. (c) An inexpensive custom stop bolt. *(Courtesy of Tim Gilles)*

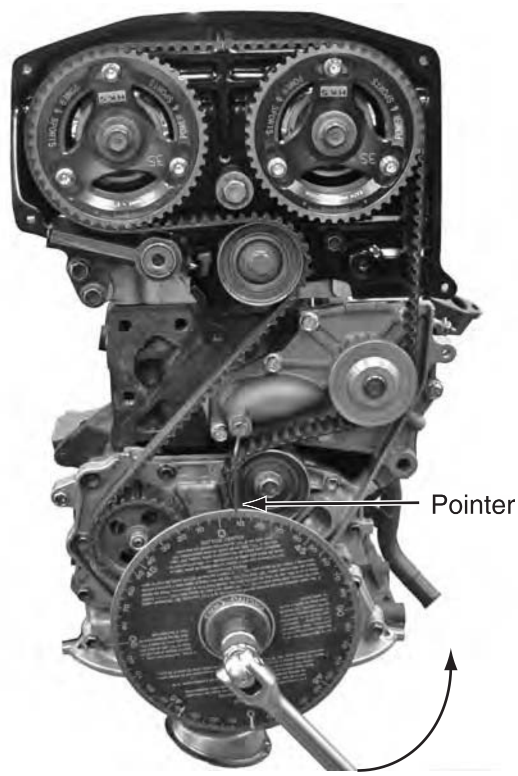


FIGURE 10.61 Rotate the crankshaft until the piston hits a stop. *(Courtesy of Tim Gilles)*

halfway between the two positions noted on the damper pulley.

SHOP TIP

This test can help determine whether the TDC timing mark on the damper has shifted position. The outer ring on an older three-piece damper sometimes shifts position as the rubber between the inner and outer ring ages and shrinks.

Reading Camshaft Timing with a Dial Indicator

Cam timing can be verified using a dial indicator. The procedure for pushrod and OHC engines is different.

Pushrod Engine. Dialing in a cam on a pushrod engine is most easily done without the cylinder heads installed, although a reading can also be taken with the heads installed by attaching a dial indicator to read off the top of a pushrod. With a hydraulic lifter, achieving an accurate reading can be difficult.

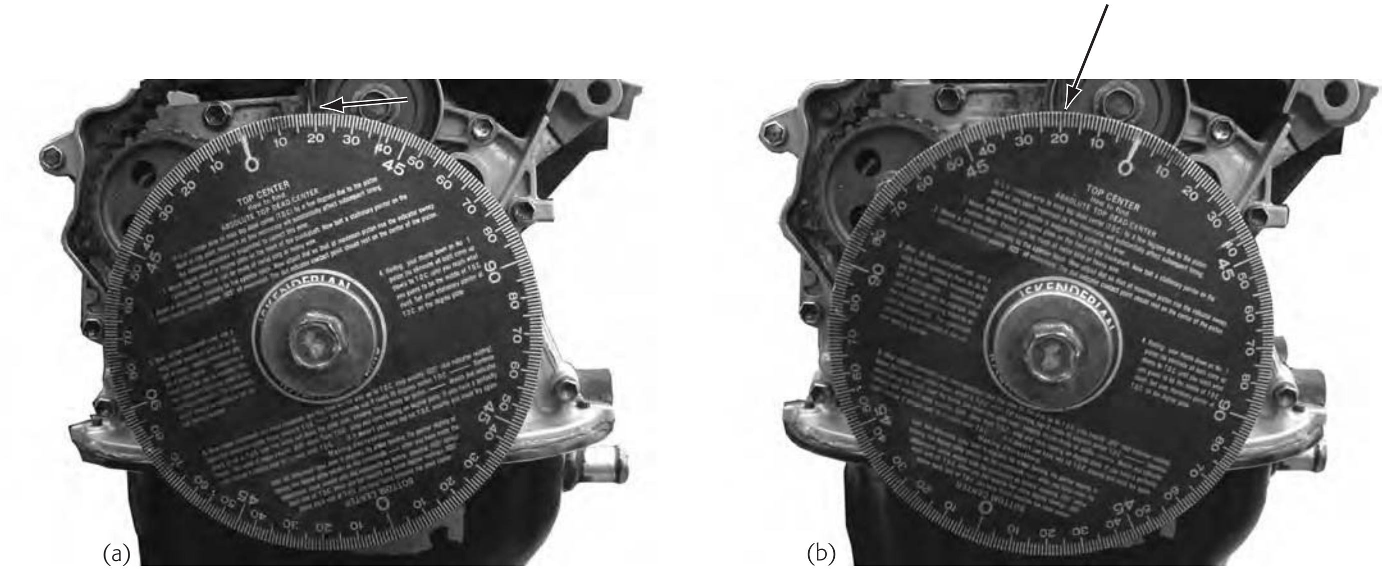


FIGURE 10.62 (a) Rotate the crankshaft until the piston hits the stop. Note the reading on the degree wheel. (b) Rotate the crank the opposite direction until the piston hits the stop again. TDC is exactly between the two degree wheel readings. Reposition the pointer so it exactly represents TDC. *(Courtesy of Tim Gilles)*

- Install a solid lifter in the lifter bore and mount a dial indicator so it can read cam lobe movement from its top. A solid lifter can be made by pressing a piece of aluminum rod into the body of a hydraulic lifter (**Figure 10.64**). Another alternative is to disassemble a hydraulic lifter and take a reading off its inside using a long extension.

OHC Engines. Camshaft timing readings on OHC engines are taken after the cylinder head is installed.

FIGURE 10.63 The dial indicator is reading the piston position. *(Courtesy of Tim Gilles)*

FIGURE 10.64 A piece of aluminum rod pressed into a lifter body for reading cam timing. *(Courtesy of Tim Gilles)*

- On OHC engines without rocker arms, dial indicator readings are taken directly off the cam followers (buckets) using a dial indicator with a long extension (**Figure 10.65**).

Rocker Arm Ratio

Cam lobe lift is measured at the lifter. An engine with rocker arms, however, has a *rocker arm ratio* determined by its pivot point (**Figure 10.66**). It is usually 1.4:1 to 1.75:1 and varies depending on the manufacturer. With a 1.5:1 rocker arm, 0.300" of cam lobe lift would increase to 0.450" lift at the valve.

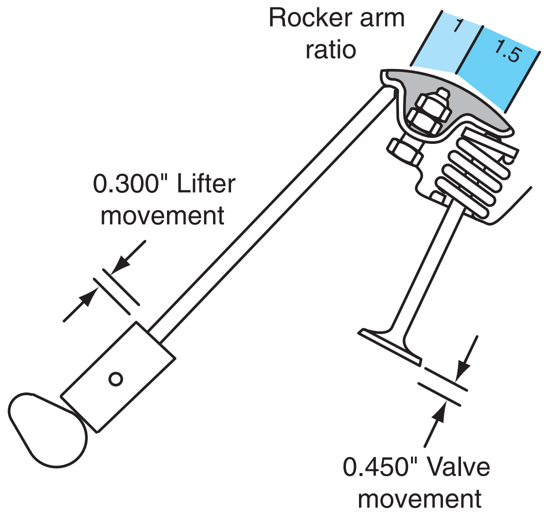


FIGURE 10.66 1.5:1 rocker arm ratio.

NOTE

At high speeds some types of rocker arms can flex, which reduces the actual lift at the valve.

Valve Retainer-to-Valve Guide Clearance. With a performance cam, there should be at least 0.125" clearance between the spring retainer and valve guide seal when the valve is fully open. Otherwise the top of the guide or bottom of the retainer will need to be machined (**Figure 10.67**).

FIGURE 10.65 Using a dial indicator to read camshaft duration from an OHC bucket. *(Courtesy of Tim Gilles)*

Piston-to-Valve Clearance. Maximum valve lift is also limited by the clearance between the valves and piston tops. Machining may be required in these areas when using high-performance camshafts. Clearance can be checked by sticking a piece of modeling clay to the top of a piston on the valve relief, where the valve comes closest to the piston. Put a drop of oil on the modeling clay so it does not stick to the cylinder head. With the head temporarily installed, rotate the crankshaft through one

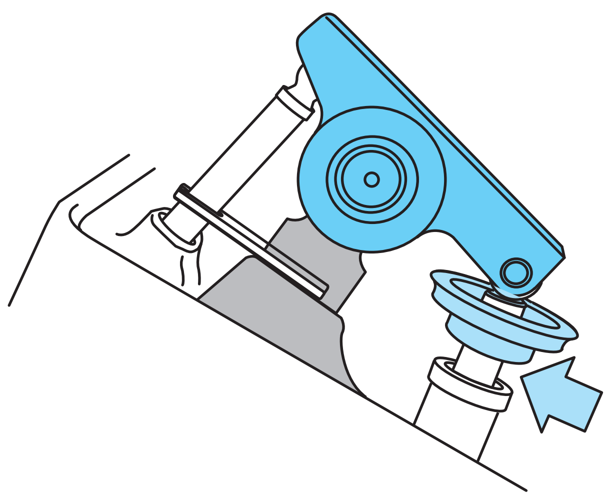


FIGURE 10.67 When a high lift cam is installed, be certain that there is at least 0.125" clearance between the spring retainer and the valve guide seal.

revolution. Remove the cylinder head and slice off a section of the modeling clay with a sharp knife. Then measure its thickness with a micrometer or vernier caliper. Typical minimum clearance is 0.080" for intake valves and 0.100" for exhaust valves. Camshaft specifications usually list net lift, which is the lobe lift multiplied by rocker arm ratio minus lash.

$$\text{Lobe lift} \times \text{rocker ratio} - \text{lash} = \text{Net lift}$$

NOTE

Some other minimum flow area in the intake manifold or the valve port can limit the flow area created by the increased valve lift.

Measuring Valve Lift

With the engine assembled, valve lift can be measured with a dial indicator. On pushrod engines, a piece of rubber hose between the end of the indicator and the pushrod will make this job easier.

Use these precautions when mounting the dial indicator:

1. Position the indicator so its plunger is aligned to follow a parallel path with the travel of the lifter or cam follower.
2. Mount it solidly, so measurements will be accurate.
3. Preload the dial indicator by at least 0.300" to allow enough indicator travel for full lobe readings. Typical lobe lift on a pushrod engine (measured directly off the cam lobe) usually ranges from 0.240" to 0.280" in stock applications.

Lift specifications are measured from the cam lobe (lobe lift) or at the valve (valve lift).

NOTE

When there is a rocker arm, its ratio will affect the reading when measuring lift at the valve.

Gross valve lift is found by multiplying the lobe lift by the rocker arm ratio. With a mechanical lash cam, net valve lift is determined by subtracting the lash specification from the gross valve lift. Most cam manufacturers use the net valve lift when listing specifications. This means the valve lash and rocker arm ratio must be taken into consideration when comparing the spec to actual lobe lift.

Preventing Lifter Pump-Up Damage

To prevent damage from hydraulic lifter pump-up (see Chapter 9), some technicians simply tighten the adjusting nut from ¼ to ½ turn past zero lash. Although the engine will operate fine, there are some problems with this procedure.

- It does not allow as much margin for wear and temperature differences as the specified procedure allows.
- When a cold engine is started after sitting all night, it will take more time for the oil pump to fill the lifters that have emptied.

If the lifter "pumps up" during high rpm, the lock ring can be knocked out. Higher-quality lock rings than stock should be installed, if the lifters are adjusted in this manner.

Duration

Longer duration raises the rpm at which maximum power is produced. Cams with short duration perform better in low and midrange applications. The low-end torque that results is especially suited for use with automatic transmissions and off-road vehicles.

NOTE

An RV cam is designed for use in recreational vehicles, like off-road vehicles whose engines require the most power at low rpm. Although a motor home is sometimes called an RV, an RV cam is not designed for use in a motor home. The better choice for a motor home camshaft is one that is most efficient at highway speeds.

Importance of Valve Lash

With adjustable lash camshafts, valve adjustment is very important. Remember from Chapter 9 that these cams have a clearance ramp at the beginning and end of each lobe to cushion the opening and closing of the valve. A change of 0.001" in valve lash will result in approximately 3° of duration change.

Measuring Duration

Duration is measured in one of two ways, the results of which are substantially different from one another. One method measures duration from the time when the cam lobe begins to move the valve; the other method measures duration after the valve has been opened to a specified amount. This second method takes into consideration the steepness of the cam lobe.

Rate of Lift

Two cam lobes with identical duration can have substantially different performance results because of the steepness of the cam lobe. This difference is called *rate of lift*. **Figure 10.68** is an exaggerated sketch of two cam lobes with the same lift and duration but very different rates of lift. The limiting factor with regard to rate of lift is increased engine wear and durability.

SAE Duration Measurement

Automobile manufacturers use the Society of Automotive Engineers (SAE) method to specify camshaft duration. SAE specifications are measured after the valve has lifted 0.006", very soon after the valve starts to move.

Performance Camshaft Duration Measurement

Performance camshafts are usually measured for duration at 0.050" lift. This is some time after the valve starts to open, which helps take into account the rate of lift, or steepness of the ramps. An SAE measured cam will have approximately 40–50° more duration than a cam measured at 0.050" lift. Here are example duration readings from one flat tappet hydraulic camshaft:

Advertised duration: Intake 270°/Exhaust 290°
Duration measured at 0.050": Intake 222°/ Exhaust 234°

This camshaft is called a *dual pattern* cam because it has different lobe profiles for the intake and exhaust lobes, with the exhaust lobe having longer duration. This can present a problem when attempting to phase the camshaft because a split overlap is not likely. This is discussed later in the section on lobe center angles.

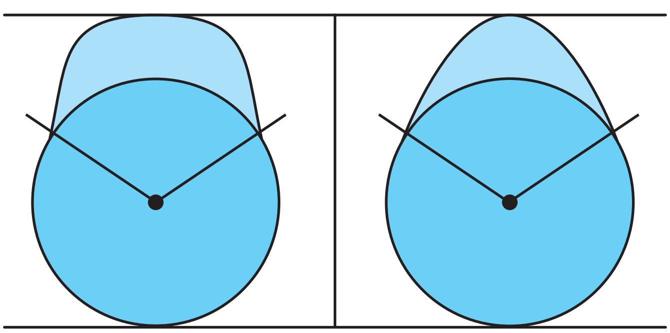


FIGURE 10.68 Both of these cam lobes have the same lift and duration, but they have different rates of lift.

Asymmetrical Camshafts

Some camshafts have lobes that are ground the same on the opening and closing ramps. Many of today's cams are asymmetrical, or nonsymmetrical; they are ground differently on the opening and closing sides of the cam lobe. Measuring the amount of valve opening at TDC on these cams will not necessarily indicate split overlap.

Base Circle Runout

The base circles of the cam lobes must be perfectly on center with the cam journals. Manufacturers attempt to keep this base circle runout specification to less than 0.001". Although base circle runout is somewhat rare, when it occurs the result can be lifters that pump up or valves that cannot be adjusted. The up-and-down motion caused by base circle runout creates clearance in a hydraulic lifter. This causes the lifter to pump up, eliminating the clearance. Runout is checked with a dial indicator and should not exceed 0.0015" for hydraulic lifters and 0.002" for mechanical lifters.

CAMSHAFT PHASING, LOBE CENTERS, AND LOBE SPREAD

Camshaft designers vary the lobe center angle, lift, duration, and cam phasing in order to come up with the best camshaft for the application. It is the engine builder's job to put the camshaft in the correct position so it can operate as designed. The following discussion will help you understand the terms and their applications.

Determining Camshaft-to-Crankshaft Phasing

Verification of the correct cam-to-crank phasing is a key part of performance engine building. When the dowel hole for the cam sprocket or the key groove for the crankshaft sprocket is slightly out of tolerance, the camshaft timing will not be as designed. In normal passenger car use, this is seldom a problem, but for performance purposes, it can be a key factor. Methods of correcting this problem are provided later in this chapter.

SHOP TIP

To perform a quick visual check for cam timing during engine assembly, position the number one piston at TDC on its intake stroke. If the intake lifter is higher in its bore than the exhaust lifter, the cam is advanced.

Performance camshafts are supplied with a specification card that lists the camshaft designer's recommended opening and closing timing points and the amount of lobe lift (**Figure 10.69**). There are three methods used for measuring valve opening and closing points. Be certain that you know which system your cam manufacturer is using. The most common method uses the opening and closing readings when the valve is open by 0.050". Another procedure is the intake centerline method. Sometimes the specifications are given at 0.006" (SAE), but some cam manufacturers use other figures, such as 0.004".

To verify cam phasing using opening and closing figures at 0.050" lift, measurements are taken from the degree wheel when the valve is 0.050" open, and then again 0.050" before it returns to zero. If you accidentally go past the 0.050" point during valve closing, back up at least 0.100" to remove cam drive slack and try again.

FIGURE 10.69 Typical specification label from an aftermarket performance camshaft. *(Courtesy of Tim Gilles)*

Cam Lobe Centerline

Cam manufacturers sometimes use another method for determining cam phasing in relation to the crankshaft. It is called the *intake centerline* method because it refers to the centerline of the cam lobe (**Figure 10.70**). Finding the centerline of the cam lobe is similar to determining the exact location of TDC. The intake lobe center can be found using a degree wheel and dial indicator, much like checking for exact TDC. The cam lobe has a relatively flat nose and the intent of this procedure is to find its exact center. The indicator numbers in the following example are arbitrary; the exact numbers are not important. Here is the procedure:

- Set up a dial indicator to read off the intake lifter or bucket. The indicator must be parallel to lifter travel.

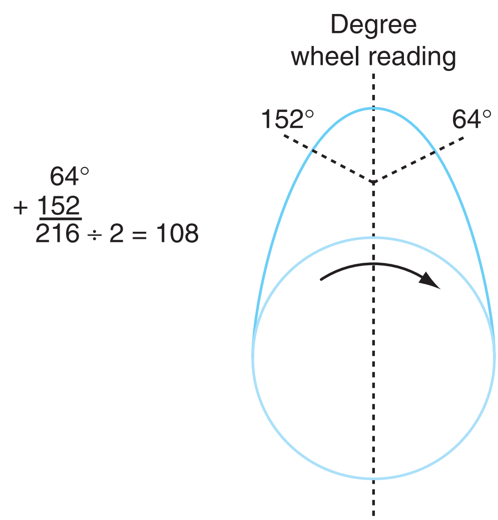


FIGURE 10.70 This cam lobe has a 108° centerline.

- To find maximum lift, rotate the crankshaft in its normal direction of rotation (usually clockwise) until the dial indicator needle stops increasing and starts to move back the other direction. Bring the crankshaft back to the neutral position at the top of the cam lobe. Then rotate the face on the indicator until it reads "zero."
- Turn the crankshaft backward until the dial indicator reads 0.100". Then turn the crankshaft forward again until the indicator face reads exactly 0.050". Note the degree wheel reading at the pointer and write it down. In the example shown in Figure 10.70 the reading is 64°.
- Rotate the crankshaft until it goes past the full valve open position and the indicator needle reading decreases once again. Continue rotating the crankshaft in the same direction and stop when the indicator face reads exactly 0.050". Write down the degree reading once again.

To find the centerline of the maximum lift of the intake lobe as it relates to the crankshaft, add the two degree readings together and divide by 2. Most intake centerlines are between 104° and 116° ATDC. The cam lobe shown in the example has a centerline of 108°.

NOTE

The intake centerline method is accurate on camshafts with symmetrical cam lobes. With asymmetrical lobes, it might be necessary to change your cam timing after a test run. Results of advancing or retarding the cam are discussed later in the chapter.

Lobe Separation Angle/Lobe Center Angle

The centerline is also used in determining the spread between the maximum lift points at the centerlines of the intake and exhaust lobes. This angle is called the *lobe separation angle* (**Figure 10.71**), also referred to as the **lobe center angle** (LCA). The term *lobe center angle* sometimes causes confusion because it so closely resembles the term *lobe center*. We refer to it as LCA. This is the one camshaft angle that is measured in camshaft degrees rather than crankshaft degrees, because it deals with the lobe-to-lobe distance and has nothing to do with the crankshaft.

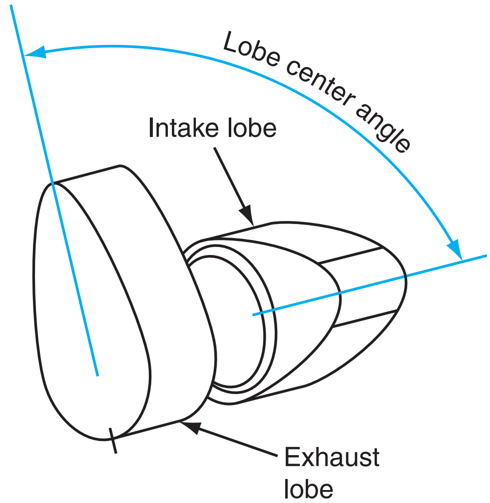


FIGURE 10.71 Lobe centers or lobe separation angle.

To calculate the LCA, the centerlines of the intake and exhaust lobes are added together and then divided by 2. For instance, if the intake lobe centerline is 108° ATDC and the exhaust centerline is 118° BTDC, the lobe center angle is 113° (**Figure 10.72**).

Two camshafts will be compared in the following example. The lobes are asymmetrical, but the duration of all lobes on both cams is 270°. The camshaft shown in the sketch for **Figure 10.73a** shows the following profile:

Intake opens 22° BTDC and closes 68° ABDC.

Exhaust opens 74° BBDC and closes 16° ATDC.

The lobe center angle is 114° and valve overlap is 38°.

The camshaft shown in the sketch for **Figure 10.73b** has the following profile:

Intake opens 26° BTDC and closes 64° ABDC.

Exhaust opens 70° BBDC and closes 20° ATDC.

The lobe center angle is 108° and valve overlap is 46°.

Figure 10.74 compares the LCAs for the two camshafts. You can see that there is more valve overlap on the camshaft with the tighter LCA. In comparing the performance of these two camshafts, the top cam in Figure 10.74 would have a smoother idle and better low-end performance. The other camshaft would suffer from poor throttle response and lower torque at lower rpm (less than 3000 rpm, for example). It would have very good power at higher engine speeds, due to its ability to take

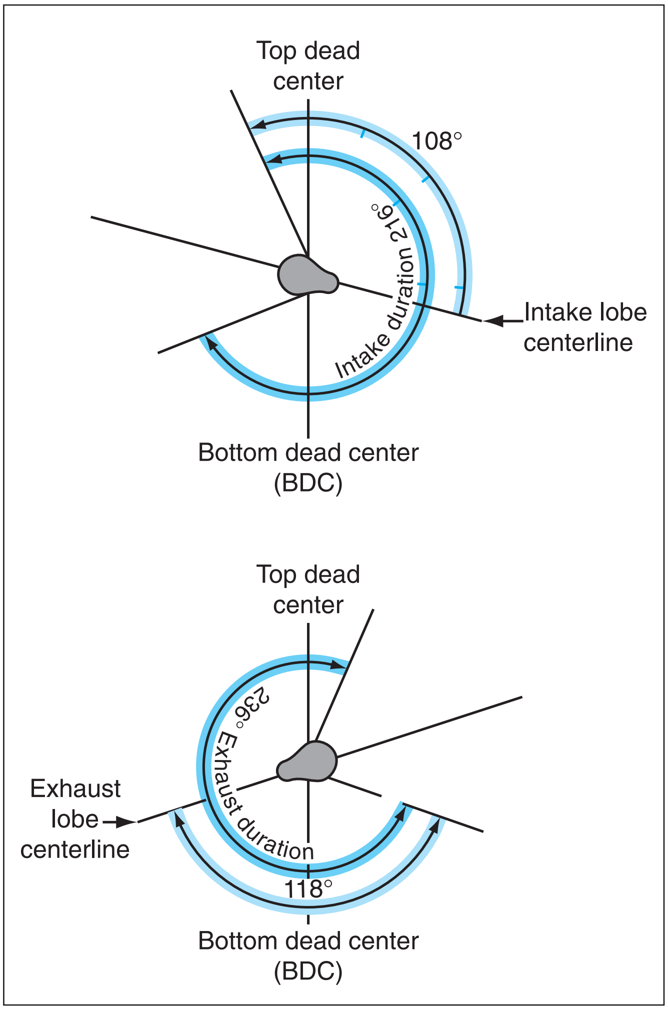


FIGURE 10.72 To determine the lobe separation angle, add the intake and exhaust lobe centerlines and divide by 2.

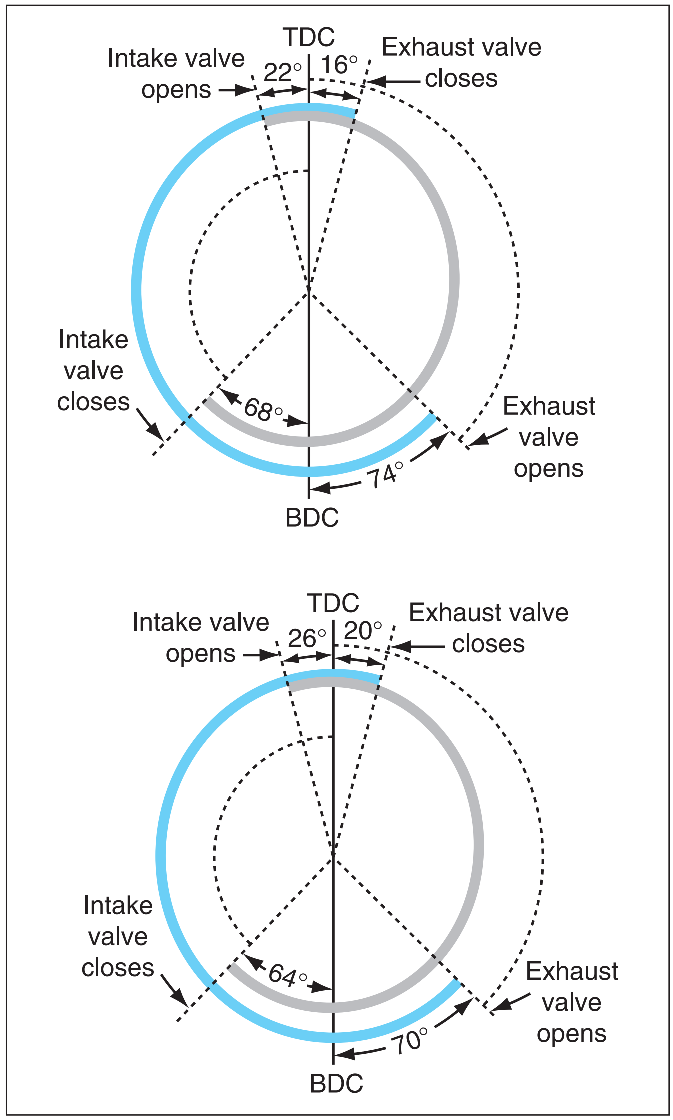


FIGURE 10.73 Two asymmetrical cam lobes. Although the lobes have different cam timing, they all have 270° duration.

advantage of the inertia of the fuel charge to help fill the cylinder.

NOTE

On a single camshaft, cast with alternating intake and exhaust lobes, the lobe centerline is obviously not variable except by grinding the camshaft. But with separate intake and exhaust camshafts, this angle can be adjusted.

Looking at Figure 10.74 you can see that as the LCA increases, overlap decreases. A cam with lobe centers at a lower angle has more overlap. For instance, a cam with an LCA of 108° has more overlap than a cam with an LCA of 114°. One of the cams shown in Figure 10.73 has 46° of valve overlap, whereas the other has 36° of overlap. If an engineer designs a new cam, leaving the lobe centers the same but increasing the duration, the cam will have more overlap.

When a cam is ground to a split overlap, this means that the intake and exhaust valves are equally open at TDC.

- If the intake valve is open more at TDC than the exhaust, the cam is advanced.
- If the exhaust valve is open more at TDC, the cam is retarded.

Most automotive applications have LCAs between 105° and 115°, although there have been some full-race big blocks (big bore and long stroke) with lobes spread as tightly as 95°. A typical street

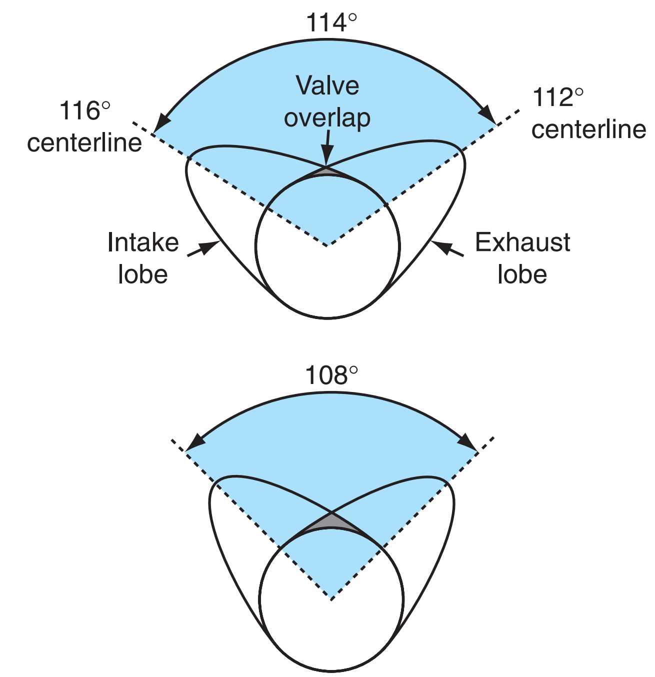


FIGURE 10.74 Cam lobes of equal duration but with unequal lobe separation angles have different amounts of valve overlap.

cam would have a LCA of about 110°, whereas a high gas mileage or RV cam would be in the neighborhood of 112–115°.

Advancing or Retarding the Camshaft

To determine whether the cam is advanced or retarded, compare the LCA to the intake centerline. If the intake centerline is less than the LCA, the cam is advanced by that number of degrees. For instance, if the intake lobe centerline is 110° and the LCA is 115°, the cam is advanced 5°.

NOTE

Most chain driven cams are ground from 4° to 6° advanced for better low-end torque and to compensate for timing chain stretch.

The results of changes in cam timing are as follows:

- Piston-to-valve clearance will have to be carefully checked because the valve will be opening sooner or later. For instance, advancing the cam timing increases the exhaust valve clearance.
- Advancing cam timing raises pressure in the cylinder because the valves close earlier. This improves low and midrange torque at the expense of high-end performance.
- Advancing a cam gives much more in low-end performance than it takes from the high end.
- Retarded cam timing improves high rpm power. Opening the intake valve longer increases high-end performance, but it kills low end.
- Retarded cam timing increases the intake valve-to-piston clearance.
- Incorrect cam timing can cause an engine to run hot. If the intake and exhaust valves do not open and close at the correct moments, increased pressure in the cylinder results and the engine can work against itself. This is especially true with the RV or economy cams.

NOTE

Do not use an RV cam in a high-compression engine. If you have a compression ratio of more than 9:1, be very careful in cam selection.

High-Performance Camshaft Considerations

Unless it has variable valve timing, an engine with a high-performance, high-overlap cam will idle rough and have increased emissions. Longer duration cams require wider lobe centers for improved idle quality.

NOTE

The performance of a camshaft depends on the stroke of the engine also. Sometimes the same cam is used for different engine applications. A stock camshaft used in a long stroke engine might be a performance cam when used in a short stroke engine.

General Camshaft Recommendations for Street Use

For street use, reasonable fuel economy and performance are necessary. The following are general parameters to follow:

- A limit of 6500 rpm will provide acceptable durability and performance.
- A limit of 0.550" valve lift will prevent excessive valve guide wear.
- Valve overlap
  - 40° overlap = street
  - 75° overlap = dragstrip
- Duration parameters are as follows:
  - 285° = street/strip
  - 285–295° = mild race
  - 295° or more = full race

NOTE

A higher compression ratio (10:1 or higher) helps to offset some of the loss of cylinder pressure at low speed that more overlap causes. However, compression this high can cause detonation, calling for compromise once again. Compression ratios for street use on service station gasoline are limited to about 9:1. Many late-model vehicles have detonation sensors that can retard timing almost instantly in response to vibrations caused by abnormal combustion.

Methods of Fine-Tuning Cam Timing

Sometimes the cam phasing needs to be changed. This could be because the camshaft dowel (**Figure 10.75**) and/or the crankshaft key was not accurately machined during manufacturing. Inaccuracies or tolerance stacking sometimes occur. Also, a change in cam phasing might be desired when "dialing in" a race engine. Changing cam timing on a race engine should be within 6° of the specified setting, or a different camshaft should be used.

Cam phasing can be adjusted using one of several methods, including multiple keyway crank sprockets, offset crank keys, offset bushings for the camshaft sprocket, and adjustable camshaft sprockets. To check for proper positions of the timing marks, follow the procedures for locating TDC.

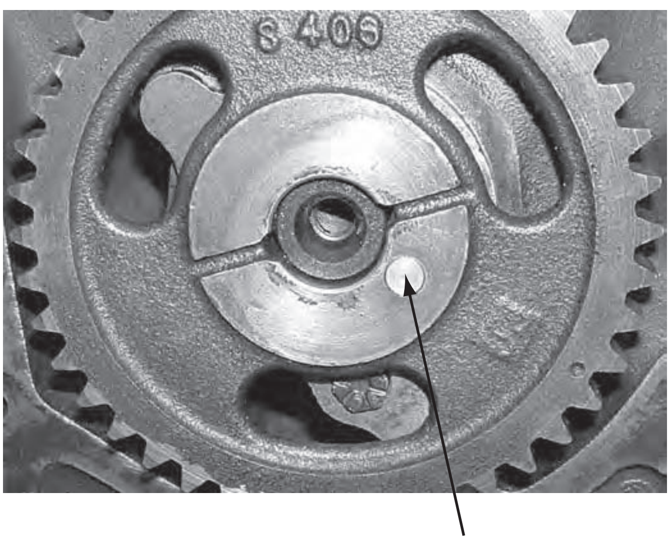


FIGURE 10.75 Manufacturing tolerance errors cause inaccurate camshaft timing when cam or crank locating keys or dowels are off to one side or the other. *(Courtesy of Tim Gilles)*

Multiple Keyway Sprockets. Crankshaft sprockets and gears with three keyway slots are available (**Figure 10.76**). The slots are marked standard, 4° advance, and 4° retard. Each mark and keyway uses a different timing mark designation. In the illustration, the 0° mark on the sprocket is used when the 0° keyway is selected; the +4° mark is used with the +4° keyway and so on. Other manufacturers use different marks. One of them uses a triangle for the advanced setting and a square or rectangle for the retarded setting, with 0 for the 0° TDC mark. Some sprockets have up to nine different keyways with different indices.

NOTE

A shortcoming of using multiple keyway sprockets for adjusting cam timing is that the degree wheel must be removed in order to reposition the sprocket. If you want to verify the corrected cam timing, TDC must be reset in relation to the degree wheel once it has been reinstalled.

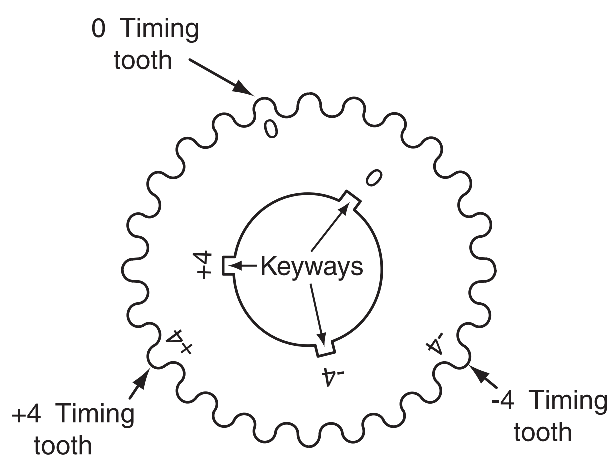


FIGURE 10.76 A timing sprocket with multiple keyways provides options for fine-tuning the cam timing.

Offset Keys. Offset crank keys are another means of adjusting cam phasing. These are not as popular an option because they are somewhat fragile. Also, TDC must be reset in relation to the degree wheel after the damper has been reinstalled.

Offset Bushings. Offset bushings are available for high-performance camshafts (**Figure 10.77**). To use these, the mounting holes on the cam sprocket are drilled oversize to allow the sprocket to move in relation to the cam, and the hole in the sprocket for the alignment dowel pin is drilled for installation of the bushing. To change cam timing by 1°, you will need to move the cam dowel by about 0.005". To advance the cam, the thicker side of the bushing goes toward the top. To retard the cam, the thicker side of the bushing goes toward the bottom.

Adjustable Cam Sprockets. **Figure 10.78a** shows an aftermarket cam sprocket with an adjustment provision available for some OHC engines. To adjust the cam phasing, loosen the screws and turn the camshaft (**Figure 10.78b**).

Some OHC engine manufacturers use cam sprockets with three different timing marks. These are for correcting cam timing to compensate for timing chain slack due to chain stretch or a surfaced cylinder head (which will retard cam timing on an OHC engine).

VARIABLE VALVE TIMING

The camshaft profile in conventional engines has always been compromised between low and high rpm demands. High-speed high-performance engines call for very different cam lobe profiles than low rpm four-wheel-drive off-road vehicles. Variable valve timing (VVT) has become commonplace in recent years. With computer controls, it is a relatively inexpensive way to significantly increase horsepower and control emissions. Power and torque can be improved across a wider rpm range. Increased torque at low rpm and increased power at higher rpm are the result. Typical power increase can be 25%. Horsepower with these engine designs has climbed above 100 horsepower per liter and is still climbing.

There are two basic types of VVT systems. One type varies the cam-to-crank phasing and also the lift and duration. The other system varies valve timing only. A third type is a combination of the two.

FIGURE 10.77 Various offset bushings for adjusting cam phasing. To advance the cam, position the thick side toward the top. *(Courtesy of Tim Gilles)*

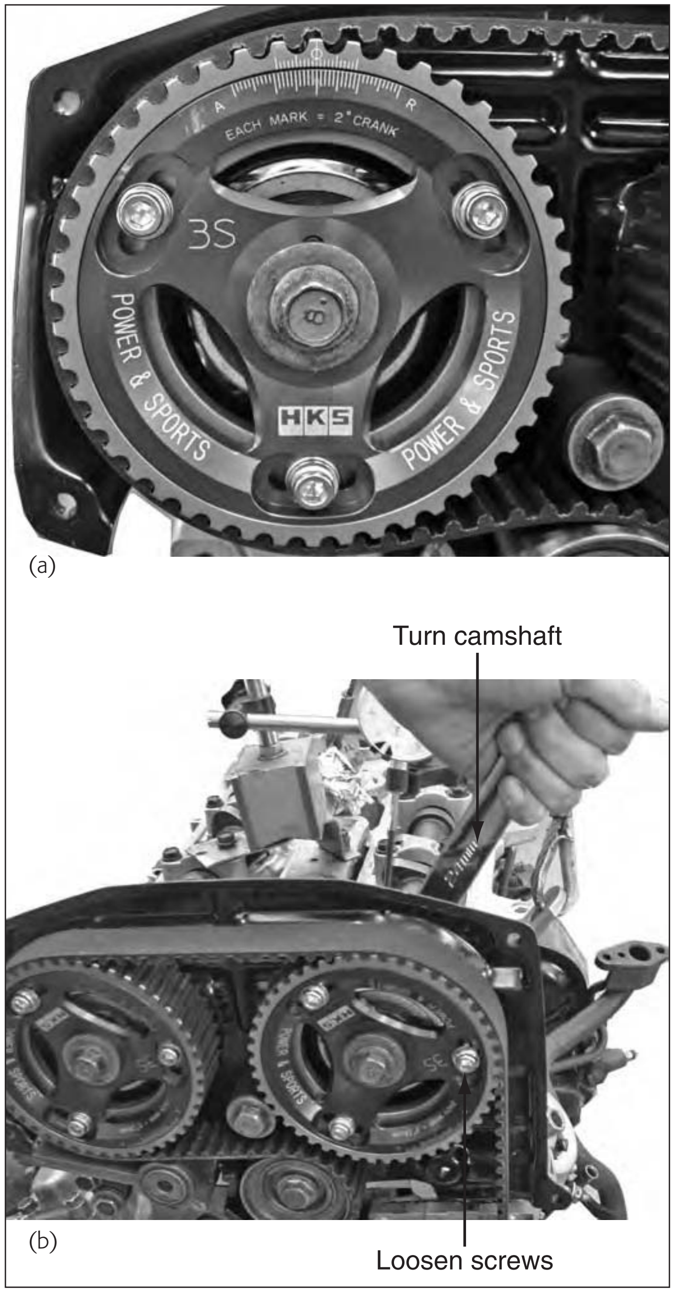


FIGURE 10.78 (a) An adjustable cam sprocket used on a dual overhead cam engine. (b) After loosening the screws, the camshaft can be turned to change the cam phasing. (*Courtesy of Tim Gilles*)

Most manufacturers now use VVT. Based on your earlier study of camshaft timing and duration, the following systems are used to illustrate concepts you should understand.

Variable Valve Timing and Lift

The *variable timing and lift* system, pioneered by Honda in 1988 and standard on most of their models, is called VTEC. The letters mean "variable valve timing and lift electronic control." This is a simple and effective system in which each pair of valves has three cam lobes. Two of the lobes operate the valves at low rpm and the third comes into play at higher rpm (approximately 4500–6500) (**Figure 10.79**). The low rpm lobes are mild, giving good low-end drivability. When the high rpm lobe takes over, its more aggressive profile locks onto the two low rpm rocker arms (**Figure 10.80**) and overrides their operation (**Figure 10.81**). Mitsubishi, Nissan, and Toyota have similar systems of two-stage variable valve lift and duration.

Variable Camshaft Phasing

Some VVT systems vary only the timing, not the lift and duration like the VTEC version. A sophisticated attachment on the cam sprocket advances and retards the cam using either a vane or piston and gear assembly operated by oil pressure, controlled by the PCM. This can be accomplished with either the intake or the exhaust valve, or both. For performance enhancement, changing the intake valve timing affects the torque characteristics of the engine, whereas changing the exhaust valve timing does not. Variable timing of the exhaust lobe is used for the control of emissions and fuel efficiency. Most systems control the intake valve only. Simpler systems have only two or three fixed phasing angles. More complex systems are continuously variable and have a position sensor.

Nissan's NVTCS (Nissan valve timing control system) was first available in 1990. This system varies the intake cam timing only, using a spring-loaded helical gear located between the cam sprocket and the intake cam (**Figure 10.82**). A solenoid and control valve at the opposite end of the cylinder head controls oil pressure (**Figure 10.83**). It moves a helical gear, which can advance the cam timing 20°. When the computer cuts off oil pressure to the camshaft, the cam is returned to its initial position by a spring.

The camshafts are ground for high-performance operation, so changes in cam timing are made to improve low-end and idle performance. The computer repositions the cam in response to sensed input on speed, temperature, load, and intake airflow and throttle position. At midrange rpm, the computer advances the cam under high load. At high rpm and low load, it retards the cam.

Mercedes introduced VVT in 1990 as well. It is similar to Nissan's in that it moves the intake cams only, although it retards and advances the cams. The cams are retarded below 2000 rpm to minimize valve overlap and improve idle. Between 2000 and 5000 rpm the cams are advanced, which closes the intake valve sooner, increasing the compression ratio and improving torque. At above 5000 rpm the cams are retarded, closing the intake valve later to increase volumetric efficiency.

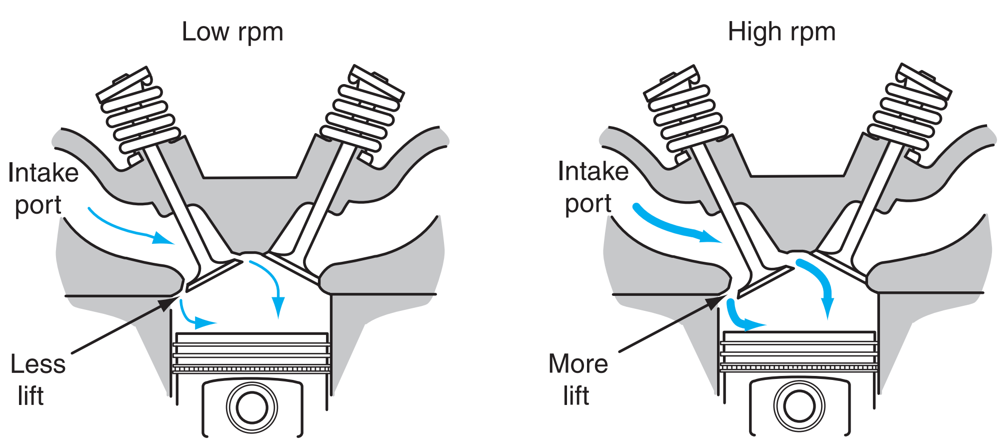


FIGURE 10.79 Variable valve timing causes changes to duration between low and high rpm operation.

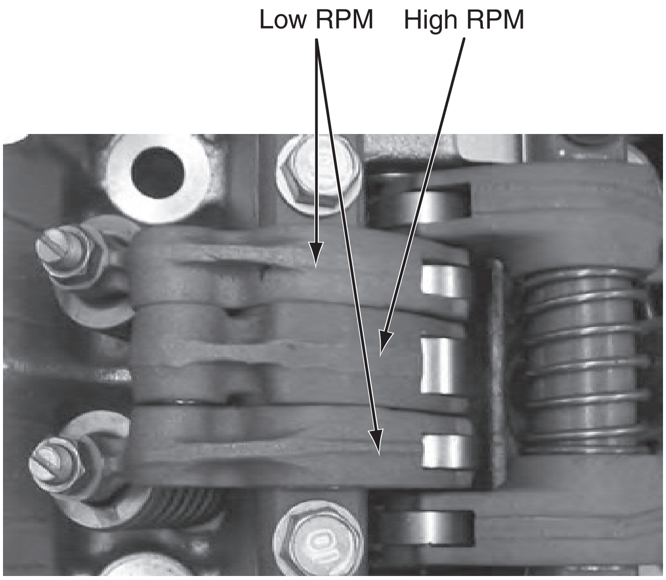


FIGURE 10.80 When the high rpm lobe takes over, its more aggressive profile locks onto the two low rpm rocker arms on the outside. *(Courtesy of Tim Gilles)*

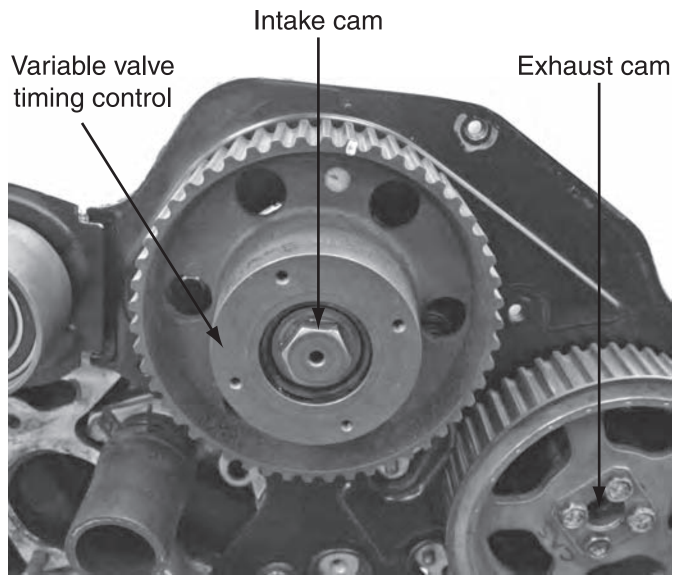


FIGURE 10.82 A spring-loaded helical gear between the cam sprocket and intake camshaft varies the intake cam timing. *(Courtesy of Tim Gilles)*

One of Ford's variable cam timing designs used on Modular V8s moves a single overhead cam, varying both intake and exhaust together. PCM controlled solenoids move a cam timing mechanism within the sprockets. The engine uses two intake valves and one exhaust per cylinder. A second intake valve usually kills low rpm performance so like many other manufacturers, Ford blocks intake manifold flow through one of the intake valves under light load conditions.

Variable Intake and Exhaust Timing

One advantage to varying timing on both cams independently is that valve overlap can be changed. This type of VVT is commonly found on dual overhead cam engines. Varying the overlap period allows for better high-speed performance, combined with a smooth idle and lower exhaust emissions. More valve overlap at medium speed eliminates the need for an EGR valve and reduces

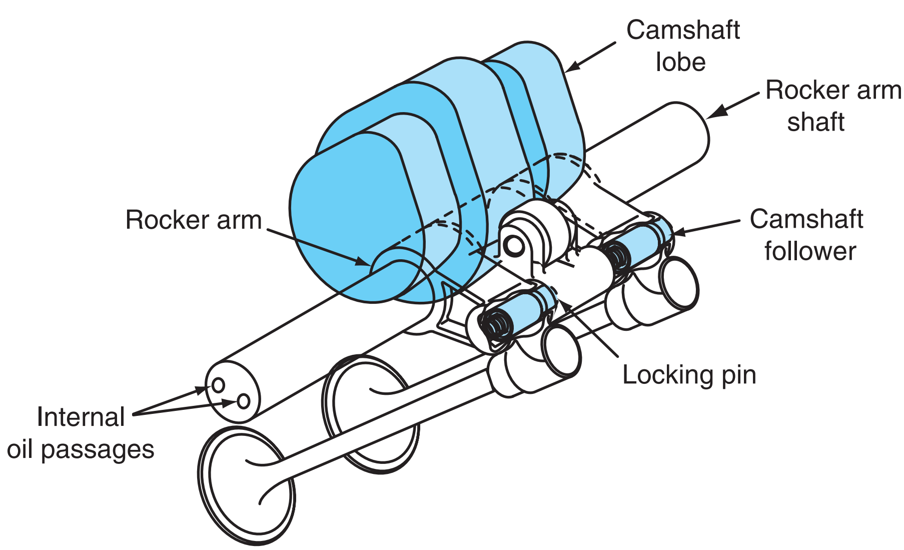


FIGURE 10.81 Variable valve timing and lift. At high speed, the more aggressive lobe in the center takes over control of valve operation.

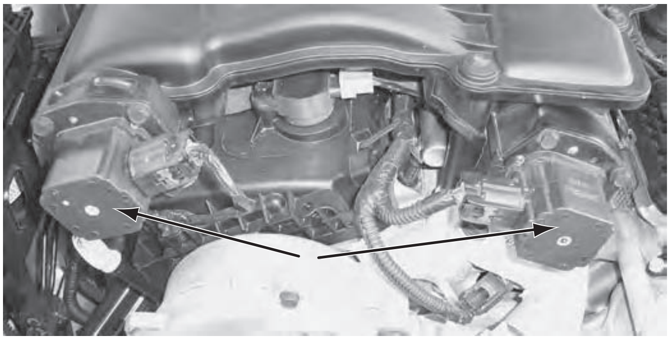


FIGURE 10.83 Solenoids on the ends of the camshafts control oil pressure to vary the cam-to-crank phasing. *(Courtesy of Tim Gilles)*

pumping loss. VVT can be also be used to make an engine easier to crank during starting.

BMW varies both intake and exhaust cam timing with its Double VANOS system. "VANOS" means *variable onckenwellen steuerung*. Toyota has a similar system. Manufacturers use several different ways to advance and retard the cams. Two methods of hydraulically varying the cam timing are shown in **Figure 10.84**. **Figure 10.84a** shows rotary vane actuation. **Figure 10.84b** shows how a piston in the center of the cam sprocket moves, changing the relationship between the camshaft and its sprocket.

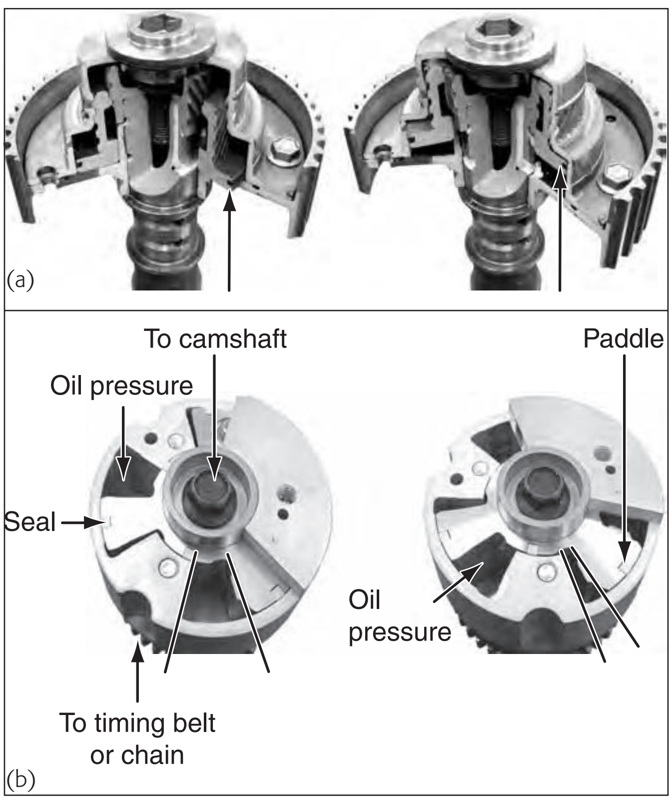


FIGURE 10.84 (a) A rotary vane actuator. (b) Hydraulic movement of the center piston causes the cam to twist.

NOTE

Engine maintenance has become even more important on engines with VVT. Regular oil changes with high-quality, low-viscosity oil are mandatory. Lack of maintenance can result in sludging of the oil galleries and failure of the VVT mechanism to operate.

Porsche and Toyota drive only the exhaust cam with the crankshaft. The intake cam is turned by the exhaust cam, allowing for variations in cam timing. Toyota varies cam timing by up to 60°. Earlier Porsches varied the position of the timing chain guide to vary camshaft phasing. Later models use hydraulic actuation similar to other VVT systems.

Variable Timing and Lift + Cam Phasing

A more complex VVT system combines VVT and lift with variable camshaft phasing (**Figure 10.85**). These systems are used on both intake and exhaust valves. They have continuously variable cam phasing and two-stage variable valve lift and duration. This is more expensive but improves torque through a wider rpm band. Porsche's VarioCam Plus, Toyota's VVTL-I, and Honda's i-VTEC (the "i" stands for intelligent) are examples of this technology. Some of the systems vary only the intake side.

More advanced systems that use computer-controlled valve actuation, like the BMW Valvetronic system, vary the valve lift and duration throughout the entire rpm range. There is no longer a throttle valve for load adjustment. Airflow is varied by the amount of valve lift, which is controlled using an eccentric valve shifting mechanism (**Figure 10.86**).

Opening Valves Using Solenoids

Some manufacturers have developed prototype variable duration systems that replace the cam and cam drive with electric solenoid actuators that work on rockers or buckets to open the valves. Valve opening, controlled by a computer, is completely independent of piston position. In the same manner that fuel injectors control fuel flow, longer valve open time can be programmed to occur with increasing engine rpm.

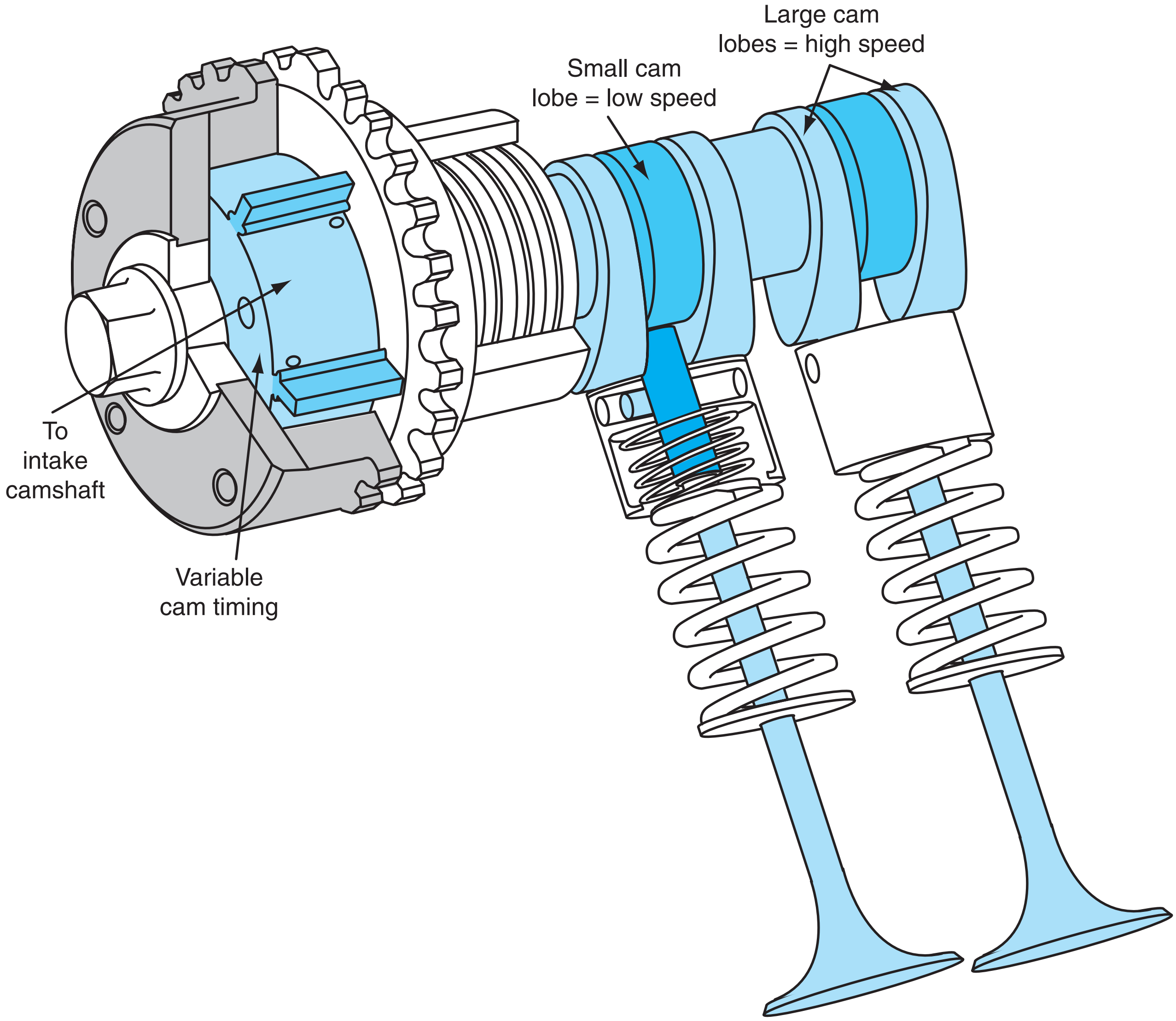


FIGURE 10.85 Porsche's VarioCam Plus varies the cam phasing and also provides a high lift and duration performance position. (*VARIOCAM is a registered trademark of Dr. Ing. h.c.F. Porsche AG. Used with permission of Porsche Cars North America, Inc. and Dr. Ing. h.c.F. Porsche AG. Copyrighted by Dr. Ing. h.c.F. Porsche AG.*)

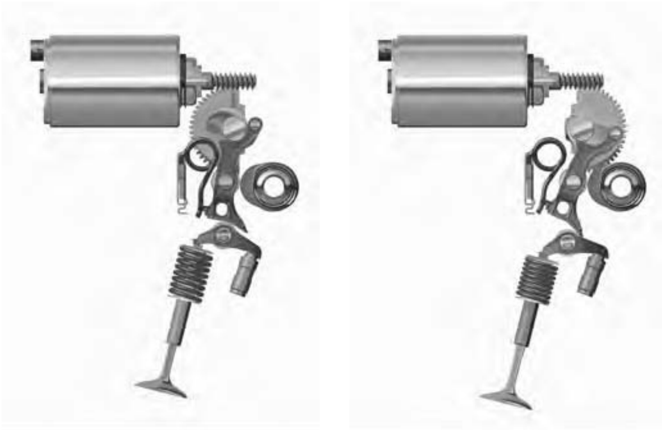
This is a technology that manufacturers hope to perfect. On the downside, larger electrical systems are required for these modifications. Vehicles equipped with this system require at least a 36-volt battery and 42-volt charging system. There is also the problem of how to close the valves *gently* 25 times per second at 3000 rpm, or even 50 times per second at 6000 rpm. On an engine with a camshaft, the shape of the cam lobe takes care of that. The valve shuts very fast but slows down just before it seats. Electronic controls are used to solve this problem.

Maximum rpm is also a concern. High-current solenoids have a difficult time working fast. It is hoped that the valves will be able to open so fast that midrange performance will be what high rpm performance is now.

This system allows interesting possibilities such as dynamic braking and shutting down cylinders for better fuel economy. These engines are also capable of higher rpm than conventional engines.

ACTIVE FUEL MANAGEMENT/ DISPLACEMENT ON DEMAND

Active fuel management (AFM), also known as displacement on demand (DOD) is one means of increasing fuel economy in larger engines. Several manufacturers, including Honda, GM, and Chrysler use this concept. General Motors tried a similar idea



Minimum lift | Maximum lift

FIGURE 10.86 BMW's variable valve lift system. (*Courtesy of BMW of North America, LLC*)

with Cadillac in 1981 on a system that switched between four, six, and eight cylinder operation. Today's system, which became more common beginning in 2005, uses existing computer controls, which are much more sophisticated and powerful, to make seamless shifts between eight cylinder and four cylinder operation. Using electric solenoids, the computer controls the deactivation and reactivation of four of the cylinders' intake and exhaust valves. Electronic throttle opening, fuel injection, and spark advance are also controlled in response to sensor inputs. Valve activation is stopped for four of the engine's eight cylinders nearly instantaneously, within one to two revolutions of the crankshaft (40 milliseconds/0.04 second).

Honda uses deactivation of the VTEC rocker arms to disable cylinders. Chrysler and GM DOD pushrod engine systems use a specially designed Eaton hydraulic lifter with a spring-loaded locking pin (**Figure 10.87**). Four solenoids control engine oil pressure to dislodge each lifter's activating pin, causing one section of each lifter to collapse into the other like a telescope. The deactivating lifter acts like a spring when disabled. Its bottom follows the contour of the camshaft, but the top does not move the pushrod so the valve remains closed. Although the pistons move up and down, no air or fuel enters the cylinders and combustion does not take place. When hydraulic pressure is bled off, the locking pin latches the two parts of the lifter together to provide normal valve activation. At first glance, it appears that power would be lost when the piston pushes against the trapped air in the cylinder. But with the valves closed, the air is compressed like a spring. It takes energy to compress the air, but when the compressed air expands again, the energy is retrieved.

Under normal light load operation with all eight cylinders operating, the throttle plate is nearly closed and the engine operates inefficiently, with greater pumping losses. An eight cylinder engine does not always need all of its cylinders to produce sufficient power to move the vehicle. With DOD,

FIGURE 10.87 A displacement on demand engine uses special valve lifters to disable cylinders in response to computer commands. (© DaimlerChrysler Corporation)

VINTAGE ENGINES

Desmodromic valvetrains use two cam lobes for each valve, one to open the valve and the other to close it. There is no valve spring so the problem of valve float at high speed was eliminated. Desmodromic valves were used initially on Ducati motorcycles; Mercedes Benz and Maserati also had some racing engines. Increased maintenance and noise are problems associated with desmodromic valves.

the outer two cylinders in one bank and the inner two cylinders in the other bank are disabled. As a result, the throttle plate is opened further and fuel efficiency increases.

Power and Power Measurement

As you do your research on improving engine performance, you will find many physical principles discussed. The following section discusses work and power and all of the basic principles you will encounter.

Physical Principles of Work

The following are principles of physics used in describing engine power output. Now that you have had some fun, it is time to do some work.

Force is measured in pounds or newtons. A force can be applied in the form of a push, a pull, or a lift and is defined as any action that changes, or tends to change, the position of something. *Work* is when an object is moved against a resistance or opposing force. The formula for work is Force × Distance. The movement can be either lifting or sliding (**Figure 10.88**). Work is measured in *foot-pounds or watts*. In the metric system, work is measured in *newton-meters or joules*.

One *foot-pound* is when 1 pound is moved for a distance of 1 foot. For example, moving a 20-pound weight 50 feet results in 1000 foot-pounds of work (**Figure 10.89**). Lifting a 10-kilogram weight a distance of 1 meter results in 10 meter-kilograms of work.

The four stroke cycle can be used to illustrate work:

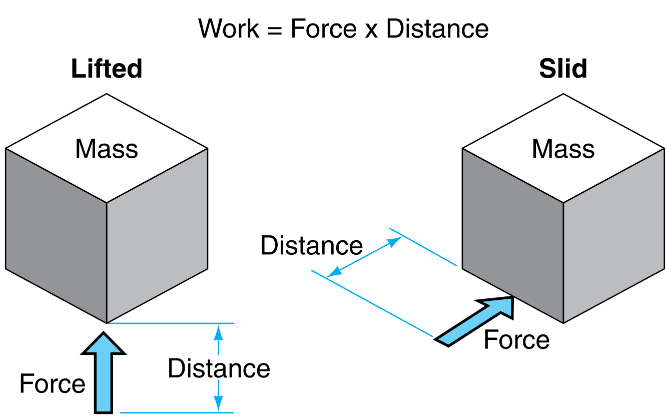


FIGURE 10.88 When work is performed, a mass is slid or lifted a certain distance.

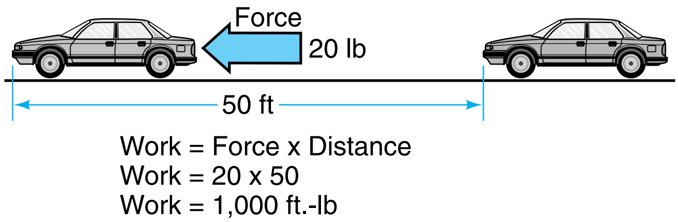


FIGURE 10.89 Work measured in foot-pounds.

- Intake stroke—the air-fuel mixture has work done on it to get it into the cylinder.
- Compression stroke—work is done as the mixture is compressed.
- Power stroke—the expanding air-fuel mixture works on the piston and crankshaft.
- Exhaust stroke—work is performed as the exhaust gas is expelled from the engine.

Energy is the ability to do work, or the ability to produce a motion against a resistance. When a weight is lifted, energy is stored in it. Dropping it performs work.

Inertia is the tendency of a body to keep its state of rest or motion. The larger the mass, the more it is effected by inertia. Inertia and energy are stored in the engine's flywheel.

When a body is in motion it has *momentum*. Momentum is a product of a body's mass and speed. A body going in a straight line will keep going the same direction at the same speed if no other forces act on it.

POWER AND TORQUE

Power is how fast work is done or how fast motion is produced against a resistance. **Torque** is the ability to make power. It is defined as the tendency of force to rotate a body on which it acts. Tightening a bolt is a use of torque (**Figure 10.90**). Torque in an engine is the amount of turning force exerted by the crankshaft (**Figure 10.91**).

NOTE

In the automotive world, the measurement of torque is commonly referred to in foot-pounds. It should actually be expressed as pounds-feet to distinguish it from work.

The definitions for torque and work are similar; both are a force being multiplied by a distance.

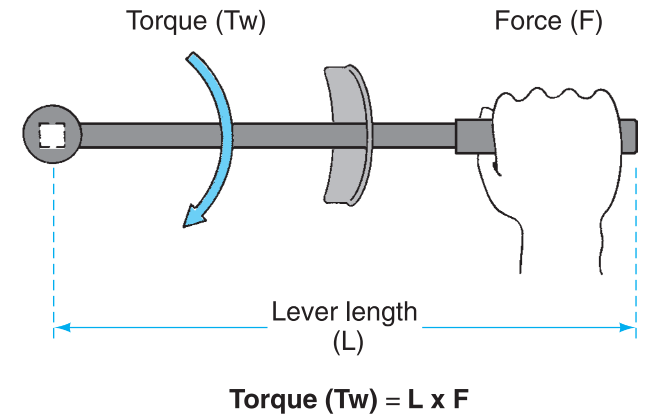


FIGURE 10.90 Tightening a bolt is a use of torque. (*Reproduced by permission of Deere & Company, John Deere Publishing, Moline, IL. All rights reserved*)

However, torque and work are very different quantities. Work is force times the distance moved (see Figure 10.89), and torque is force times leverage, which is the distance from a pivot point to the applied force (see Figure 10.90). When distinguishing work from torque, the metric unit of measurement for torque is the *newton-meter* (Nm) and the metric work unit is the *joule* (J). The English imperial system expresses torque as *pounds-feet*, whereas work is expressed as *foot-pounds*.

Engine torque varies with rpm. A force of 1 lb exerted at a distance of 1 ft. from the center of a crankshaft results in 1 ft.-lb of torque. The pulling ability of a car from a standing start depends on its engine's torque. This means that torque should be high at lower speeds.

To convert a torque reading to newton-meters:
multiply ft.-lb × 1.356

To convert a torque reading to ft.-lb:
multiply newton-meters by 0.737

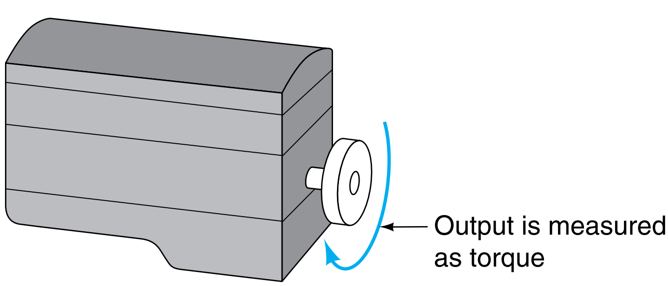


FIGURE 10.91 Torque is the amount of turning force exerted by the crankshaft.

Horsepower

Horsepower is the measurement of an engine's ability to perform work. James Watt described 1 horsepower as 33,000 foot-pounds of work per minute or the amount of power described by a horse pulling a weight of 330 pounds across a distance of 100 feet in 1 minute. One horsepower is the amount of work required to lift 550 pounds 1 foot in 1 second (**Figure 10.92**). In **Figure 10.93**, notice that the torque and horsepower readings are given at specific rpm increments. Torque over the full rpm spectrum is what is useful for measuring performance.

In the metric system, horsepower is measured as *watts*. One watt is the power to move 1 Nm per second. Because this is so small a measurement,

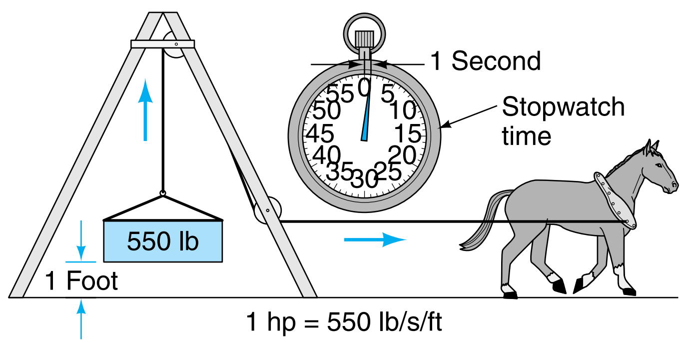


FIGURE 10.92 One horsepower is the amount of work required to lift 550 pounds 1 foot in 1 second.

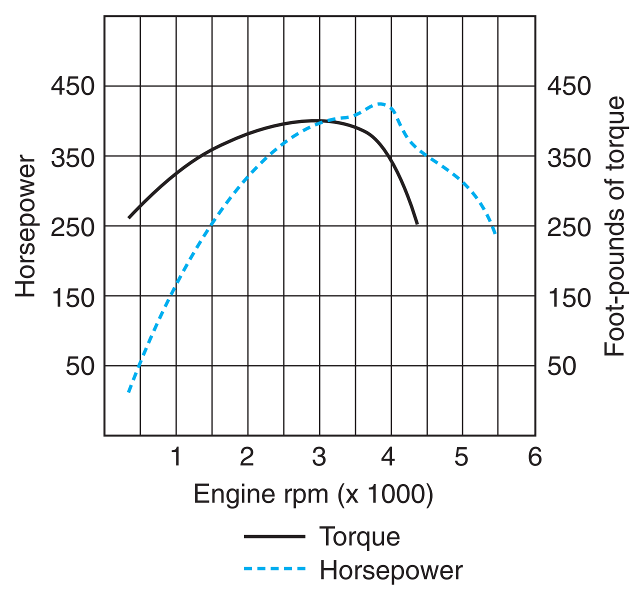


FIGURE 10.93 The relationship between torque and horsepower.

kilowatts (kW) are used. One horsepower equals 0.746 kW.

Horsepower is a measure of work performed in a straight line in a specified time. Torque measures force in a rotating direction.

Power produced at the crankshaft is called gross *horsepower*. Accessories that rob power include the alternator (charging system), air conditioning, coolant pump, cooling fan, power steering, and smog pump. These absorb about 25% of the power available at the crankshaft. The power that remains for use is called *net horsepower*. Power is also lost through friction in the driveline (transmission and differential) and due to wind resistance, vehicle weight, tires, and weather.

There are several measurements of engine horsepower:

- *Brake horsepower (BHP)* is the usable horsepower at the crankshaft.
- *Indicated horsepower (IHP)* is the amount of pressure made in the combustion chambers. It is measured with special instruments and varies throughout the four stroke cycle. This is a theoretical measurement, which does not consider friction losses.
- *Frictional horsepower (FHP)* is the power lost due to friction. It is the difference between brake horsepower and indicated horsepower (**Figure 10.94**). It considers the power need to compress the air-fuel mixture and friction between engine parts such as the piston rings and cylinder walls.
- *Net horsepower* is the maximum power available from the engine when all the accessories are turned on.
- *Gross horsepower (GHP)* is the power available with only the water pump and alternator using power.

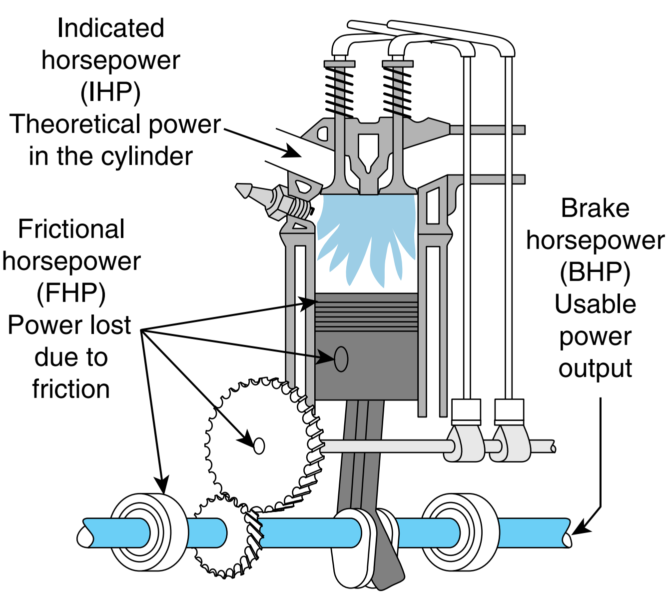


FIGURE 10.94 Frictional horsepower is the difference between brake horsepower and indicated horsepower.

Dynamometer

An engine's output can be measured using a **dynamometer**, commonly called a *dyno* or *dyne*. The engine must be loaded (braked) to measure the torque it can produce. Depending on the type of dynamometer, braking can be done by electricity, hydraulics, or friction.

A simple dynamometer that uses friction is called a *prony brake* (**Figure 10.95**). An arm pushes on a scale to provide a reading in pounds. When the length of the arm is known, the measurement can be converted to foot-pounds or newton-meters.

Engine Dynamometer

An engine dynamometer measures horsepower coming out of the engine (**Figure 10.96**). The horsepower measured is called *brake horsepower* because the dynamometer acts as a brake on the engine's crankshaft.

Chassis Dynamometer

Chassis dynamometers are used when a complete vehicle is needed for measurement of fuel consumption, noise, or emissions. A *chassis dynamometer*

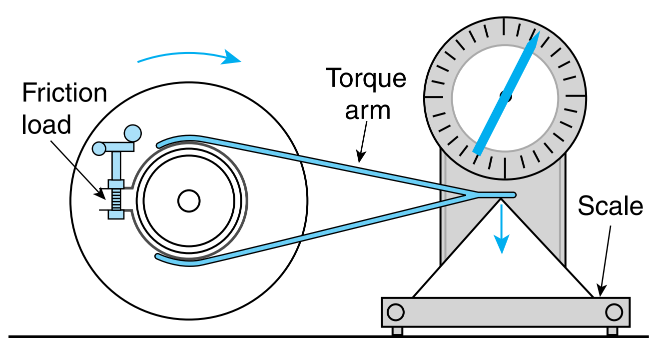


FIGURE 10.95 A prony brake.

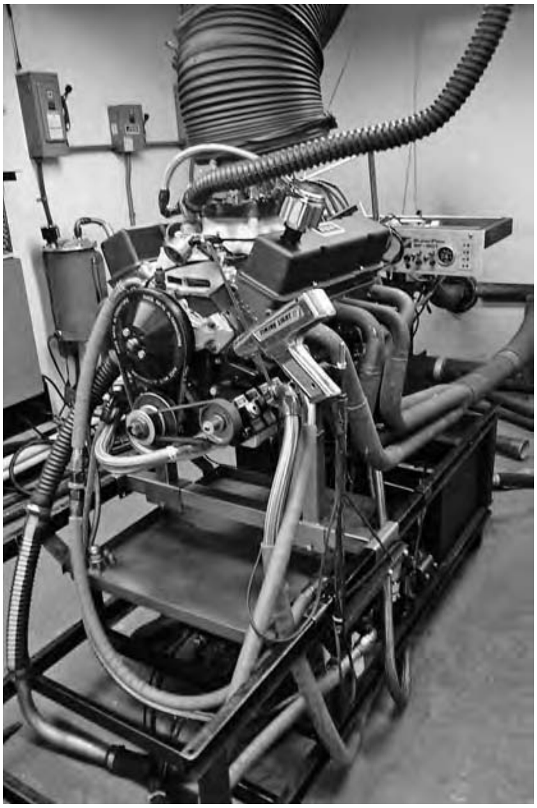


FIGURE 10.96 This engine is set up and ready to run on the dyno.

(**Figure 10.97**) measures horsepower available at the vehicle's drive wheels. This is called *road horsepower* (**Figure 10.98**). It is always less than brake horsepower because of friction losses through the driveline.

Chassis dynamometers can be driven by the wheels or connected directly to the hubs. Wheel-driven dynos have a single or double roller. A *dual roll* dynamometer, with smaller rollers (typically 11" diameter), is sometimes called a *cradle roll*. One roller is attached to the power absorption unit (covered later) and the other is an idle roller. The idle roller has the speedometer pickup, although some dynamometers use infrared measurement of tire speed instead of simply measuring the speed of the roller. A single roll dynamometer uses only one large roller; for instance, 42". A larger roller tends to be safer because it provides a greater contact patch with the tires, resulting in less heat and tire distortion.

With the hub-driven, or Dynapak dyno, there is no wheel slip or inertia from the tire and wheel assembly. The system is portable so it can be taken to the race track.

MEASURING TORQUE AND HORSEPOWER

To make an engine perform work during a dynamometer test, the engine is put under load using a power absorption device. Automotive dynamometer power absorption units are one of two types: electromagnetic (eddy current) or water brake (hydraulic), controlled by the amount of water that enters the device.

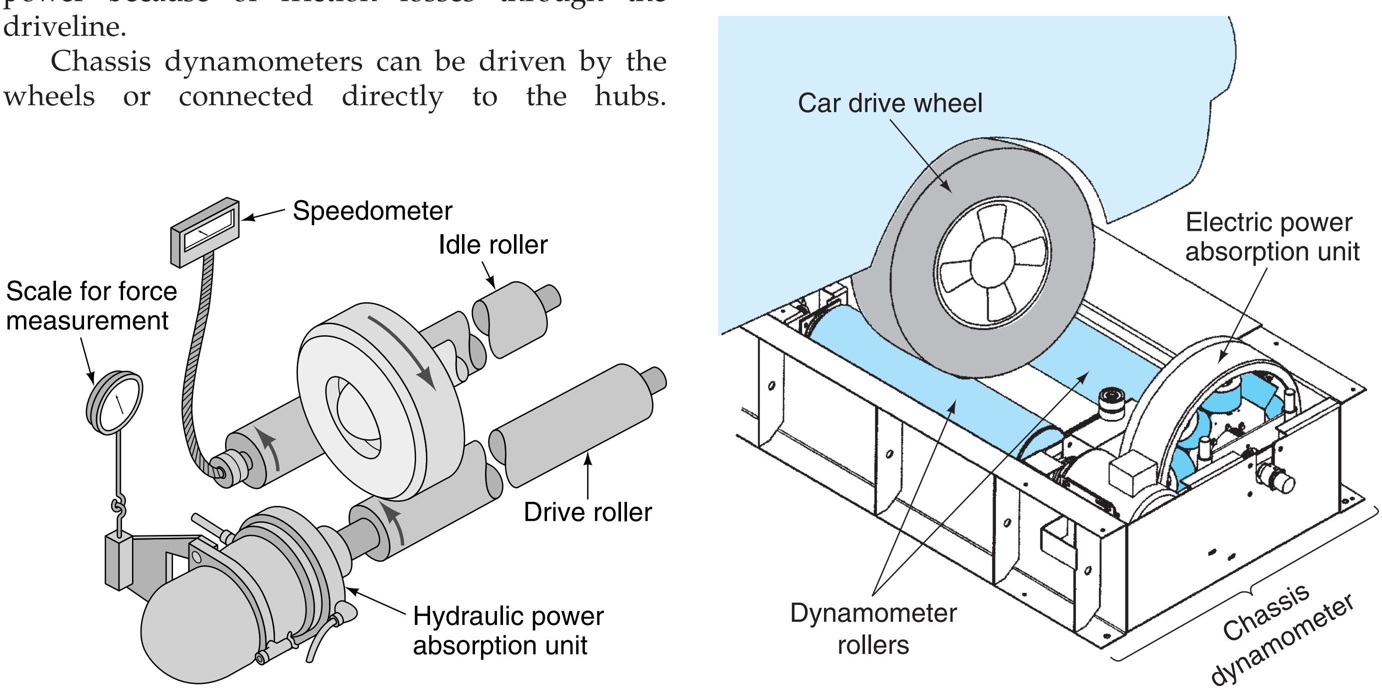


FIGURE 10.97 The rollers on a chassis dynamometer run off the car's drive wheels.

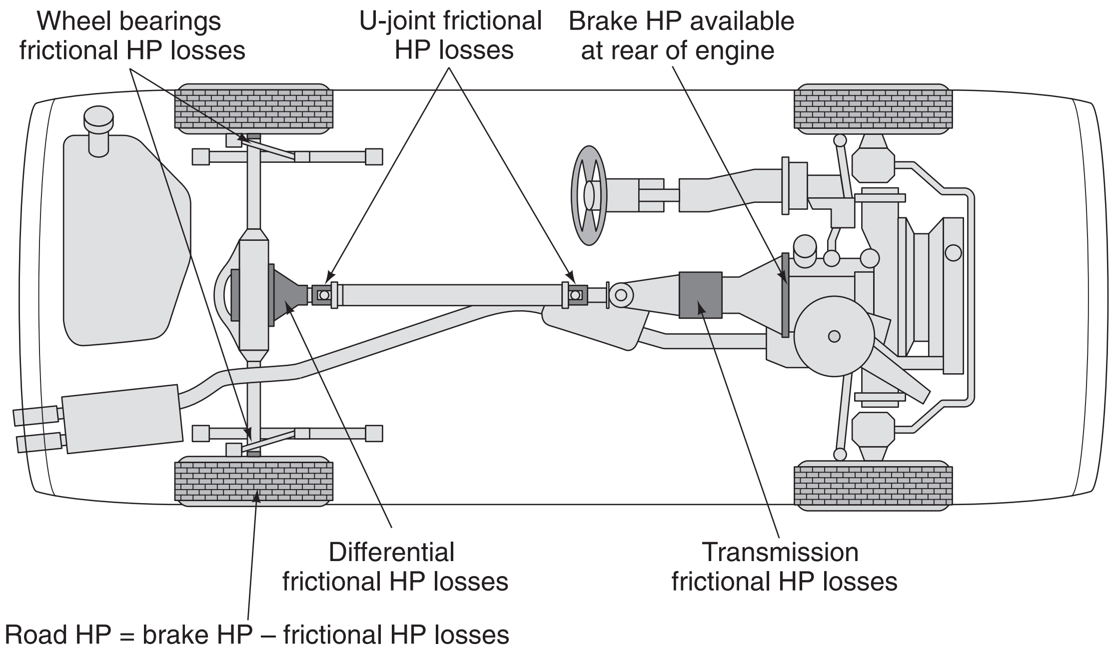


FIGURE 10.98 Road horsepower is always less than brake horsepower because of friction losses through the line.

Water brake units are more popular in the engine performance field. An EC, or eddy current, dynamometer has a magnetic eddy current brake like those used on the brakes of many municipal busses. The EC power absorber is used in emissions and research because it is more efficient at low rpm and is easier to control accurately than a water brake. Dynamometers used for measuring exhaust emissions are called IM240 dynes. They can measure downhill inputs, whereas a water dynamometer without monitoring capability cannot.

Eddy current engine dynos are water cooled and precise but costly. Water brake dynamometers deal with higher loads effectively. With higher power and speed requirements, the water brake is a more economical alternative to the eddy current dynamometer.

A fluid power absorption unit is a fluid coupling consisting of two members: a turbine and a stator (**Figure 10.99**). The turbine tries to move the water, but the stator prevents it from moving. The load unit is like a torque wrench that measures the load applied. The load is varied by the amount of water that is put into the fluid coupling.

Torque can be measured at the flywheel or the rear wheels, but horsepower is a calculation made from the torque measurement. The amount of load put on the engine and the amount of torque it produces are used to calibrate horsepower. A typical dynamometer control panel that displays torque, voltage, engine rpm, and temperature is shown in **Figure 10.100**. The formula for horsepower is:

$$\frac{\text{Torque} \times \text{rpm}}{5250} = \text{HP}$$

Thus, an engine tested at 2625 rpm that develops 500 foot-pounds of torque produces 250 horsepower.

$$\text{Torque (500)} \times \text{rpm (2625)} = 1{,}312{,}500$$

$$\frac{1,312,500}{5250} = \text{HP (250)}$$

Torque readings are made at every 500 rpm. An engine that is warmed to operating temperature produces its best horsepower and has its lowest loss due to friction.

Newer dynamometers have computers that plot horsepower and torque curves.

Horsepower Correction Factors

An engine is an air pump that needs as much as it can get of the 21% of oxygen contained in air. Correction factors are used to compensate for high altitude air or hot air, both of which are less dense. Air is a gas, so it can be compressed. Air intake temperature, humidity, atmospheric pressure, and density also make a difference in the amount of horsepower produced.

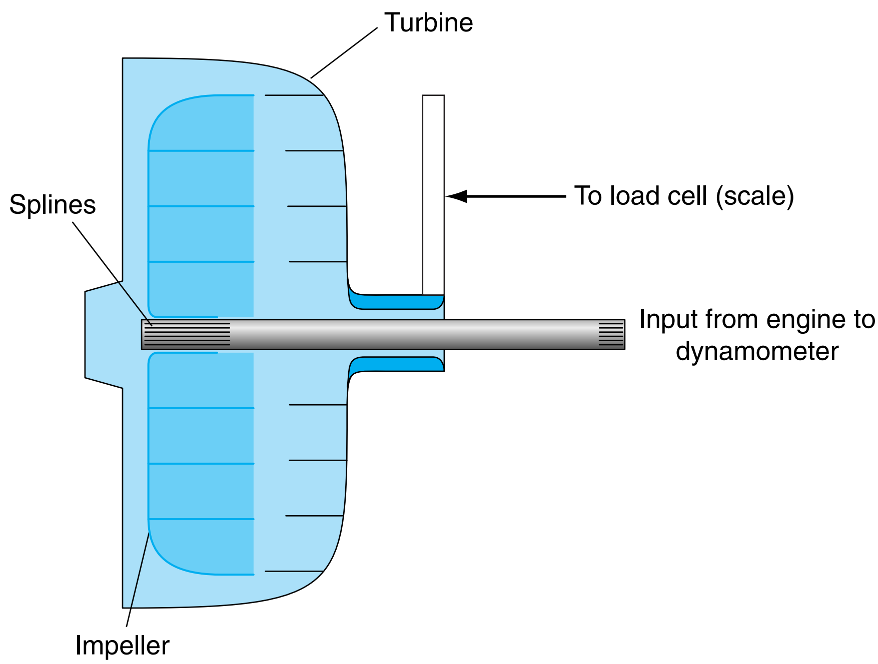


FIGURE 10.99 A dynamometer power absorption unit is a fluid coupling. The input from the engine goes to the impeller, which causes the turbine to push on the load cell.

- Intake air at a lower temperature produces higher oxygen content, which makes better combustion. More air and fuel can enter the engine in a colder (smaller) environment.
- Power production at sea level is greater than in Denver at an altitude of 5000 feet.

Horsepower Comparisons

Horsepower comparisons are only valid if done on the same dynamometer. If you heat the air temperature sensor, the chart horsepower goes up. Also, there is more than one way of correcting dynamometer readings, called the STP (standard temperature and pressure). SAE J-607, which was created in 1956, has been outdated since 1984. J-607 results in higher horsepower readings than the more modern J-1349 (104 vs. 100). Whereas J-607 measures barometric pressure at sea level with an air temperature of 60°F (16°C), the J-1349 test standard calls for 800 feet and 77°F (25°C). The J-1349 standard has changed several times since 1984.

FIGURE 10.100 A dynamometer control panel.

DYNAMOMETER SAFETY CONCERNS

Several safety cautions need to be observed when working with dynamometers. There are different concerns, depending on whether you are working with an engine dynamometer or a chassis dynamometer.

Engine Dynamometer Safety Concerns

Engine dynamometers are usually contained within a small room called a test cell. The engine is controlled by an operator in another room, observing and controlling the engine through a window. Fire is always a concern because air is being pushed into the test cell.

Because the engine is being severely loaded, parts sometimes fail. Flywheel and clutch assemblies occasionally blow up. Sometimes connecting rod bolts fail when they are overloaded if the engine is decelerated from high rpm when the engine is still under full load.

Noise is another problem, which is another reason why the dynamometer is usually installed within an isolated test cell.

Chassis Dynamometer Safety

Carbon monoxide (CO) is a major concern when using a chassis dynamometer. A portable CO tester will be triggered at 25 parts per million, giving you a chance to withdraw from the area until the air can be cleared. Air around a chassis dynamometer needs to be exchanged 8–10 times per minute. A sufficient exhaust system is mandatory and exhaust hoses must be of premium material because abnormal exhaust heat is a concern. Exhaust outlet temperature, which can approach 800°F (427°C), can melt anything but high temperature hose. Plymovent flex hose is a popular material, but it is expensive.

Loading a running vehicle on a chassis dynamometer can be safe if done correctly. However, a mistake can result in a catastrophic accident. The obvious consideration is to keep the vehicle secured on the roller(s) during the test. Tremendous power is imparted to the rollers during a load test. Several methods are used to keeping the vehicle connected to the rollers. T-type tow hooks, like those used by tow trucks, can be used as a redundant backup to the tie downs. A front strap is used to prevent the vehicle from backing off from the roller when you let off the throttle.

Do not stand near the vehicle when doing a dynamometer test. Imagine the consequences that could result from a broken drive shaft when chassis dynamometer testing a high-performance vehicle at 150 mph.

Running a dynamometer test is noisy so operators of chassis dynamometers often use radio headsets so they can talk to one another.

Other Dynamometer Types

Other dynamometer types are also designed for other applications. For instance, *towing dynos* are pulled behind a vehicle, loading it through its trailer hitch. Manufacturers use these to collect data on test tracks and on highways. These dynamometers are expensive.

A dynamometer that tests motorcycle output is often called a *cycle dyne*. SuperFlow has measured 541 HP during one of its dynamometer tests. The motorcycle must be strapped *down* during the test so the tire is held against the roller. This consumes some power, but an accurate power reading cannot be obtained unless this is done.

More in-depth engine dynamometer information can be found at http://www.superflow.com/support/.

Engine Efficiency

To rate an engine in terms of efficiency, both the output and the input must be expressed in a common value. There are three types of engine efficiency measurements: *mechanical efficiency*, *volumetric efficiency*, and *thermal efficiency*. An efficiency measurement is a value less than 100%. The difference between the efficiency measurement and 100% is the amount of loss.

Mechanical efficiency describes all of the ways friction is lost in an engine (**Figure 10.101**). Horsepower is a value that can be used to compare the mechanical efficiency of two engines. BHP divided by the indicated horsepower gives the mechanical efficiency of the engine.

The formula is:

$$\text{Mechanical Efficiency} = \frac{\text{BHP(engine output)}}{\text{IHP(engine input)}}$$

If an engine had 100 IHP and 80 BHP it would have a mechanical efficiency of 80%.

$$\text{Mechanical Efficiency} = \frac{80\text{BHP}}{100\text{IHP}} = 80\%$$

Volumetric Efficiency

The measurement comparing the volume of airflow actually entering the engine with the maximum that theoretically could enter it (this is the same as the displacement) is called *volumetric efficiency (VE)* (**Figure 10.102**). VE determines the engine's maximum torque output.

The rpm at which the engine does its best breathing usually determines its maximum torque. Remember that the engine is like a big air pump.

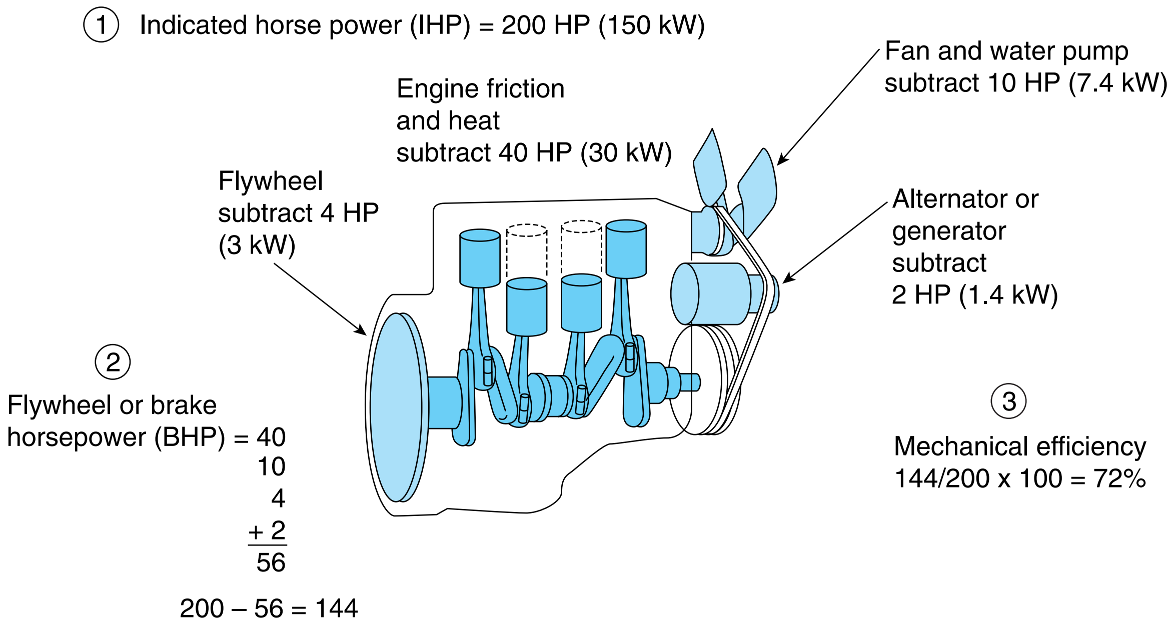


FIGURE 10.101 Mechanical efficiency.

Actually, a pump uses energy to compress air; an internal combustion engine gets its power from expanding air. Heat is what makes the air expand.

VE changes with temperature, engine speed, load, and throttle opening. For instance, at 2000 rpm VE may be 85%, while at 4000 rpm it may be only 60%. At lower engine speeds, the engine has enough time to fill with air at atmospheric pressure. With increases in speed, there is less time for the air to move through the intake and exhaust systems. This results in decreased VE. Closing the throttle also causes a restriction resulting in lowered VE.

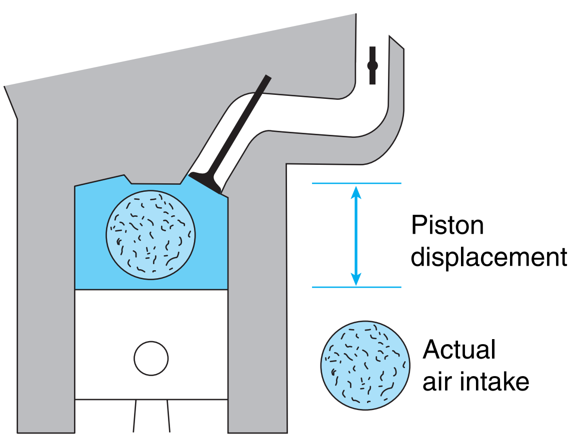


FIGURE 10.102 Volumetric efficiency.

The formula for measuring VE is:

$$\frac{\text{the actual amount of air taken into the engine}}{\text{the cylinder displacement}} \times 100$$

NOTE

More than 100% VE is actually possible, 108% for instance. This is because of the space in the combustion chamber. The compression ratio is determined without using the combustion chamber. The increased amount of VE is limited somewhat by some intake leaking out the exhaust during the overlap period.

Air-Fuel Ratio

The air-fuel ratio of the engine is measured by weight in pounds, or mass. A 15:1 air-fuel ratio is 9000 gallons of air to 1 gallon of fuel. Stoichiometric (14.7:1) is the best air-fuel ratio for the most complete combustion for emission purposes. Maximum power occurs at from 12:1 to 12.5:1 air-fuel ratio. The ratio for maximum economy is 15:1–16:1.

Heat

Heat is another form of energy. It is measured in *British thermal units (Btu)*. One Btu is the amount of heat required to heat 1 pound of water by 1°F.

One *joule* is an equivalent value that compares heat energy (Btu) to mechanical energy (ft.-lb).

1 Btu = 778 ft.-lb

Thermal Efficiency

Thermal efficiency is the ratio of how effectively an engine converts a fuel's heat energy into usable work. Each fuel has a certain amount of heat or thermal energy. Gasoline's thermal energy varies between fuels, but its average is about 19,000 Btu per pound. The energy of the fuel has the potential to produce a certain amount of work when burned in the engine. This thermal efficiency is a theoretical value.

A more useful measurement of thermal efficiency is called *brake thermal efficiency*. This is the BHP converted to Btu, divided by the fuel's heat input in Btu with the result multiplied by 100. **Figure 10.103** shows how the formula works in a typical engine.

In a spark-ignition engine, only about ¼ of the energy from the burning of the fuel is converted to work at the crankshaft. The remainder of the energy is wasted as heat; part of it goes out the exhaust or is lost to the air. The other part is carried off by the cooling system (**Figure 10.104**). If the thermal efficiency of a gasoline engine were doubled, its fuel economy would also double.

Diesel fuel has more heat energy than gasoline (19,000–20,000 Btu/lb). Diesel engines also have higher compression ratios. Both of these are reasons why diesels get better fuel economy than gasoline engines. Compared to gasoline engines, passenger car diesel engines of the past have lower power, weigh more, are noisier, and do not perform as well. Modern turbo diesels with common rail direct injection have better performance, matching the power and performance of spark-ignition engines, and with higher torque. The overall efficiencies of different types of engines are shown in **Figure 10.105**.

1 ENGINE DEVELOPS 100 FLYWHEEL OR BRAKE HP (75kW PER HOUR)
2 2545 100 BHP = 254,500 BTU (75kW)
3 FUEL BURNED PER HOUR = 800,000 BTU (234kW)
4 BRAKE THERMAL EFFICIENCY =

$$\frac{254{,}500}{800{,}000} \times 100 = 31.8\%$$

FIGURE 10.103 Brake thermal efficiency for a typical engine.

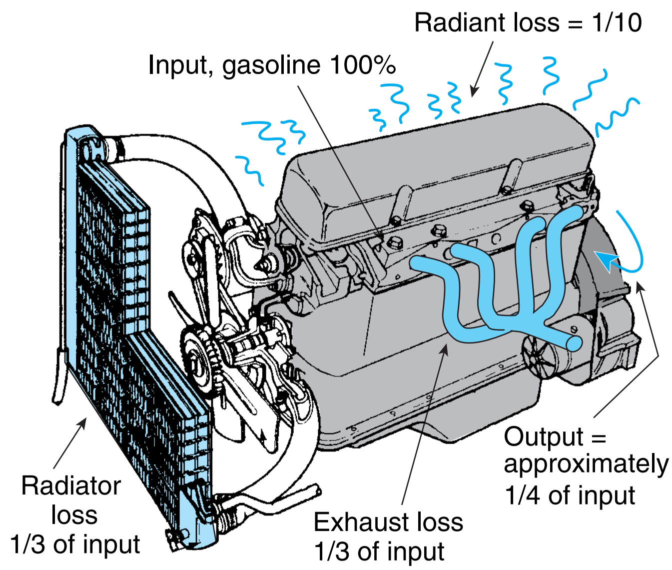


FIGURE 10.104 A gasoline engine loses the majority of its heat energy.

Mean Effective Pressure

The pressure within the cylinder increases during the compression stroke and becomes highest after ignition. The peak pressure in the cylinder should occur at about 10° to 20° after top dead center (ATDC). This is similar to where a bicycle rider would want to apply pressure to the bicycle pedal. As the piston moves down on the power stroke, the pressure drops once again (**Figure 10.106**).

There are two kinds of mean effective pressure. The average pressure within the cylinder is called *indicated mean effective pressure (IMEP)*. This calculation requires equipment usually found only in laboratories and is used to determine thermal efficiency on stationary and marine engines that run at low rpm.

Gasoline Engine	25–28%
Diesel Engine	35–38%
Aircraft Gas Tribune	33–35%
Liquid Fuel Rocket	46–47%
Rotary Engine	20–22%
Steam Locomotive	10–12%

FIGURE 10.105 Overall efficiencies of different types of engines.

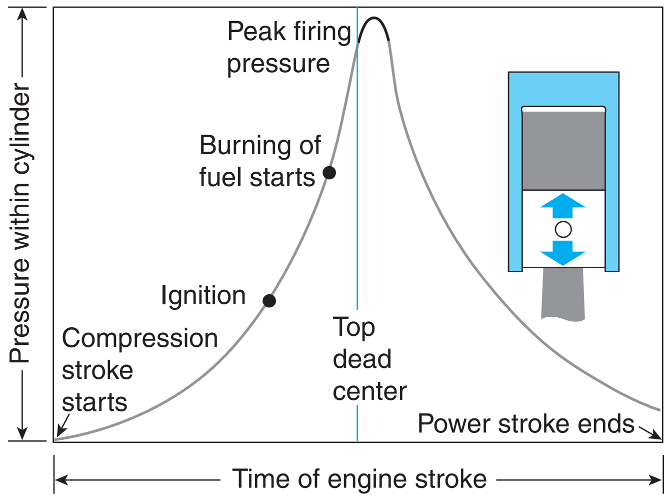


FIGURE 10.106 Pressure in the cylinder is called mean effective pressure.

Brake mean effective pressure **(BMEP)** is a term commonly heard in automobile and motorcycle racing. It is calculated from the horsepower reading on a dynamometer and is an indicator of how hard an engine is working. A more efficient engine has a higher BMEP. BMEP depends on the temperature of gases in the cylinder so more fuel, or better use of the existing fuel, is required for an increase in BMEP.

Horsepower is a function of rpm and torque, whereas torque is a function of BMEP and displacement. Low BMEP at high rpm and high BMEP at low rpm can result in equal power. *Mean* is a term for *average*. BMEP indicates the average effective pressure of all stroke cycles, including two or four stroke cycles. To produce the same amount of power as a four stroke engine running at the same rpm, a two stroke engine requires half of the BMEP.

The formula for BMEP is: 1,008,000 × brake horsepower ÷ $D^2 \times LNS$

D = piston diameter

L = length of stroke

N = number of cylinders

S = engine rpm (if two stroke divide by two)

Compression Ratio and Engine Power

During combustion the potential energy of the air-fuel mixture is turned into thermal (heat) energy and kinetic energy. Compression ratio affects the amount of power an engine can produce by increasing the thermal efficiency of the engine. Squeezing the mixture into a smaller space results in higher combustion pressure and more expansion of the mixture throughout the power stroke. More of the heat energy of the fuel is converted to work, as less heat is allowed to escape from the engine.

Increasing pressure in the cylinder by raising compression can make a relatively big difference in engine power. Each point of change in compression ratio (8:1 to 9:1, for instance) is said

VINTAGE ENGINES

Very early gasoline engines had compression ratios of about 2.5:1. Compression ratios of about 4:1 were common until the mid-1940s. Some engines had a 6:1 compression ratio after the mid-1920s because lead was added to the fuel to give it higher octane. During World War II, higher octane fuels were required for high-performance airplanes, and refining technology improved. By the 1950s, 10:1 compression ratios were available on high horsepower cars. In the late1960s, compression ratios on gasoline engines rose as high as 13.5:1.

In the 1970s, two environmental reasons called for compression ratios to be lowered to about 8:1. The first was higher emissions. Higher compression results in higher temperatures of combustion. This caused more oxides of nitrogen (NOx). Leaded fuels were phased out, too. Tetraethyl lead was an economical way to protect the valve seats and raise the octane of gasoline, but it was a pollution problem. Computerized fuel and ignition timing controls have allowed compression ratios to climb once again in newer cars.

to be worth about 4–6% change in horsepower, proportional throughout the engine operating range. There are limits to raising compression, however. In addition to additional pumping losses and more heat lost to the piston, cylinder wall, and head, the octane of the fuel must be high enough to resist detonation.

To calculate an engine's compression ratio, add together the volume of the cylinder, piston deck height volume, piston volume, compressed head gasket volume, and combustion chamber volume. The sum of these is divided by the sum of the piston deck height volume, cylinder volume, compressed head gasket volume, and the combustion chamber volume.

NOTE

A typical method of calculating compression ratio uses a 0.030" oversize piston with a combined deck clearance and gasket thickness of 0.040".

Effective Compression Ratio

The point at which the intake valve closes determines an engine's effective compression ratio. As an engine runs, the static compression ratio becomes secondary to the effective compression ratio because compression cannot begin to build in the cylinder until the intake valve closes. Therefore, closing the intake valve later lowers the effective compression ratio. This complicates the cam designer's job because leaving the intake valve open longer is a proven way to bring more air into the cylinder at high engine rpm.

The effective compression ratio is considerably lower than the static compression ratio. When the throttle plate is partly opened the engine needs more compression to run efficiently. A higher static compression ratio, therefore, will help part-throttle operation, as will using VVT to close the intake valve sooner.

Figure 10.107 shows the effect of different intake valve closing points on an engine with a static compression ratio of 12:1. Closing the intake valve at 70° after BDC yields an effective compression ratio of 9.138:1. If the valve is closed later at 85° ABDC, the effective compression ratio will be 7.833:1. **Figure 10.108** shows one racing cam manufacturer's recommendations for effective compression ratio. *Swept volume* is a term that describes the cylinder volume that the piston sweeps through during one stroke (0.7854 ×Bore diameter^2 × Stroke).

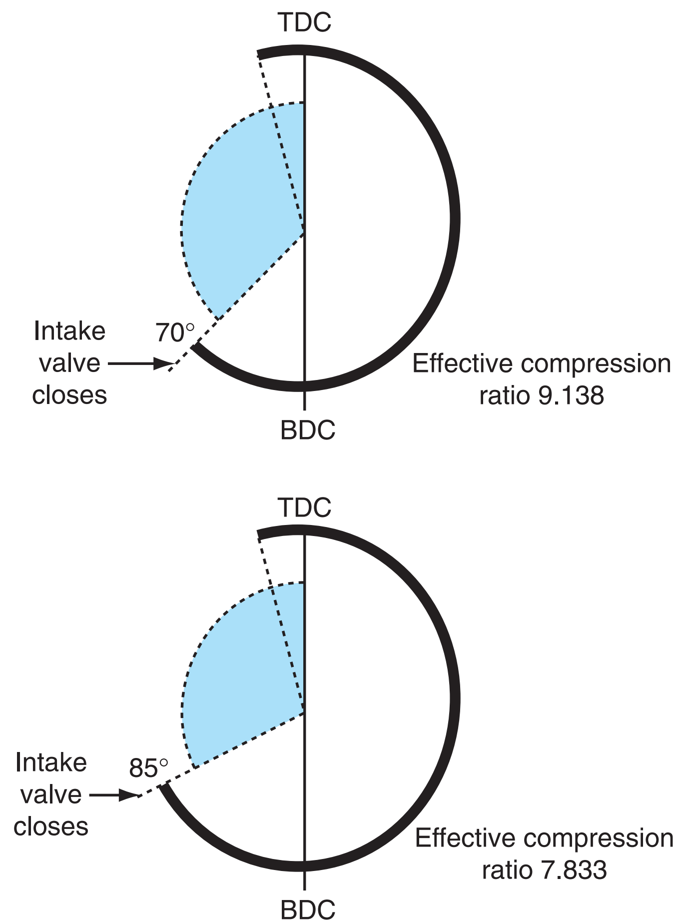


FIGURE 10.107 Closing the intake valve later lowers an engine's effective compression ratio.

On the preceding example engine with a static compression ratio of 12:1, the actual swept volume was 7.27 cubic inches. With the intake valve closing at 70° ABDC the dynamic swept volume was 9.138, and at 85° ABDC the dynamic swept volume was 7.833.

Effective Compression Ratio	
7:1	Maximum for street engines with good compression, intake, and exhaust systems. Pump gas can be used.
7.5:1	Maximum for hot street engines or engines with poor intake systems and low volumetric efficiency. Pump gas can be used.
8:1 and above	Racing gas and dyno tuning required.

FIGURE 10.108 Gasoline requirements for various effective compression ratios. (*Courtesy of Dimitri Elgin, D. Elgin Cams*)

Key Terms

back-cut valve
BMEP
boost pressure
boost threshold
CFM
dynamometer
horsepower
lobe center angle
normally aspirated
shrouding
torque
turbo lag
volumetric efficiency

Study Questions

1. An engine not equipped with a supercharger is referred to as a normally _____ engine.
2. On an in-line engine, when intake and exhaust manifolds are on opposite sides of the head, the head is called a _____ _____ head.
3. The two most common superchargers in automotive use are the _____ and the _____ types.
4. A turbocharger relief valve is called a _____ gate.
5. What is the name for the point at which boost first starts (1800 rpm, for instance)?
6. A power gain of about 1% is achieved for every _____ °F that the air-fuel mixture is cooled.
7. What is the name for a pump that delivers the same amount of air with each revolution regardless of the speed?
8. What is the term that describes the camshaft position when the piston is at the top of the intake stroke, the intake valve is beginning to open, and the exhaust valve has not yet finished closing?
9. What would be the valve lift with a 1.5:1 rocker arm ratio and 0.300" of lobe lift?
10. A change of 0.001" in valve lash will result in approximately _____ of duration change.
11. SAE specifications are measured after the valve has lifted _____". Performance camshafts are usually measured for duration at _____" lift.
12. When a cam lobe is ground differently on its opening and closing sides, this is known as a(n) _____ cam lobe.
13. What is the name of the one camshaft angle that is measured in camshaft degrees instead of crankshaft degrees?
14. The usable horsepower at the crankshaft is known as _____.
15. Which dynamometer design deals with higher loads more effectively: water brake or eddy current?

ASE-Style Review Questions

1. Technician A says that a draw-through supercharger pressurizes the air *before* it enters a carburetor or fuel injection system. Technician B says that an aftermarket blow-through turbocharger is often easier to fit under the hood. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Which of the following is a name for the device used to cool supercharged or turbocharged air?
   a. Intercooler
   b. Charge air cooler
   c. Aftercooler
   d. All of the above
   e. None of the above
3. All of the following are true about turbochargers with full-floating bearings except:

a. They have full-floating bearings, which have oil clearance on both sides.
b. A defective compressor shaft seal can also cause oil consumption and an intake manifold air leak.
c. The turbocharger spins at about one-third the shaft rpm of a supercharger.
d. A normal turbo shaft will feel loose.
e. A restriction in the oil return can result in oil consumption and smoke.

4. If the _____ _____ does not close when the intake side of the turbo is under boost, the crankcase can be pressurized.
   a. wastegate
   b. PCV valve
   c. both of the above
   d. neither of the above

5. Technician A says that the point where the intake valve closes controls the rpm range of the engine. Technician B says that closing the intake valve later in the compression stroke lowers the effective compression ratio. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. Technician A says that it is normal for the piston to remain stationary at TDC for a few degrees of crankshaft rotation. Technician B says that if the intake valve is open more at TDC than the exhaust valve, the cam is retarded. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Both of the following cams have intake and exhaust lobes of identical lift and duration. Which has more overlap, the camshaft with lobe centers at 112° or the camshaft with lobe centers at 114°?
   a. 112°
   b. 114°

8. High rpm power is improved by _____ cam timing.
   a. retarded
   b. advanced
   c. neither of the above

9. To improve idle quality on longer duration cams, _____ lobe centers are used.
   a. wider
   b. narrower
   c. Lobe centers do not affect idle quality.

10. Technician A says that variable timing of the exhaust lobe is used for the control of emissions and fuel efficiency. Technician B says that most VVT systems control the intake valve only. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

SECTION 3

Cylinder Block Assembly

OVERVIEW

Section 3 includes coverage of inspection, service, and repair of the engine block, lower end parts, lubrication, and cooling system. Cylinder boring, honing, and other service procedures are covered in Chapter 11. Chapter 12 includes information on the crankshaft, bearings, and engine balancing. Pistons, piston rings, wrist pins, and connecting rods are covered in Chapter 13. Lubricating oils, the oil pump, oil filters, and crankcase ventilation are dealt with in Chapter 14 under the heading Lubrication. Cooling system coverage, found in Chapter 15, includes the coolant pump, belts and hoses, thermostat, radiators, and coolant.

CHAPTER 11

Cylinder Block: Inspection and Service

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Analyze wear and damage to the cylinder block.
- Select and perform the most appropriate repairs to the block.
- R&R cam bearings, gallery plugs, and core plugs.
- Explain theories of cylinder wall surface finishes.
- Prepare a block for assembly.

Introduction

Cylinder blocks are made of iron or aluminum. Some aluminum blocks have integral high-silicon aluminum cylinders, but most of them have cast-in iron cylinder sleeves, also called liners (**Figure 11.1**).

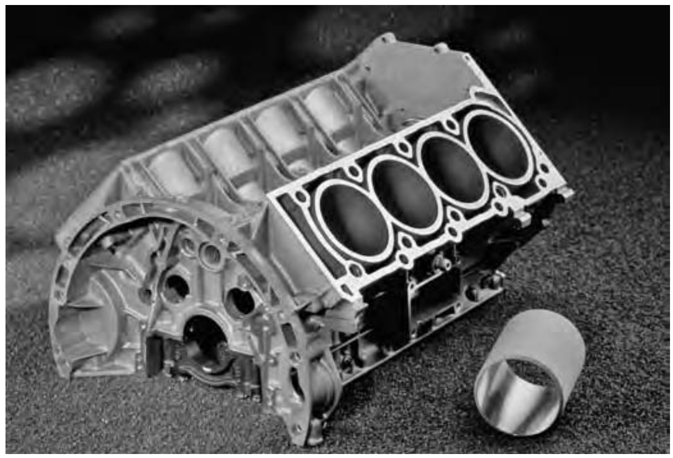


FIGURE 11.1 An aluminum block casting with iron sleeves cast-in. *(© DaimlerChrysler Corporation)*

Usually, cylinder blocks can be reused after certain service procedures are performed. Some blocks with excessive wear need to be rebored oversize to accept new pistons; others simply require cleaning and minor service operations. Some engines require major machining, such as main bearing bore align honing or the installation of sleeves in cracked or damaged cylinders. This chapter deals with all the areas of service that an automotive engine block might require. Cracks and crack repair for a block are similar to the procedures for head repair, which are covered in Chapter 7.

CLEANING THE BLOCK

The first step is to completely disassemble and clean the block. All core plugs, oil gallery plugs, and any other removable parts are removed (see Chapter 4). Cam bearings should be removed and labeled, in case the new bearings come without a list of bearing positions. Cam bearings are usually inexpensive and are not normally reused. Some are made of copper, which is a metal not corroded by alkaline hot-tank cleaning. These cam bearings, which are sometimes difficult to reinstall, need not be removed before hot-tanking the block.

NOTE

When there is an oil groove in the block surrounding the outside of a cam bearing (**Figure 11.2**), the bearing must be removed. This area can trap dirt, which can ruin a new set of crankshaft bearing inserts.

Hot-tank the block and flush it thoroughly to remove any cleaning solution and sediment remaining in the water jackets. The block will dry very quickly because it is hot when it comes out of the tank. Lubricate all machined areas *immediately* to prevent rusting, which can happen in as little as 10 minutes.

If the engine had a coolant loss problem, check the block for cracks in the cylinder bores after hot-tanking (**Figure 11.3a**). Some V-type blocks also have a tendency to crack in the lifter valley area (**Figure 11.3b**).

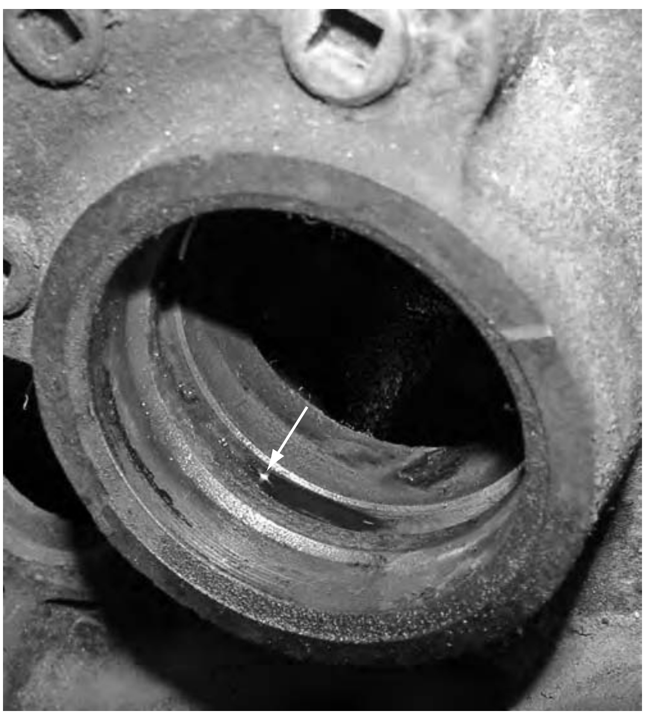
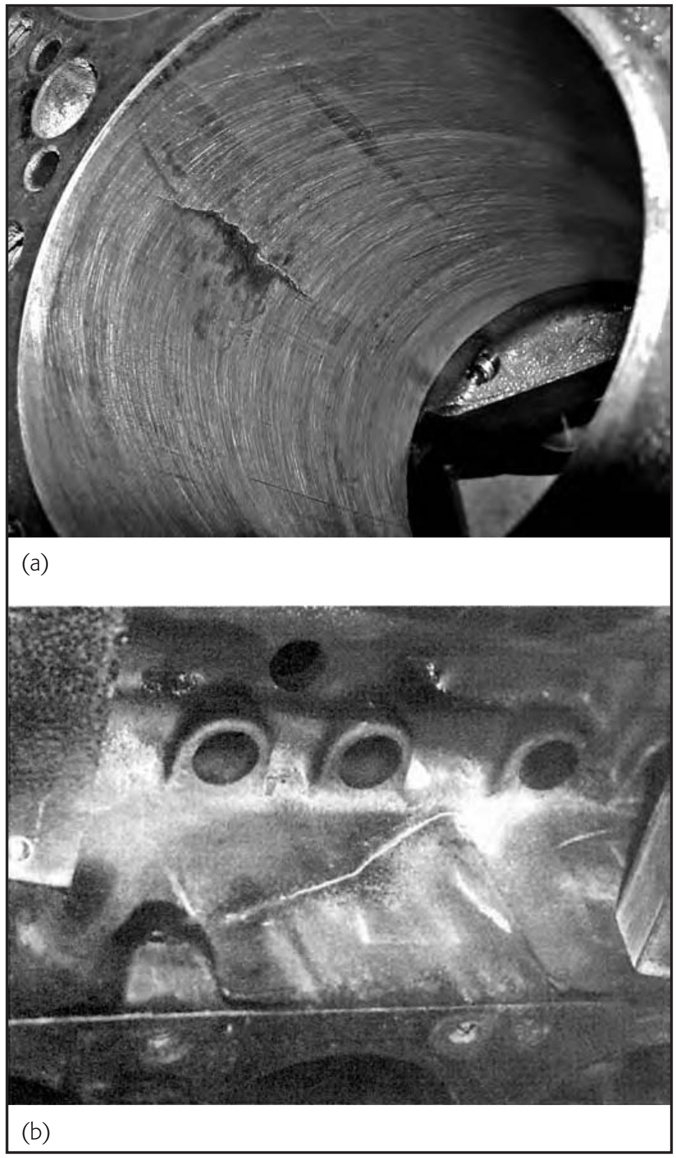


FIGURE 11.2 This groove in the cam bearing bore supplies oil to the outer circumference of the bearing where it will flow through the oil hole to lubricate the camshaft bearing journal. *(Courtesy of Tim Gilles)*



(a)

(b)

FIGURE 11.3 Block cracks. (a) A crack in a cylinder wall. (b) This block has a crack in the lifter valley. *(Courtesy of Tim Gilles)*

OIL AND WATER PLUGS

Following hot-tanking, the oil galleries and main bearing oil supply holes must be cleaned (**Figure 11.4**). Simply cleaning the block in the hot tank is not enough. Loosened particles in the oil passageways can damage a newly rebuilt engine. Oil galleries are filled with sludge that can trap metal shavings and grinding grit produced during block machining (**Figure 11.5**). Use a stiff bristle brush with hot soapy water to clean galleries that run the full length of the block (**Figure 11.6**). Gallery cleaning brush sets are available from engine parts suppliers.

FIGURE 11.4 Clean all oil passages with a brush. Main bearing oil passages are shown here.

FIGURE 11.5 Sludge trapped behind an oil gallery plug. *(Courtesy of Tim Gilles)*

FIGURE 11.6 Cleaning oil galleries.

NOTE

Failure to clean galleries is an invitation to engine failure. See the related case history in Chapter 5.

Tapered pipe threads are found on most oil gallery plugs and threaded heater hose connections. Pipe threads wedge together as they are tightened, making a very tight seal (see Chapter 16). There are three types of oil gallery plugs; female thread, male thread, and pressed-fit cup. The female plug is removed with a special plug driver that resembles a ⅜" to ¼" socket adapter, except that it is solid (**Figure 11.7a**).

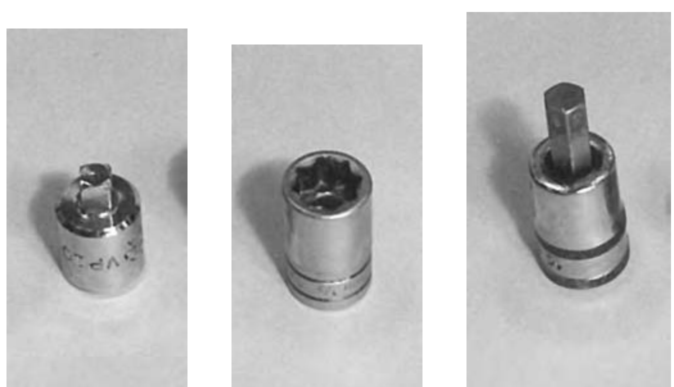
SHOP TIP

Using a socket adapter to remove these plugs will usually result in a broken tool.

Male plugs can be removed with an eight-point or square drive socket (**Figure 11.7b**). An Allen head socket drive can be used to remove a hex-type plug (**Figure 11.7c**) An air impact wrench is often helpful in removing these plugs.

SHOP TIP

Sometimes an oil gallery plug will not come out because it is rusted in place. A rusted plug can usually be removed by heating it with a torch (**Figure 11.8a**) and then applying paraffin wax (a door-ease® wax stick is handy) to the drive hole of the



(a) (b) (c)

FIGURE 11.7 Three types of gallery plug tools. (a) Square oil plug tool. (b) An eight-point socket. (c) An Allen wrench with a socket drive.

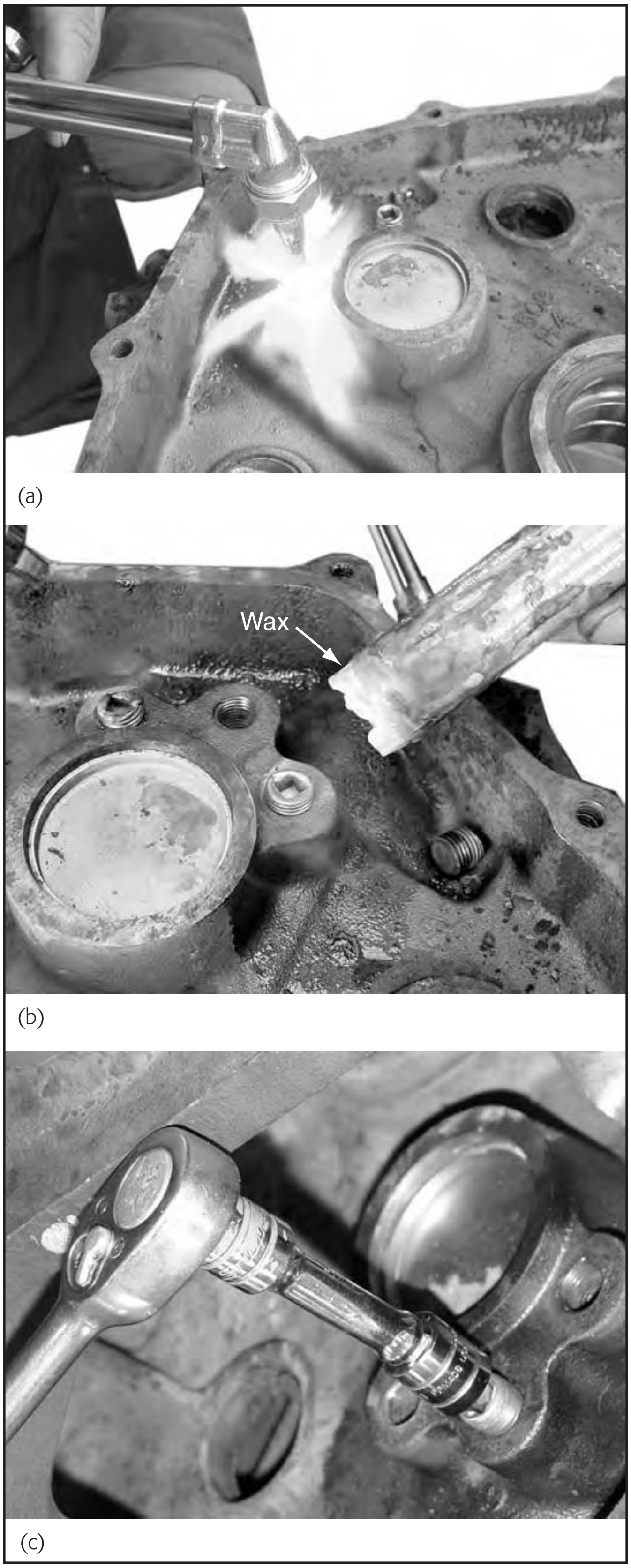


FIGURE 11.8 Removing stuck oil gallery plugs. (a) Heat the plug with a torch. (b) Apply paraffin to the plug. (c) Remove the plug. *(Courtesy of Tim Gilles)*

plug (**Figure 11.8b**). The wax acts like a heat sink, shrinking the plug, which is then removed (**Figure 11.8c**). If all else fails, an extractor set may be required (see Chapter 16).

Small core plugs are sometimes used to close off oil galleries in the front of the block. Following removal of the threaded plugs at the back of the block, core plugs can be knocked out from the rear with a long metal rod (**Figure 11.9**). Sometimes pressed-fit gallery plugs are left installed and the galleries are washed out with a long metal brake line attached to a hose.

Large plugs that are threaded into water jackets are sometimes found in a head or block. These

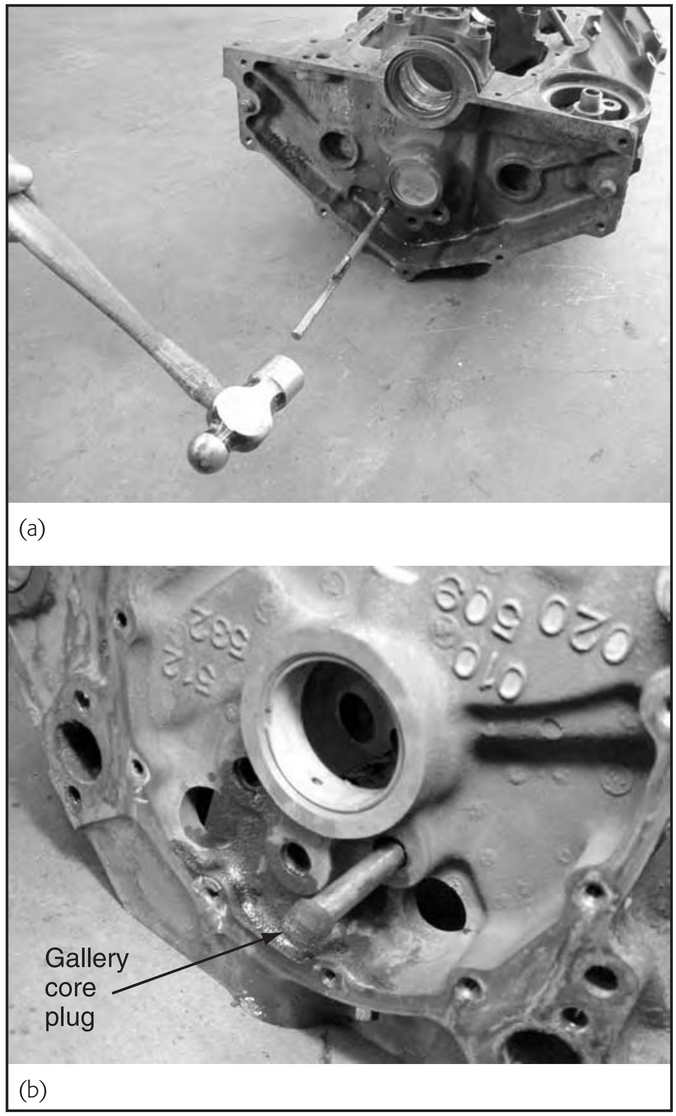


FIGURE 11.9 (a) This long rod is inserted in the oil gallery from the rear of the engine. (b) The rod knocks the oil gallery plug out the front of the block. *(Courtesy of Tim Gilles)*

should be checked using a hammer and center punch to make sure they are not ready to rust through.

OIL JET COOLING

Some engines have oil jets that spray oil onto the underside of the pistons (**Figure 11.10**). The original intention of using oil jets to the inside of the piston was to provide lubrication to the wrist pins. However, the center of the piston is the most prone to increased heat, and cooling this area is more important in some engines. Keeping the inside of the top of the piston under 600°F (316°C) reduces the chance of detonation and prevents the formation of soot on the inside of the piston. Soot becomes a problem when it breaks loose and plugs the oil pump pickup screen (see Chapter 14).

Be sure to carefully remove the jets and clean the oil galleries beneath them.

ALIGNING DOWELS ON THE BACK OF THE BLOCK

Dowels at the rear of the block align the transmission or transaxle housing to the engine (**Figure 11.11**). Aligning dowels are often hollow. These can be removed but are easily damaged.

SHOP TIP

Insert a large tapered punch into a hollow alignment dowel before removing it with pliers.

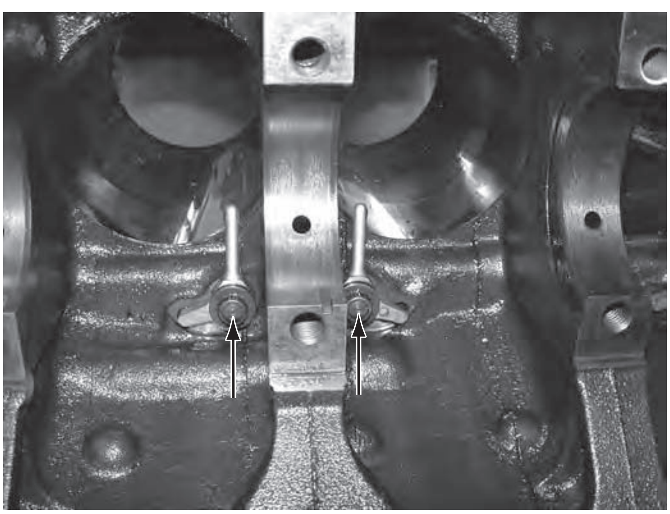


FIGURE 11.10 Oil jets are used on some engines to cool the inside of the piston crown. (*Courtesy of Tim Gilles*)

FIGURE 11.11 Dowels at the rear of the block align the engine to the transmission or transaxle. (*Courtesy of Tim Gilles*)

It is important that aligning dowels be in good condition to avoid misalignment. Occasionally, these dowels are not on center, which can be a source of engine vibration that is irritating and difficult to diagnose. When an engine breaks a flexplate, this is often due to misalignment of the transmission to the engine, either heightwise or sideways. If misalignment is suspected, sweep the transmission pump area with a dial indicator attached to the crankshaft. To correct the problem, machine shops use off-center dowels or eccentric sleeves that fit over existing dowels. The aligning holes in the transmission will need to be drilled oversize to allow the new dowels to fit.

MAIN BEARING CAPS AND REGISTERS

On most newer engines, main bearing caps are aligned and held in position between two shoulders machined into the cylinder block (see Figure 4.64). This design is called a *dual register*. **Figure 11.12** shows a brass hammer being used to seat the cap in place.

Main bearing bores are align bored at the factory with the bearing caps torqued in place. Main caps are not interchangeable and must be returned to the original positions from which they were removed. Some heavy-duty engines use four or more main cap bolts to provide extra strength (**Figure 11.13**). Some engines use a *bedplate* to provide extra support for the block structure. A bedplate is a structure that includes all of the main bearing caps

FIGURE 11.12 Main bearing caps fit snugly into a machined register (notch) in the block. *(Courtesy of Tim Gilles)*

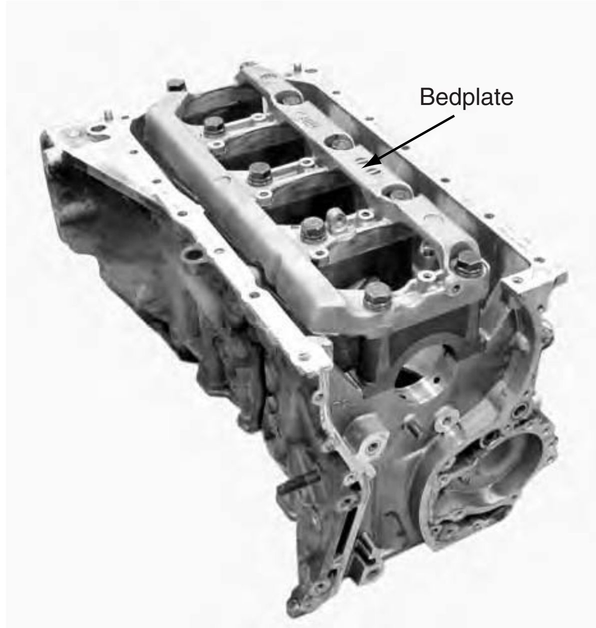


FIGURE 11.14 A bedplate includes all of the main caps and provides rigidity to the block.

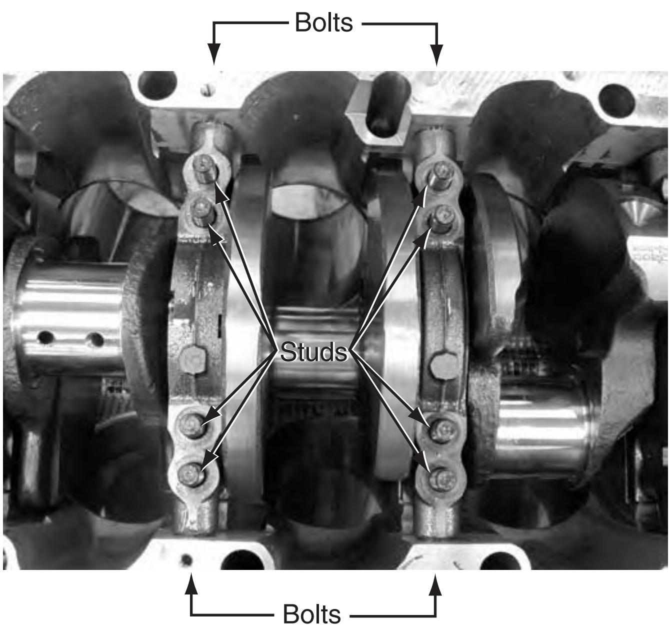


FIGURE 11.13 These main bearing caps have four studs and two more from the side. *(Courtesy of Tim Gilles)*

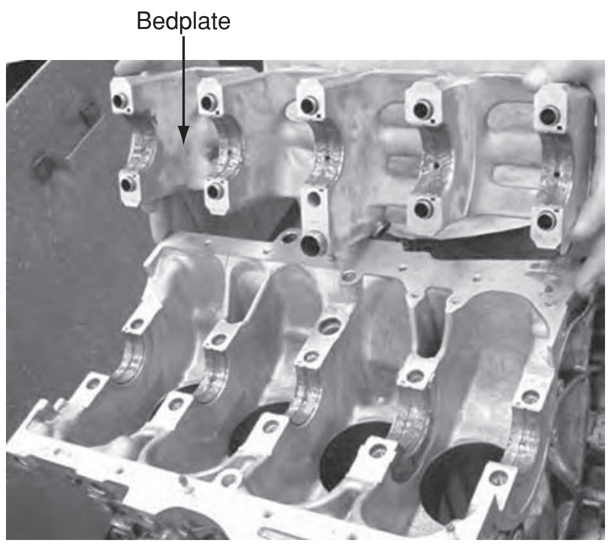


FIGURE 11.15 The lubrication system in this engine feeds oil to the *lower* main bearings through oil galleries in the bedplate. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Some older engines, like the Model A and Model T, Chevrolet 6, and Hudson, had no registers to align the main caps in the block. After the crankshaft was installed, the main caps needed to be aligned. First, the main cap bolts were "snugged down" but not fully torqued. Then a large hammer was used to tap on unmachined areas like counterweights while rotating the lubricated crankshaft. Cap alignment was "adjusted" until the crankshaft could rotate freely. This is how the hammer became known as a "Model A bearing adjuster."

(**Figure 11.14**). In some cases the oil pan is bolted to the bedplate. There are also engines that have oil galleries in the bedplate; oil is routed to the crankshaft through the lower main bearings (**Figure 11.15**).

MAIN BEARING BORE ALIGNMENT

Repeated heating and cooling of an engine block can result in misalignment of the main bearing bores (**Figure 11.16**). The bearing caps and bearings shown in **Figure 11.17** have been laid out in order so unusual main bearing wear can be observed **Figure 11.18** shows main bearing wear that resulted from a twisted crankcase. Main bearing *saddle* bore alignment can be checked with a 0.0015" feeler gauge and a straight bar or a straightedge (**Figure 11.19**).

SHOP TIP

The block should *not* be mounted on a universal engine stand during the alignment check. The block must not hang from one end; this could produce a false reading because of the flexibility of the casting. Set the block on a workbench when measuring.

Production engine shops either remachine the main bearing bores of all rebuilt blocks or check them with an arbor that is accurately ground to 0.001" *less* in diameter than the main bearing bore size (**Figure 11.20**). If the bar cannot be rotated, the crankcase might be warped or one or more of the bores could be out of round.

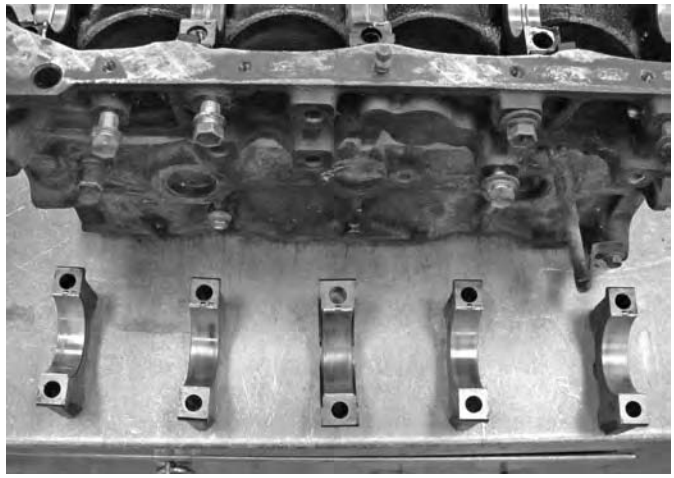


FIGURE 11.17 These main bearings are laid out in order, revealing an unusual wear pattern. *(Courtesy of Tim Gilles)*

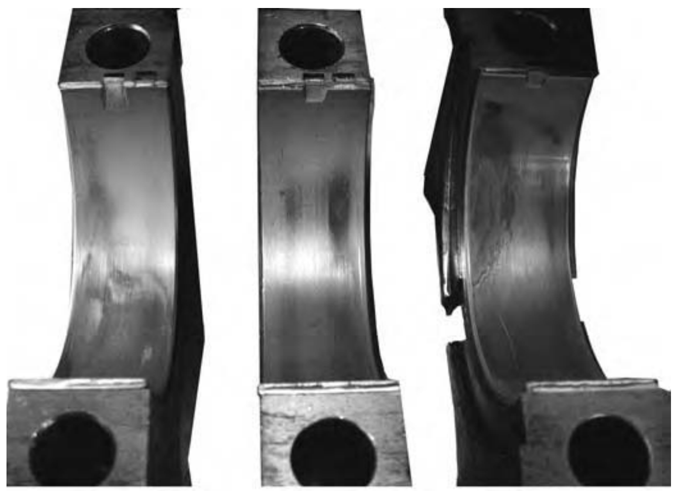


FIGURE 11.18 A misaligned or twisted crankcase caused this unusual wear to the center lower main bearings. *(Courtesy of Tim Gilles)*

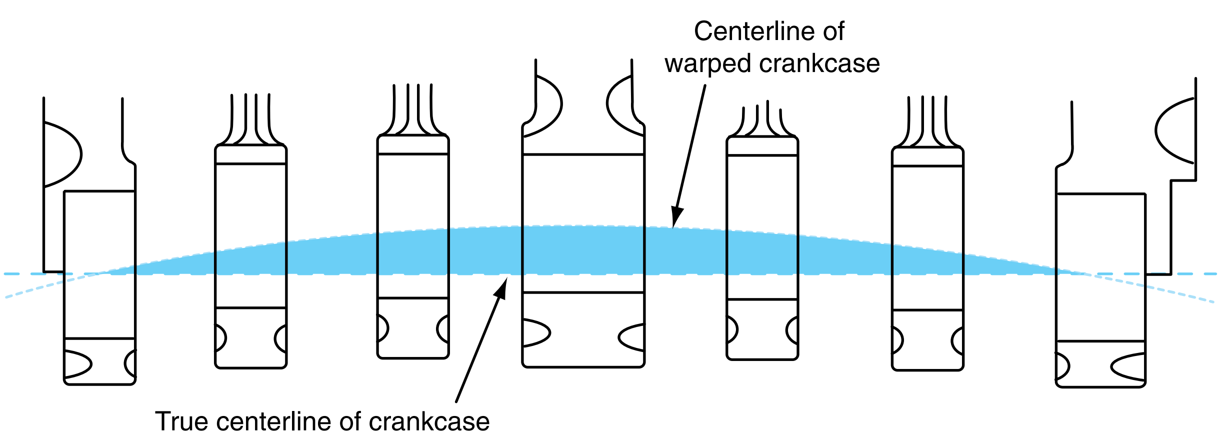


FIGURE 11.16 Repeated heating and cooling of an engine block can result in misalignment of the main bearing bores.

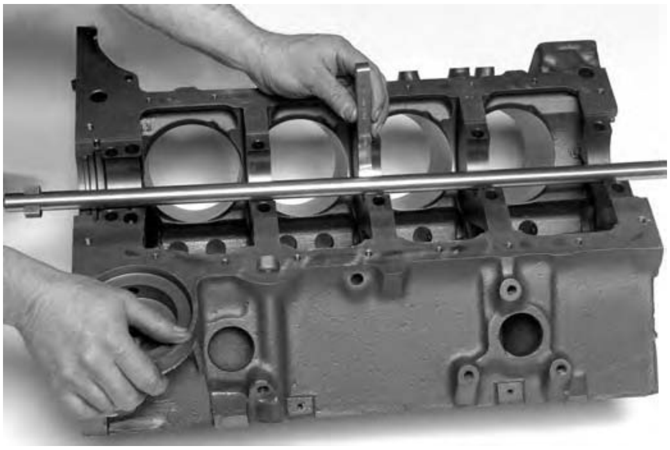


FIGURE 11.19 Checking main bearing bore alignment with a straight bar and feeler gauge.

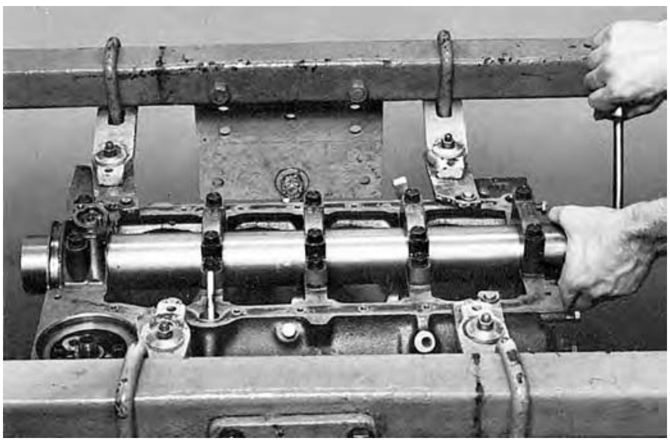


FIGURE 11.20 Using an arbor to check main bearing bore alignment. *(Courtesy of AE Clevite Engine Parts)*

Clevite, a bearing manufacturer, suggests the following procedure for checking main bearing bore alignment:

- Coat the main journals of the crankshaft with Prussian blue.
- Install the crank and bearings in the block.
- After torquing the main caps, rotate the crankshaft twice.
- Turn the engine upside down, and rotate the crank through two more revolutions. This ensures that the weight of the crank will fall on both the upper and lower bearing halves of the bore.
- Carefully unbolt the main caps and remove the crank. At least 75% of the bearing area should be "blued" for acceptable alignment. An area of about ⅜" on either side of the bearing cap parting line may not become blued because of normal bearing eccentricity.

Main Bearing Bore Roundness

When a main bearing has become hot enough to burn, or the block has changed color, the bore will usually shrink, which means that the main bearing bores must be remachined. This can be determined by measuring the main bearing bores in several directions (**Figure 11.21a**) with a dial bore gauge (**Figure 11.21b**). The vertical measurement should not be larger than the horizontal; if it is, stretch has occurred. An out-of-round measurement of less than 0.001" is acceptable if the horizontal reading is the largest. Any main bearing bore that shows discoloration should also be checked for cracks before doing any repair work on the block. Remember to always check for out-of-round main bearing bores when an engine has a broken crankshaft.

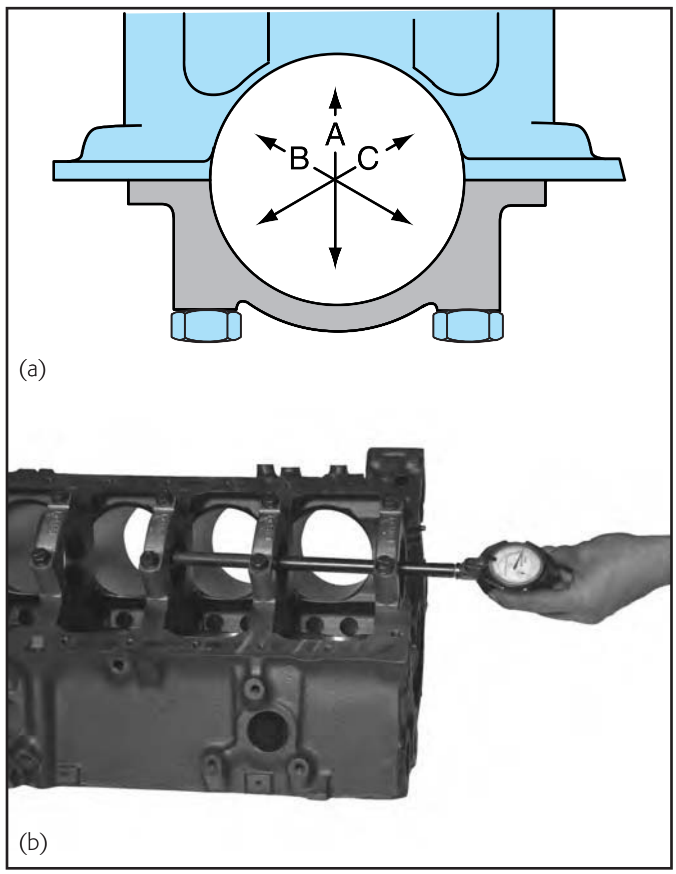


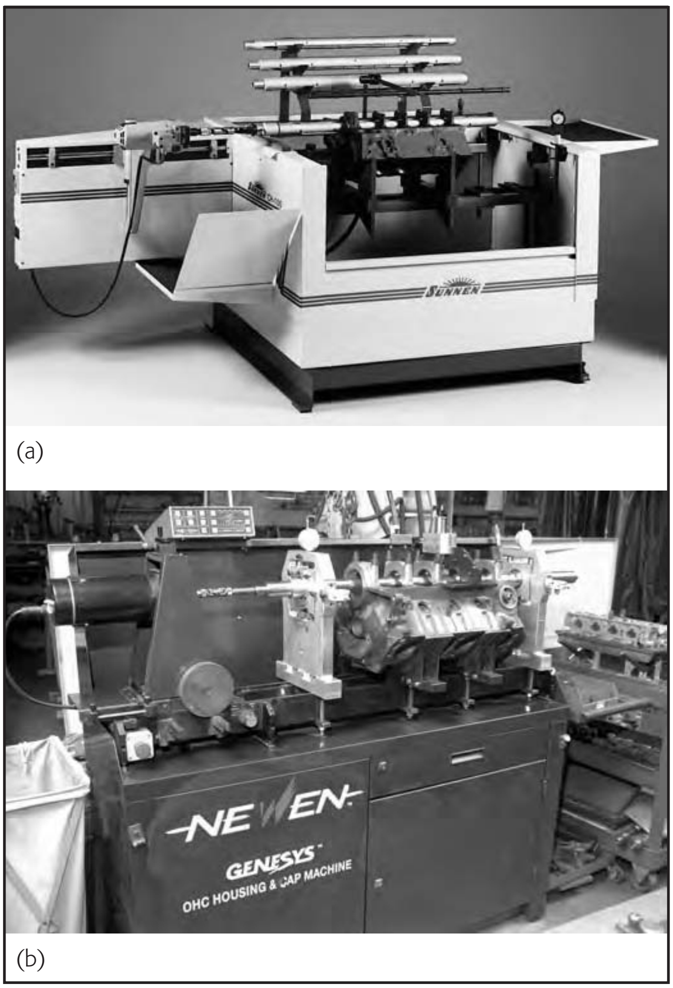
FIGURE 11.21 Checking main bearing bores for roundness. (a) If a main bearing has become hot, the measurement at C and B might be less than the measurement at A. (b) Checking main bearing bores with a precision gauge.

Main Bearing Bore Realignment

Realignment of the main bores is accomplished either by **line boring** or **line honing** (**Figure 11.22**), also called align boring or align honing. There are several reasons why an engine block might need to be line bored or line honed. During normal engine life, the block undergoes cycles of repeated heating and cooling. Distortion, warpage, and misalignment of the main bearing bores can result when the stress in the original casting dissipates. When warpage happens over a long period, the main bearing inserts can compensate as they wear. When new bearing inserts are installed, however, even a slight amount of misalignment can bind the crankshaft and cause wear to the new bearings.

Another main bearing bore problem results from high engine loads. This normally causes the bore to stretch vertically as it pinches horizontally at the bearing cap parting line. Again, when new bearings are installed, the crankshaft can bind.

Excess heat can also damage a main bearing bore. This is often due to a lack of lubrication, which can cause the bearing to weld to the crankshaft. Ultimately, the bearing will spin in the main bearing housing, damaging the bearing bore.



(a)

(b)

FIGURE 11.22 Realigning main bearing bores. (a) Honing main bearing bores with a line honing machine. *(Courtesy of Sunnen Products Company)* (b) Line boring.

Line Boring vs. Line Honing

The line hone finishes all of the bearing bores at once with a hone stone, whereas line boring cuts each one separately using a cutting bit. Compared to line boring machines, the line honing procedure is faster and removes less metal, but the honing machine is considerably more expensive. When a main cap or the corresponding saddle bore in the block has been repaired by welding, however, a line boring machine must be used for removing the larger amount of metal required.

Line Honing

Some engine rebuilders line hone every block without measuring to see if the block needs correction. This is because it takes approximately half as long to measure and verify the alignment of a block as it does to perform a line hone. Sunnen, a honing equipment supplier, makes hone units that cover diameters of car and truck main bearing bores ranging from 1.8 to 5.0" (61 to 127 mm). Before installing a block in the line hone several items need attention.

First, check that the main caps fit tightly to the block. Be sure that the bearing caps are numbered so they can be returned to their original places on the block.

Grind or mill the main caps on their parting faces (where they meet with the block). The parting surfaces are shortened by grinding to shrink the bore diameter so honing can restore the original main bearing bore size. Some machinists take 0.004–0.005" off each cap or simply grind the main cap parting faces until the factory machining marks are removed.

SHOP TIP

Measure the bore sizes with the caps tightened to specifications. When you remove metal from the parting lines, grind so that all bores are the same undersize. Starting with the bores the same undersize helps keep the stones wearing evenly.

The block is your mandrel. Keep in mind that the main bearing bores are what keep your stones true. If the stones are tapered, you will not get an accurate finish. You can keep the stones from becoming tapered by periodically turning the block around and honing from the other side. When stones are new, true them in a scrap block before use, applying just enough oil to keep the stones from loading up. If a main bore is coming out larger, turn the block around and true up the stones.

The block is mounted in the hone using a cradle that allows for adjustment of the block to the hone. The distance the hone stone can extend from either end of the block is controlled by setting adjustable stroke stops. This is called the overstroke setting.

The line hone uses a spring-loaded stone like the connecting rod hone. Hone stone pressure against the bearing bore is controlled by a spring tension adjustment with a limit stop so the diameter cannot advance without being adjusted by the machine operator. This is similar to using a connecting rod hone (see Chapter 12).

Honing is done wet with honing oil. After removing metal from the parting surface of the bearing cap, start the drive motor and manually stroke the hone back and forth in the main bearing bores to the preset stroke stops. Honing quickly increases the bore size, so remove the hone and check often (approximately every 15–20 seconds) using a dial bore gauge (**Figure 11.23**). The amount of metal removal slows down as the bores become round once again. Do not let the stones move out too much before checking the bore size or you will have to regrind the main caps and start over again.

When align honing or align boring, removal of too much metal can move the crankshaft up too far toward the camshaft. This causes excessive timing chain slack and retarded cam timing. It also moves the pistons higher in their cylinders, resulting in a higher compression ratio. Engines with gear drive cams will require special timing gears because stock timing gears will not have enough clearance between the teeth.

NOTE

Some engine builders replace OE main cap bolts with high-performance studs, washers, and nuts. The replacement studs are of a higher property class than stock and a higher torque specification is often given. To be done properly, the studs must be installed and torqued to the higher specification while the block is line honed. Otherwise, using the higher torque specification on a stock bearing bore will pull the bore out of round and might result in engine failure.

FIGURE 11.23 A dial bore gauge is calibrated in a setting fixture. *(Courtesy of Tim Gilles)*

DECKING THE BLOCK

A whetstone or a file can be used to clean the deck surface of the block. On older engines with cast iron heads and blocks, do not make the surface too smooth; head gasket sealing problems may result. Just remove any nicks or burrs that might give false readings when checking for warp.

After thorough cleaning, check the deck surface for flatness (**Figure 11.24**). Blocks do not warp nearly as often as heads. When the block deck surface is warped or is not parallel to the main bearing bores, the surface can be corrected using a milling machine (**Figure 11.25**) or grinder, like machining a cylinder head. This is called **decking a block**.

Alignment dowels must be removed prior to surfacing the deck. Dowels are often installed in blind holes and can be removed using a special slide hammer puller. When dowels are installed in through holes, they can be removed using a punch to drive them into the water jacket in the block. They are retrieved from the water jacket using a magnet through a core plug opening.

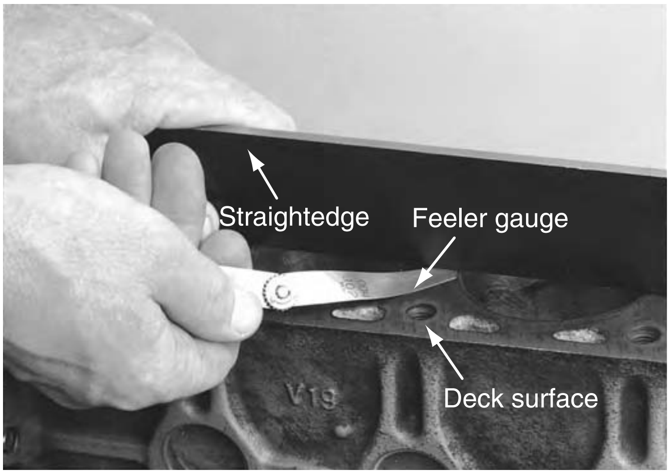


FIGURE 11.24 Check the deck surface for flatness.

FIGURE 11.25 Decking a block. *(Courtesy of Storm Vulcan Mattoni)*

INSPECTING CYLINDER BORES

Inspect cylinder bores for taper and *out-of-round* wear (**Figure 11.26**). Maximum wear occurs at 90° to the wrist pin, just under the ring ridge. The top of the cylinder wall lives in a severe environment. It is subjected to extreme heat and the high pressure of the piston rings against it when the air-fuel mixture is ignited. It receives less lubrication and is subjected to fuel wash, which removes oil from its surface. These conditions sometimes cause taper wear, which forms the ring ridge at the top of the ring travel. (Ring ridge removal is covered in Chapter 4.)

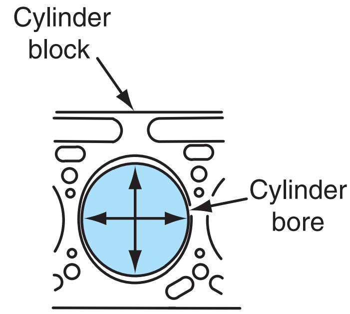


FIGURE 11.26 Measure for out-of-round wear.

NOTE

Oil cannot burn from cylinder walls because it is quenched. When oil is washed from the cylinder wall surface, it can be burned with the fuel.

Cylinder Bore Wear Limits

Different considerations determine cylinder bore wear limits. One situation is when new rings are installed accompanying a valve job and lower end overhaul. This is commonly known as an in-chassis overhaul or a re-ring and valve job. Life expectancy of the repaired engine will not compare with that of a new engine.

Another scenario is the complete engine rebuild, where the engine block is machined and a master

VINTAGE ENGINES

Some older engines suffered more taper wear in some cylinders than others. This was found to be due to uneven cooling. Colder water at the point of entry to the engine would cool the cylinder walls and cause increased wear due to fuel wash. For instance, in the Model A the center cylinders would wear more than the outside ones. In the Chevrolet 216 in-line six, the number one cylinder would experience more wear.

engine rebuilding kit is installed. All work is done to industry standards, with the life expectancy of the rebuild being equal to or better than that of a new factory engine.

Newer engines live much longer than they did 20 or 30 years ago. Excessive cylinder bore taper, relatively rare today, is not the regular occurrence it once was. Unlike older carburetors with chokes, newer engines with fuel injection are less likely to wash oil from the cylinder walls when the engine is cold because the computer controls the timing and length of time of the injector pulses. Also, the quality of lubricants is continuously improving and newer engines are produced with newer honing methods and higher quality metallurgy.

Taper Limit with Low Friction Rings

By the year 2000, most new engines were equipped with low friction rings (see Chapter 13). Engine manufacturers are producing engines to far more exacting standards than in the past, and life expectancy of internal engine parts is currently listed as 150,000 miles. There are published standards for allowable taper during machining of a cylinder. A rule of thumb from honing manufacturers allows a maximum of 0.0005" per inch of ring travel, with 0.001" maximum deviation in the total bore. An example of even closer tolerances is Ford's 4.6L V8, which uses low-friction piston rings. According to an AERA bulletin, in Ford's remanufacturing program the engine is rebuilt under controlled temperature conditions. When machining is completed, the block has a 24-hour rest before the final measurements on the bores are completed. If the block does not meet tough specification standards, it is discarded. For instance, Ford has a very tight tolerance for maximum taper allowance of 0.0002" ($^2/_{10}$ of a thousandth); maximum allowable out of round is 0.0008". Be sure to check specifications.

Taper and Out-of-Round Wear

Consider the problems caused by cylinder wear. Taper wear causes the end gaps of the piston rings to change as the rings move up and down the cylinder. Too much taper wear is also accompanied by out-of-round (oval) wear, which results when the piston rocks on its wrist pin at TDC and BDC. Excessive piston-to-cylinder wall clearance increases out-of-round wear. Another contributing cause of out-of-round cylinder wear is gasoline washing oil from the cylinder walls when the engine is cold.

Most out-of-round cylinder wear is on the piston's major thrust side. When viewed from the rear, most engines turn counterclockwise and the major thrust side is on the right side of the piston. The minor thrust side of the piston pushes on the cylinder wall from BDC to TDC on the compression and exhaust strokes when there is not as much load.

VINTAGE ENGINES

Older engines were allowed cylinder bore taper wear of up to 0.010" and out-of-round wear of up to 0.005". New rings could be installed on the old pistons, but the rings had to be ordinary cast iron. OEM engines came with premium top rings. Having tapered bores and using ordinary cast iron rings in the top groove is considered by some to be a patchwork repair, not meeting what many industry members would say were minimum quality standards for a long-lasting engine repair. However, during an in-chassis overhaul this can provide an affordable approach to getting a customer back on the road. Although the engine's life expectancy will be less, this method is still an acceptable practice in the repair industry. Taper is checked below the ridge in the top ½" of the bore. For re-ring jobs, 0.004–0.006" is now considered to be the maximum allowable upper cylinder taper wear by most aftermarket piston ring experts. Manufacturer specifications vary according to the engine. Chrysler's 2.7L manual states that maximum taper allowed is 0.002", which is hardly enough to feel a ridge with your fingernail.

Out-of-round wear is more serious than taper wear because a thicker oil film can accumulate on the cylinder wall where the out of round is greatest. This will not be wiped off by the ring. Also, it is more difficult for new rings to seal against an out-of-round cylinder than a tapered one. A good rule of thumb for maximum out-of-round wear is 0.002–0.003" for iron rings.

NOTE

Premium top rings (chrome or moly) should *never* be used in tapered or oval cylinders.

SHOP TIP

One test for out-of-round wear is the "light test." When light is shined on a new ring installed in a cylinder, no light should leak between the ring and cylinder wall.

Measuring the Bore

A cylinder bore can be measured in several ways. One simple check for taper without any special measuring instruments is to use a feeler gauge and an old piston ring:

- Square up the ring just below the ring ridge and measure the ring butt gap with a feeler gauge (**Figure 11.27a**, **Figure 11.27b**, and **Figure 11.27c**).
- Compare this measurement to the butt gap measurement at the bottom of the cylinder (**Figure 11.28a** and **Figure 11.28b**).
- To determine the taper, divide the difference between the two gaps by 3. This is done because the change in the gap is really a measurement of change in cylinder *circumference*, not *diameter*. Converting from circumference to diameter requires division by 3.14 (π), but the approximation of 3 is close enough.
- **Figure 11.29** shows the effect taper has on the ring gap.

Other methods of measuring the bore include using a telescoping gauge and micrometer, an inside micrometer, or a cylinder dial bore gauge. The dial bore gauge is usually more accurate than the other instruments.

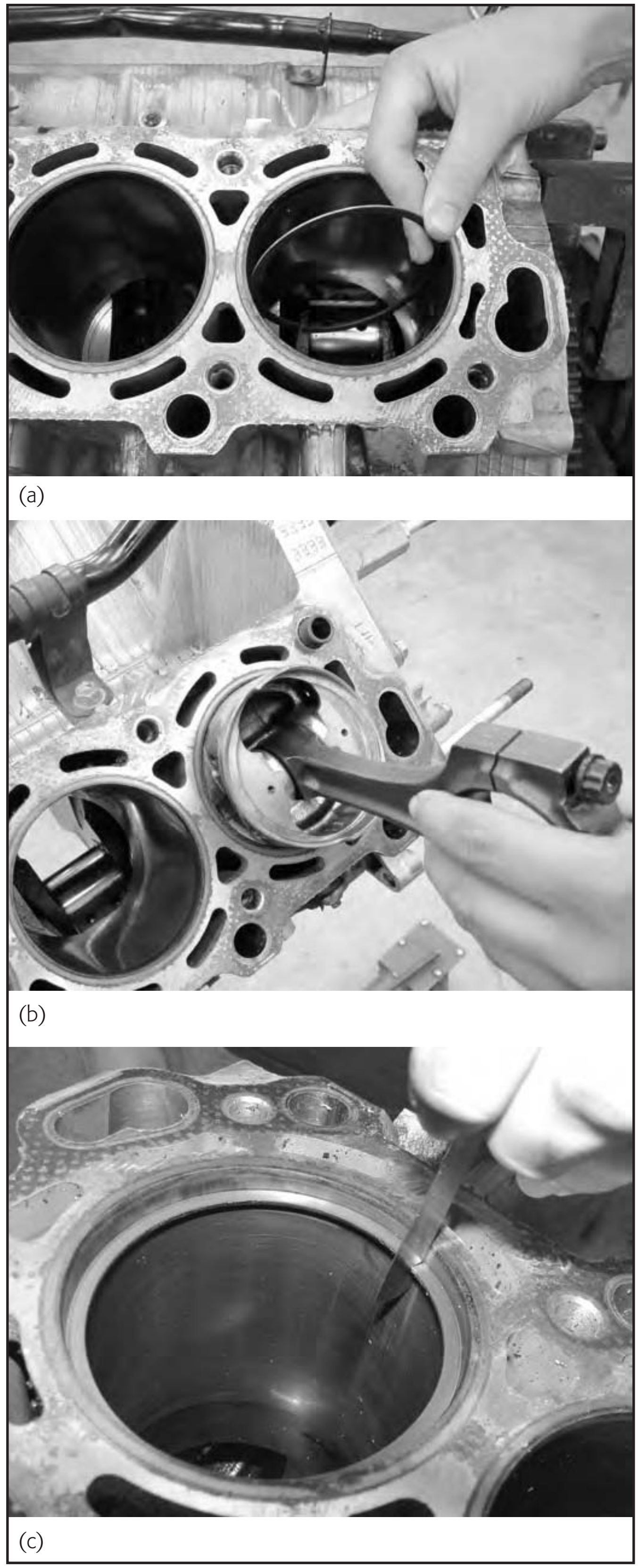
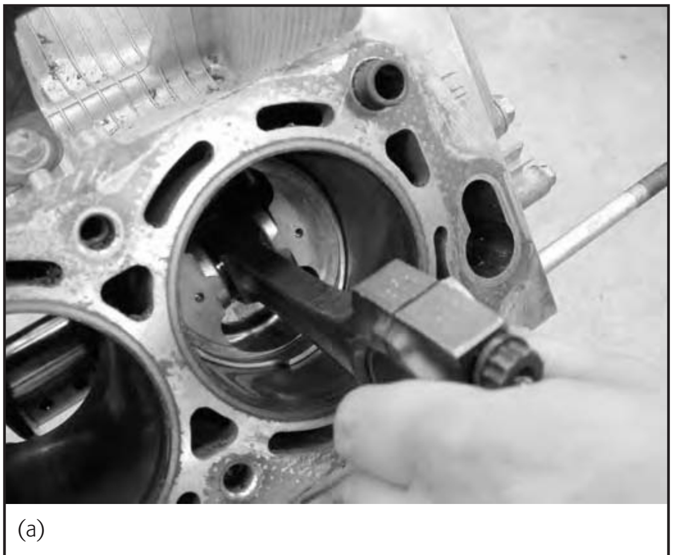


FIGURE 11.27 (a) Insert the ring into the cylinder as shown. (b) Use the piston to square up the ring in the bore. (c) Measure the ring gap just below the ring ridge. *(Courtesy of Tim Gilles)*



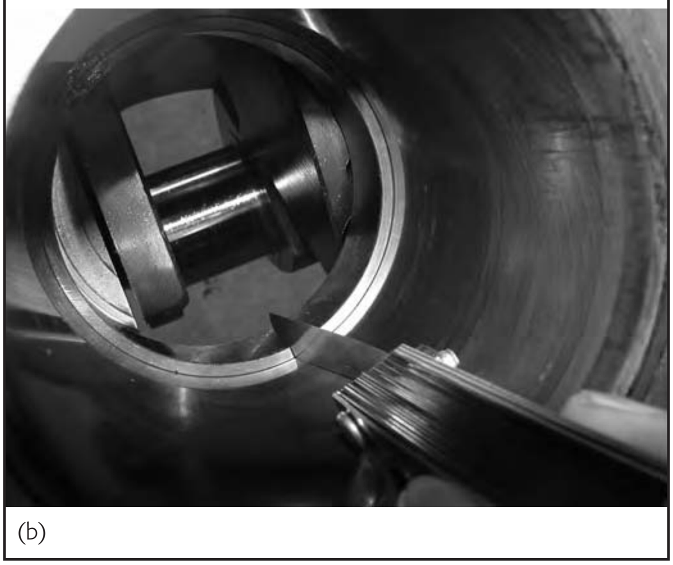


FIGURE 11.28 (a) Push the ring to below normal ring travel. (b) Measure the gap at the bottom of the bore. *(Courtesy of Tim Gilles)*

Reading a Dial Bore Gauge

When you rock the gauge in either direction, away from the shortest distance across the cylinder, the reading on the face of the dial indicator will increase (**Figure 11.30**). To determine the diameter of the cylinder, move the dial bore gauge back and forth and select the smallest measurement.

Dial indicators are comparison instruments because an indicator reading must be compared to a known measurement. **Figure 11.31** shows how an inexpensive dial indicator can be read using a micrometer. A high-quality dial bore gauge has its own micrometer setting fixture (**Figure 11.32**).

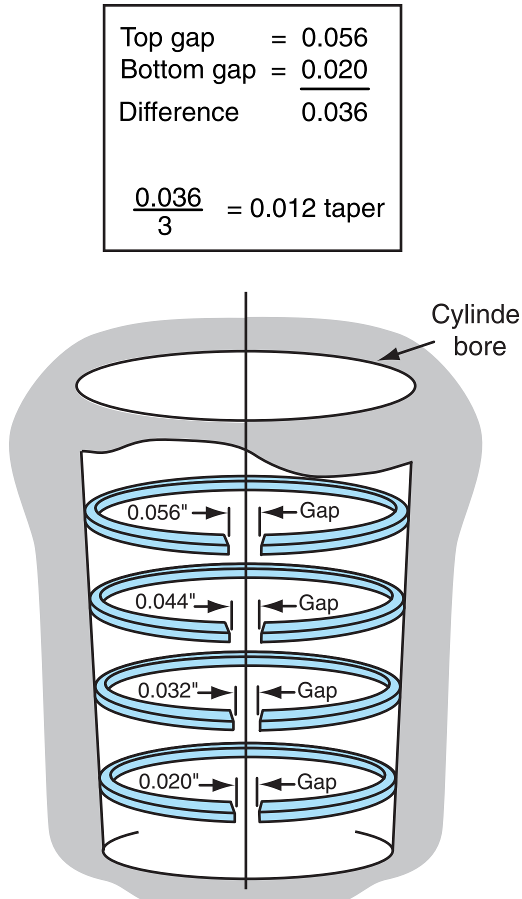


FIGURE 11.29 Effect of a 0.012" cylinder bore taper on the ring gap in a 4" bore.

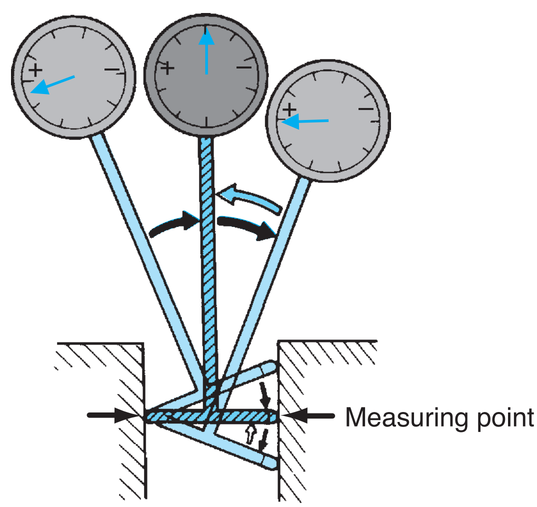


FIGURE 11.30 Rock the dial bore gauge back and forth. Select the smallest measurement.

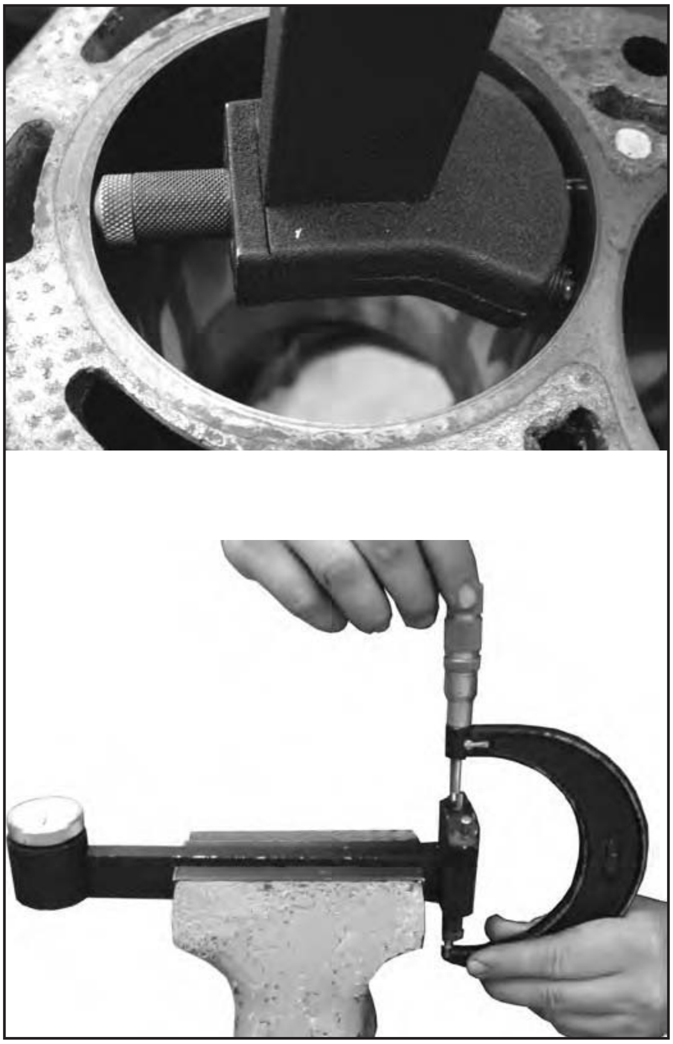


FIGURE 11.31 A dial indicator is measured for comparison.

DEGLAZING CYLINDERS

Cylinders become **glazed** where the piston rings ride against the cylinder wall (**Figure 11.33**). The glaze can be removed with lacquer thinner or with a glaze breaker that leaves a honed, crosshatched pattern (**Figure 11.34**). The purpose of the **crosshatch** is to provide channels to hold oil to promote proper wear-in of the rings to the cylinder walls. As the bore becomes glazed the crosshatch fills, reducing the thickness of the oil film.

The crosshatch angle should be between 20° and 60°. Depending on the speed of the drill motor, stroking about once per second should provide an acceptable crosshatch angle. A drill motor with a rotation speed of approximately 450 rpm works well. If the crosshatch angle is flatter than desired, slow down the drill speed or speed up the stroke rate

FIGURE 11.32 A dial bore gauge measuring a cylinder bore.

(**Figure 11.35**). A crosshatch angle that is too steep will allow oil to run down the cylinder wall; too flat causes too thick an oil film and allows the rings to skate over the film, causing oil consumption.

SHOP TIP

Deglaze the ring contact area of the cylinder only. There is no need to travel through the bottom of the cylinder, which can cause damage to the glaze breaker.

Dana Corporation recommends that engines that are re-rung while they are still in the vehicle should *not* have the glaze broken with a glaze

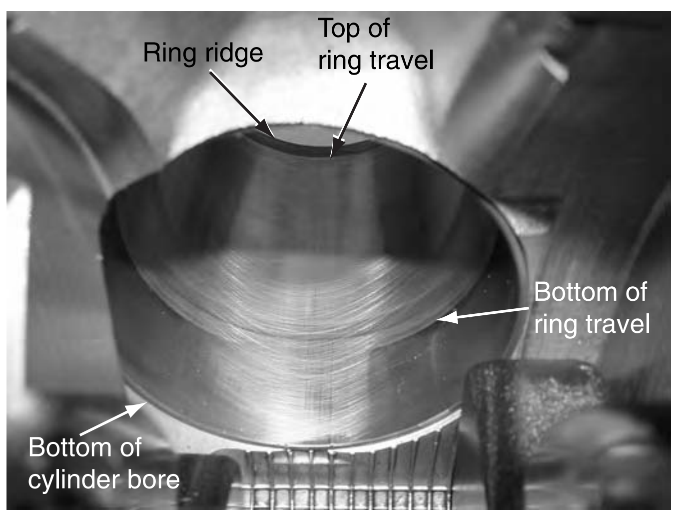


FIGURE 11.33 The glazed area contacted by the piston rings. The crosshatch pattern will still be visible in the unworn area below ring travel. *(Courtesy of Tim Gilles)*

FIGURE 11.34 Crosshatched appearance of a honed cylinder wall. *(Courtesy of Tim Gilles)*

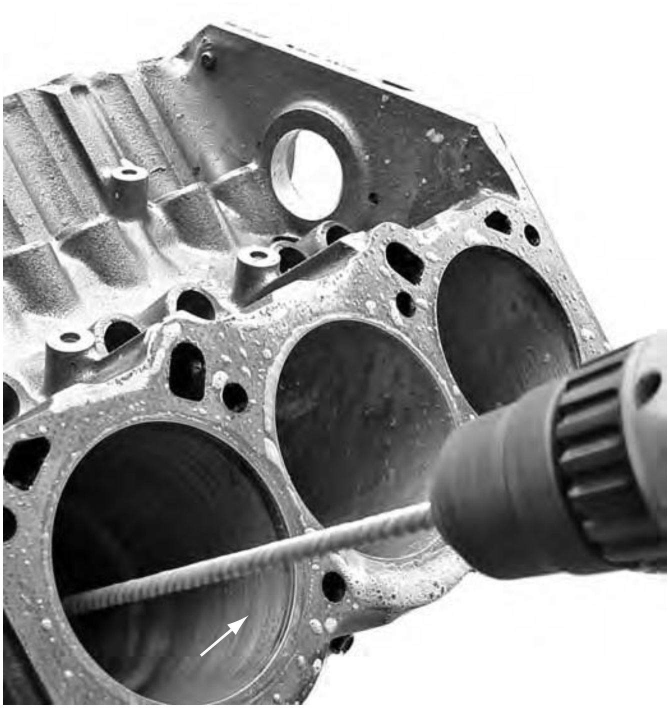


FIGURE 11.35 Watch the pattern in the solvent on the cylinder wall to determine the crosshatch angle. To change the angle, stroke the drill faster or slower. *(Courtesy of Tim Gilles)*

breaker, unless the block is to be thoroughly cleaned afterwards. They feel that glaze breaking is desirable, but that the damage done by leaving grit in the engine outweighs the benefit gained by glaze breaking. If the factory crosshatch is still visible, glaze breaking is not necessary.

When breaking the glaze with the engine in the vehicle, rotate the crankshaft to BDC and put a length of hose on the center of the glaze breaker shaft so it will not accidentally nick the crankshaft. Putting newspaper in the bottom of the bore can also help protect the crankshaft from oily grit.

There are two principal types of glaze breakers. Both are driven by drill motors and cooled with honing oil. Using kerosene as a solvent for honing tends to drive contaminants into the voids in the cylinder wall surface, making cleanup more difficult. The spring-loaded glaze breaker (**Figure 11.36**) removes very little metal. Its main advantage is that its stones highlight worn areas of the cylinder, which helps the technician see scratches and other potential problem areas.

The stones on a spring-loaded glaze breaker can be accidentally broken in two ways:

- Removing the tool from the cylinder while the drill motor is still spinning
- Allowing stones to spin below the bottom of the cylinder bore and come into contact with main bearing webs or crankshaft

The ball-type glaze breaker, or Flex-Hone® (**Figure 11.37**), removes material at a slightly faster rate, but its chief advantage is its ease of use. The Flex-Hone can be rotating as it enters and leaves the cylinder. Although it is not as susceptible to stone breaking, the balls tend to wear off on the bottom end of the hone from repeated contact with main bearing webs. Remember, it is not necessary to stroke all the way to the bottom of the cylinder. Deglaze only to the bottom of the ring travel.

Increasing the size of the cylinder is not the intended use of a Flex-Hone. Flex-Hones remove metal at a much slower rate than rigid hones (covered later in this chapter).

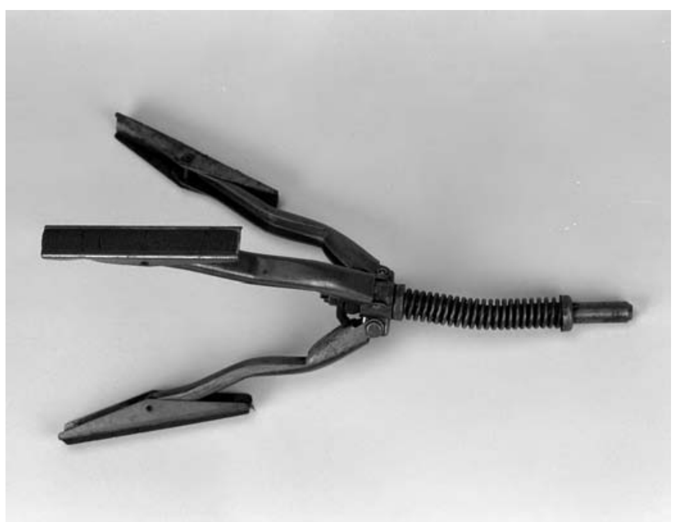


FIGURE 11.36 A spring-loaded glaze breaker.

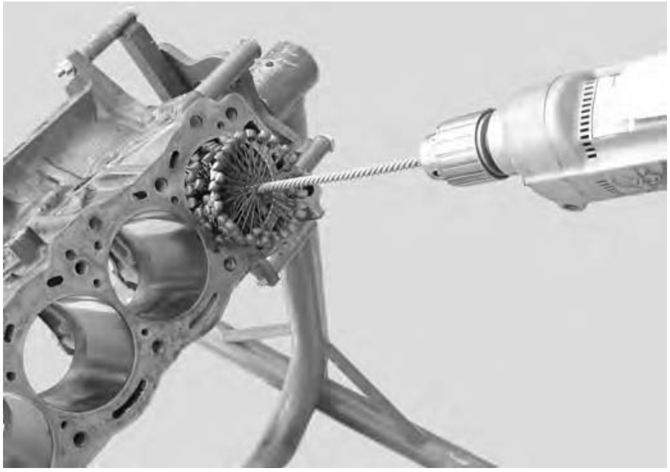


FIGURE 11.37 A Flex-Hone. *(Courtesy of Tim Gilles)*

A disadvantage to the Flex-Hone is that it covers up irregularities in the cylinder, including distortion and taper, rather than highlighting them. Also, Flex-Hones come in different sizes, so it might be necessary to buy several to fit the different bore diameters encountered in the shop. The initial cost will be higher than the cost of a spring-loaded glaze breaker, which can cover diameters of from 2 to 7 inches.

Clean the Block of Grit

A thorough cleanup of the block is necessary after glaze breaking or honing. Grit that remains on the block will rapidly wear out new parts. Clean the block with a stiff bristle brush and hot, soapy water (**Figure 11.38**). The brush can be used by hand or powered by an air drill or battery-operated drill motor. Do not use a 110V drill motor because of the danger of electric shock when used in water.

- Ordinary cleaning solvent will not lift grit from the pores in the metal.
- Check cylinder walls and the crankcase for cleanliness with a clean cloth. Leftover grit will be deposited on the cloth (**Figure 11.39**).
- Following cleaning, grit can often be found in the crankcase area, just under the cylinder bores (**Figure 11.40**). Be sure to check this area carefully to be sure that cleaning has been thorough.

Ferrous parts should be thoroughly coated with oil to prevent rusting, which begins immediately after cleaning.

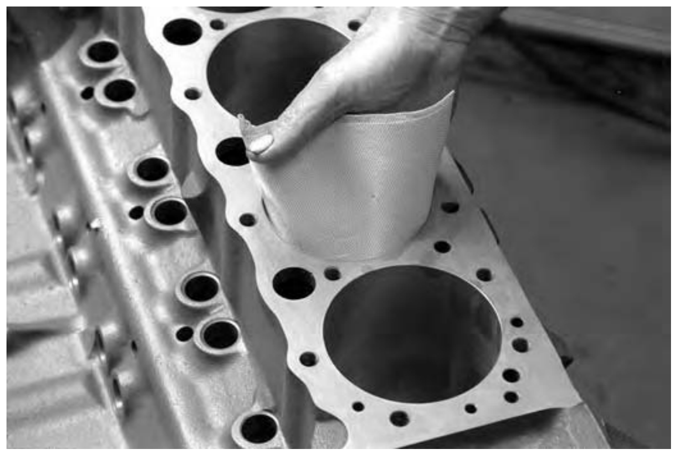


FIGURE 11.39 Use a clean cloth to check a cylinder for cleanliness after cleaning the bores.

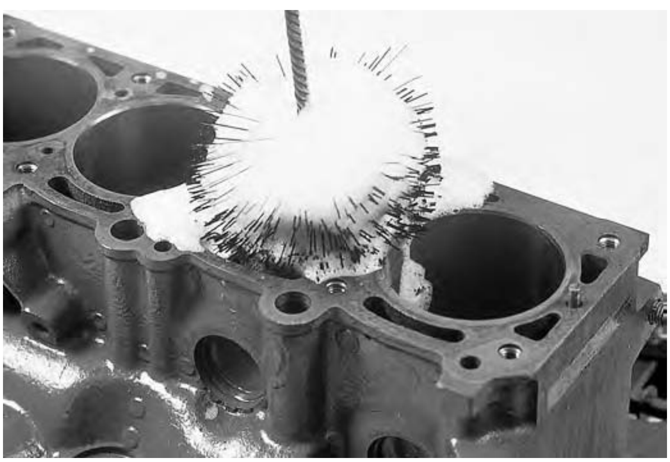


FIGURE 11.38 Clean the cylinder bores with hot, soapy water. *(Courtesy of Federal-Mogul Corporation)*

FIGURE 11.40 Be certain that this area of the block is cleaned thoroughly of honing grit.

VINTAGE ENGINES

For some vintage engines, larger pistons can sometimes be purchased. This will not work with newer engines due to the decreased cylinder wall thickness that results from boring the block. In fact, some later model blocks do not have enough cylinder wall thickness to accommodate boring to 0.060" oversize. Rebuilders subscribe to technical bulletins to keep abreast of any abnormal considerations for particular makes of engines.

REBORING CYLINDERS

Cylinders are deglazed for use with new rings only if they have less than the maximum specified bore taper. Cylinders with excessive or unusual wear or rust should be rebored (**Figure 11.41**). Following boring, cylinders are honed to fit new oversized pistons. Pistons are generally available in oversizes of 0.020", 0.030", 0.040", 0.060", and 0.5 mm, 0.75 mm, and 1 mm.

NOTE

Always check piston size availability before boring a block.

Pistons of 0.030" oversize are commonly used because worn cylinders do not always clean up perfectly when rebored to 0.020" oversize. Using a 0.030" cut for each rebore (0.015" of metal removal from each cylinder side) allows for two rebuilds (0.030" and 0.060") per block, which is usually more than enough; 0.040″ oversize pistons are popular with production engine rebuilders.

SHOP TIP

If a piston has been scuffed or damaged, bore that cylinder first, in case it does not clean up at the desired oversize; an increase of 0.010″ or more might be required.

NOTE

The compression ratio will change slightly when a cylinder is rebored. Boring cylinders oversize increases the compression ratio because it adds to the swept volume: 0.030" oversize will increase the compression by about one-tenth of a ratio; 0.060" results in a change of about one-quarter of a ratio.

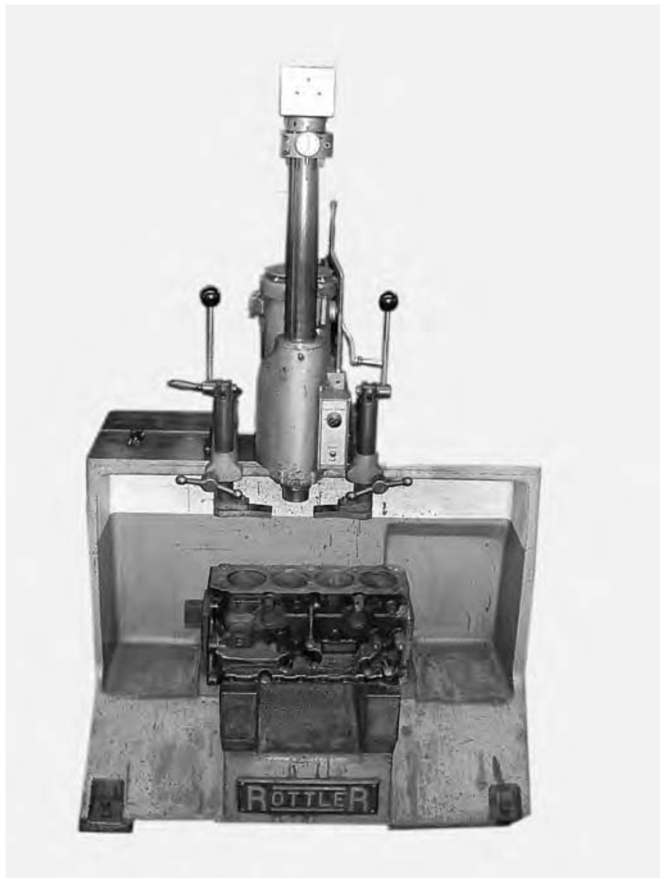


FIGURE 11.41 Boring a block with a boring bar and stand. *(Courtesy of Tim Gilles)*

Ultrasonic Thickness Testing and Core Shift

Cylinder wall thickness can be checked using an ultrasonic thickness gauge (**Figure 11.42**) or a less expensive caliper-type thickness tester (measuring through a core opening). On most late-model engine blocks, standard cylinder wall thickness is about 0.240". Remember from Chapter 1 that cores are used during the casting process to prevent metal

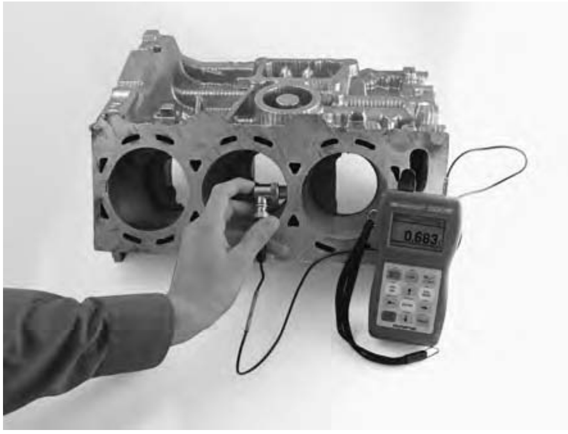


FIGURE 11.42 An ultrasonic thickness gauge. *(Courtesy of Olympus NDT)*

from filling areas like cylinder bores and water jackets. Occasionally during sand casting, the core accidentally moves, resulting in a cylinder wall that is thicker on one side and thinner on the other. A core shift of 0.050" will mean that one side of a cylinder will be 0.025" thicker and the other side will be 0.025" thinner (0.240 – 0.025 = 0.215).

Today's engines are cast with interlocking cores that ensure correct spacing between the cylinder bores. This has eliminated the "core shift" problems experienced in some earlier lightweight castings.

Check the service information for maximum rebore size. When boring a cylinder 0.060" oversize, the cutter removes 0.030" from each side of the bore. The minimum cylinder wall thickness for a 350 Chevrolet after honing is 0.190" on the thrust sides of the cylinder. If 0.190" is the recommended minimum cylinder wall thickness and one side of the cylinder wall was only 0.215" to start with, then boring the cylinder 0.060" will result in a wall thickness of 0.185"—not thick enough. This is an example of why an ultrasonic thickness tester can be a valuable tool in a machine shop.

Testing with ultrasonic sound waves is a *nondestructive test* (NDT). A wide variety of materials can be tested, including metals, ceramics, plastics, and glass. Newer ultrasonic testers are hand-held and can be accurate to 0.0001". A piezoelectric transducer generates pulses of sound waves at frequencies between 500 KHz and 100 MHz. Higher frequencies are used on thicker materials, and lower frequencies are for thinner metals.

The "pulse-echo" test reveals a part's thickness by measuring the time required for the pulse generated by the transducer to travel through the material and echo back to the transducer. A thicker part takes longer for the sound waves to return. The transducer pickup must be at a 90° angle to the part being measured in order to be accurate.

Racing Blocks

Cylinder blocks used in top fuel dragsters are made of solid aluminum forged from a billet. These engines create over 7000 horsepower during a ¼ mile dragstrip run, using nitro-methane fuel at an air-fuel ratio of about 1.5:1—nearly all liquid. They do not have water jackets because they have no cooling system.

Block Distortion

A boring stand is useful when boring and honing a cylinder block, supporting it at the main bearing bores. An iron block will distort considerably when it is allowed to hang. When the block hangs from one end on a conventional engine service stand, cylinders can be up to 0.002" out of round. Boring cylinders while the block is mounted on an engine stand can produce oval-shaped cylinders.

In an effort to improve fuel economy, today's engine castings are about 25% lighter in weight than earlier designs. Lightweight castings often distort when heads and main caps are torqued. Cylinder distortion can be from 0.001" to 0.005". In extreme cases, this distortion can result in piston scuffing because piston clearance is usually between 0.001" and 0.002". Cylinder distortion can result in poor piston ring sealing or piston slap.

Torque Plates

Sometimes a **torque plate** is torqued to the top of the block to stress it and simulate assembled conditions when refinishing cylinders (**Figure 11.43**). A torque plate can also be called a deck plate, honing plate, or stress plate. A typical torque plate is made of 1¾" thick cast iron and is torqued to the block using a head gasket. It is important that the fasteners used on the torque plate are threaded into the block the same depth as normal head bolts and that the torque sequence recommended by the manufacturer is followed. Torque plate manufacturers recommend using two plates on a V-type engine (or using one plate while the other head is torqued in place). Main bearing caps should be torqued in place, also.

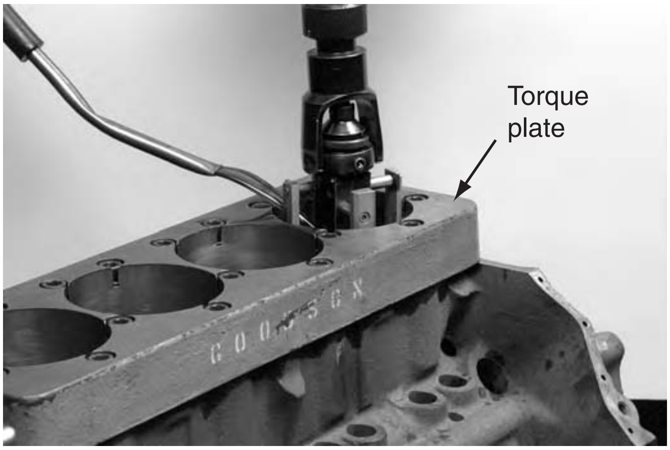


FIGURE 11.43 A torque plate.

SHOP TIP

If in doubt about the need for a torque plate for a particular make of engine, check the block as follows:

- Torque the main caps to the bare block.
- Bolt the heads to the block and torque them.
- From the bottom side of the block, measure the bore with a dial indicator.

Here is another test you can try. First install all of the main caps on a bare block and tighten them. Then remove the bolts and turn the engine upright. Next install the cylinder heads. Did all of the main caps remain in place, or did some of them fall off of the block?

Boring Procedure: Portable Boring Bar

When using a portable boring bar, the deck surface and the bottom of the boring bar must be very clean and free of nicks. A rough whetstone or file can be used to dress off any roughness. The deck surface often has pressed-fit dowels to locate the head gasket to the block (**Figure 11.44**). Their removal is not always necessary, because these can usually be straddled by the bottom of the boring bar. If you need to remove them, they can be pounded in and removed from the water jacket using a magnet.

- Before clamping the boring bar to the block, center it in the cylinder using the catspaws, also called bear paws. These are precision inserts that are screwed to the expandable centering jaws of the boring bar.
- Sharpen the carbide cutting tool to specifications.

FIGURE 11.44 Pressed-fit dowels in the block deck are used to align the head and head gasket. They must be removed if the deck surface is to be machined. *(Courtesy of Tim Gilles)*

SHOP TIP

The cutting tool advances about 0.005" per revolution of the boring bar. To provide a good finish on the cylinder wall, the width of the cutting area of the tip should be no wider than 0.020"; 0.010–0.012" works well.

- As you begin to bore the first cylinder, make a small cut above the ring ridge first. Retract the boring bar and measure the diameter of this cut to verify that the boring bar cutter has been accurately set. If not, reset the cutter and then bore the rest of the cylinder to the corrected size. The previously bored area above the ring ridge will not make a difference as long as it is not so large that it allows the head gasket to leak.
- Bore the cylinder to within 0.0025"–0.003" of the finished bore size.

During manufacture, the *bottoms* of the cylinder bores are chamfered. When the block has been rebored, check the bottoms of the cylinders to see

VINTAGE ENGINES

Older high-tension piston rings were more forgiving about surface finish. Given enough time, they often wear-mated to the cylinder wall. Newer low-tension piston rings do not have this ability.

that some of the original chamfer remains. A sharp edge at the bottom of the cylinder can scrape oil off the piston skirt and result in piston scuffing from too little lubrication.

HONING CYLINDERS TO SIZE

The boring cutter leaves a fine thread and microscopic fractures in the cylinder wall (**Figure 11.45**). Following boring, cylinders are honed to remove these imperfections, providing a surface for new rings that will promote long ring life. The ring and bore do not fit exactly into each other and the honed crosshatch surface provides an area where they can wear into each other.

As the cylinder is cut, small chips break away its surface, leaving cavities that are about 0.001" deep, depending on the condition of the tool bit. Removing 0.001" of metal from the cylinder wall surface by honing will make the cylinder 0.002" larger in diameter. Manufacturers of honing equipment recommend honing to increase the cylinder's diameter by at least 0.0025".

The honing crosshatch holds oil and helps prevent the rings from scuffing the cylinder walls during initial engine break-in.

Honing Cylinders

An automatic honing machine (**Figure 11.46**) can hone eight cylinders to 0.030" oversize in less than an hour. There are also less expensive manually

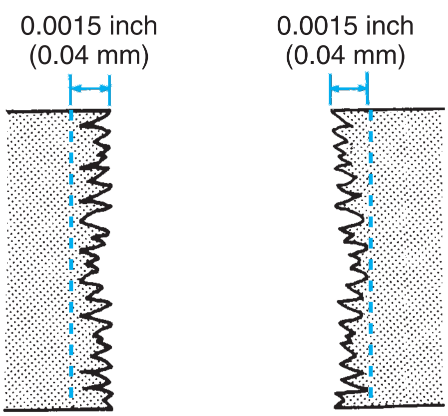


FIGURE 11.45 A bored cylinder wall is very rough. It would cause excessive ring face wear if used "as is." *(Courtesy of Tim Gilles)*

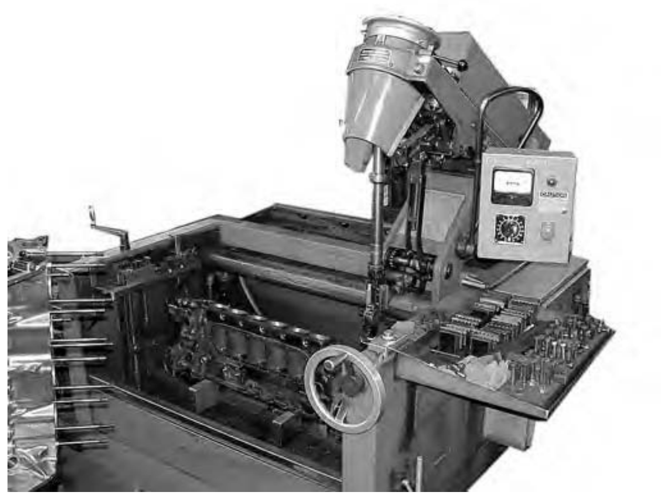


FIGURE 11.46 An automatic cylinder honing machine. *(Courtesy of Tim Gilles)*

operated honing machines that use a **rigid hone** requiring some skill and practice to operate.

- A rigid hone has two stones and two aluminum guides. As stones wear, the aluminum guides are supposed to wear at the same rate.
- As you finish honing each bore, allow the stones to run with very little pressure for several strokes.

When honing a cylinder to size in a honing machine, set the return stop to allow the stones to stroke barely above the top of the block deck. If you allow the hone to move out of the top of the cylinder, the cylinder will become tapered. It will be larger at the top and can be difficult to correct. As the top of the cylinder becomes tapered, the stones become tapered and will, therefore, leave a tapered finish as you continue honing other cylinders. Grinding stones are not forgiving; the stones must be kept true if you are to achieve a true surface.

Cylinders can also be honed with a rigid hone and a large drill motor (**Figure 11.47a**). This requires some skill and practice. First, hone the bottom of the cylinder to size to create a **choke bore** where the bottom of the bore is larger than the top. Next, the size of the top of the bore is quickly increased by stroking the hone several times through the top.

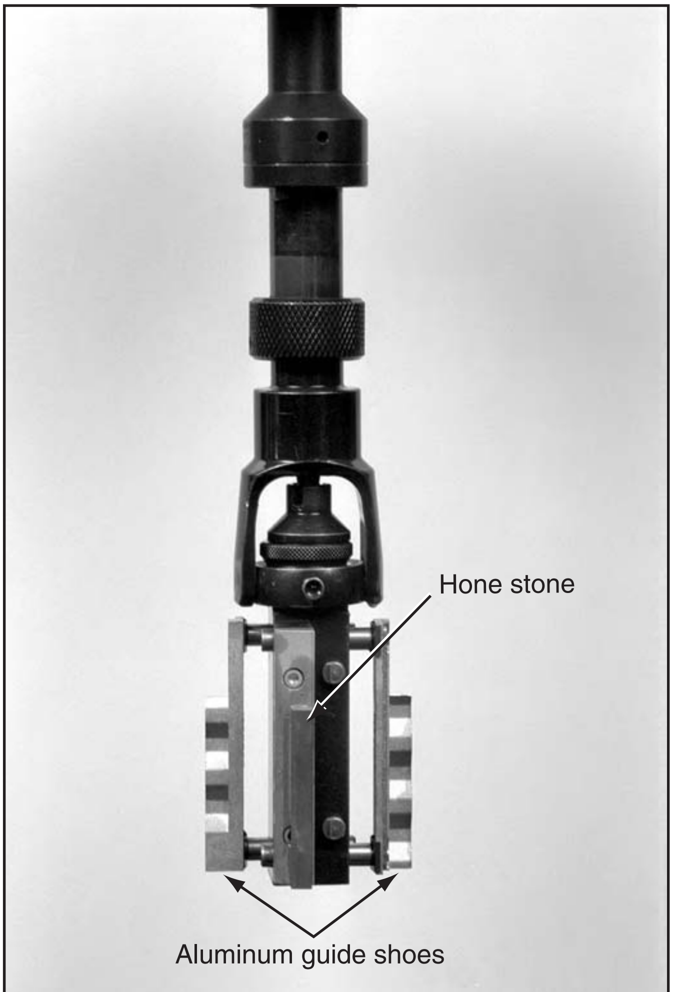
Be careful not to accidentally hit a main bearing web with the bottom of the hone stone. In addition to the damage this can cause, it can be dangerous. There are honing fixtures available that support the drill and limit the travel of the hone in the cylinder, but new honing accuracy requirements make these older methods impractical for all but the most skilled operators.

Hone Stones/Cylinder Surface Finish

Cylinders are honed with diamond, silicon carbide, or aluminum oxide stones of a specified grit. The depth of the groove that a honing stone leaves in the surface is measured in **microinches**.

- One microinch equals one millionth of an inch.
- In a surface of 100 microinches, the average depth of the grooves is 0.0001".
- The higher the microinch number, the rougher the finish.
- The average finish recommended by several manufacturers is from 25 to 30 microinches.
- After about 500 miles of driving, the cylinder finish will measure about 5 microinches.

The chart shown in **Figure 11.47b** displays the various grits and microinch finishes of honing stones (the higher the number, the finer the grit). The boring bar leaves a rough cut finish of 95 to 125 microinches and a finished cut of 55 to 70 microinches, which is too coarse for proper ring seating.



(a)

	Grit	Approximate microinch finish on cast iron
Roughing	70	100
Coarse finish	150	32
Medium finish	220	20
Polishing	280	12
Fine	400	6
Extra fine	600	3

(b)

FIGURE 11.47 (a) A rigid hone. (b) A chart of various hone grits and finishes.

When honing, a rougher stone is usually used first, followed by a 280- to 400-grit stone for finish honing, at least the last 0.0005". Cast iron, chrome, or moly rings will seat after a two-step process that uses a 280-grit stone last. But piston rings often come with specific honing or deglazing recommendations. Sealed Power/Federal-Mogul recommends:

- 280-grit for chrome rings
- 400-grit for moly rings

NOTE

Very fine stones used with moly rings must be honed with a suitable honing oil or kerosene.

A good honing oil cools the block and prevents stone loading by flushing away loose pieces of abrasive and metal. According to the Sunnen Products Company, honing oil also prevents spot welding of the hone to the bore. Spot welding occurs when temperatures rise too high during honing and the sulfur in the oil combines with iron to form iron sulfide, an unweldable compound. To help keep the block cool during honing, use ample lubrication, hone a little at a time, and switch bores occasionally. Do not allow the stones to load up from too little lubrication—this will also cause heat.

NOTE

Softer stones are used to hone harder materials. The material that bonds the stone wears quickly away to expose more abrasive material, resulting in faster cutting action.

Diamond Honing

Engine manufacturers use diamond hones instead of conventional vitrified abrasive stones. Diamond hones cost about 20 times as much as conventional stones. Although they do not remove metal any faster, they hold their shape and have a much longer life, provided they are not accidentally damaged.

Diamond hones are harder and blunter than conventional stones, so more force is applied during honing. This causes more distortion to the cylinder wall. Because more honing pressure is required, a power-stroke hone with sufficient power is needed. Use a synthetic water-based honing fluid instead of honing oil when using diamond hones to finish the cylinder to a rough size. For finishing, silicone polishing paste is used with silicone carbide stones or felt pads. No lubricant is used during the finishing process with silicone paste.

Diamond hones tend to tear the surface metal more than conventional stones during honing, so plateau honing is an even more important part of the finishing process.

Plateau Honing

The Society of Manufacturing Engineers (SME) has approved a technique known as **plateau honing**. Plateau honing is said to reduce cylinder bore wear by 80% and oil consumption by 90%, compared to engines with conventional finishes.

- A coarse (70-grit) stone produces the finished cylinder size.
- Then a very fine (600-grit) stone is stroked through the cylinder for only 45 seconds. The fine stone removes an immeasurable amount of material from the bore.

The theory is that plateau honing eliminates the break-in period for new rings. Normally, peaks left by the hone stone are worn to a plateau finish by the piston rings. Plateau honing removes these peaks instead of allowing the rings to wear them off and deposit them in the engine's lubrication system. Oil is retained in the valleys that remain after finish honing, providing lubrication during the critical moments when the engine is first started.

Piston Clearance

Dana Corporation recommends 0.0015" clearance for its cast automotive pistons. Typical cast pistons are about 0.0015" undersize to the standard bore sizes. For example, a 4.030" piston will actually measure about 4.0285", and a 4.040" piston will measure about 4.0385".

It is a good idea to obtain the pistons before finish honing so the bores can be sized to fit them. There is some variation in sizes of pistons within a set, so measure them all first and mark the size on the piston crown with a felt marker. During honing, larger pistons can be matched to larger bores for a better fit.

SHOP TIP

Be sure that the piston and the engine block are at room temperature before measuring. Sizes change with temperature.

Many engine rebuilders simply bore and hone blocks to the proper oversize and install the pistons without measuring. Some piston manufacturers provide graded pistons, which are sorted and marked for size.

Forged piston clearance is generally 0.0015" to 0.002", although some racing pistons have considerably more clearance. Follow the instructions that come with the pistons, or consult the service literature for the recommended clearance.

Thirty or 40 years ago, it was popular to measure piston clearance with a feeler gauge and a spring scale. But this would be a primitive way of measuring today's close tolerances and is no longer acceptable. A more accurate method of checking clearance is to measure the bore with a dial bore gauge and compare it to the size of the piston. The dial bore gauge is set with a micrometer setting fixture.

CHAMFERING THE CYLINDER

After boring and honing, chamfer the top of the bore so the new rings can easily enter the cylinder without being chipped during piston installation. The top of the bore can be chamfered with a special boring bar cutter, with a chamfering cone and a drill motor, or with a ridge reamer (**Figure 11.48**). The chamfer should be only about 1⁄16".

Hard and Reinforced Cylinder Surfaces

Some aluminum engine blocks use cylinder wall coatings like Nikasil, a thin (0.0025–0.003") hard nickel and silicon carbide coating electrolytically applied to cylinder walls. Used in BMW motorcycles since the early 1980s, it has also been used by Mercedes, BMW, Porsche, Jaguar, Cadillac, Lotus, NASCAR, snowmobile and outboard motor manufacturers, and others. One reported problem with Nikasil coatings when used with older lower-quality high-sulfur gasoline was upper cylinder wall wear. The result was a rough idle and sometimes hard starting. There are other alloys used to plate cylinder walls, including Alusil, Lokasil, and Galkinal (chrome).

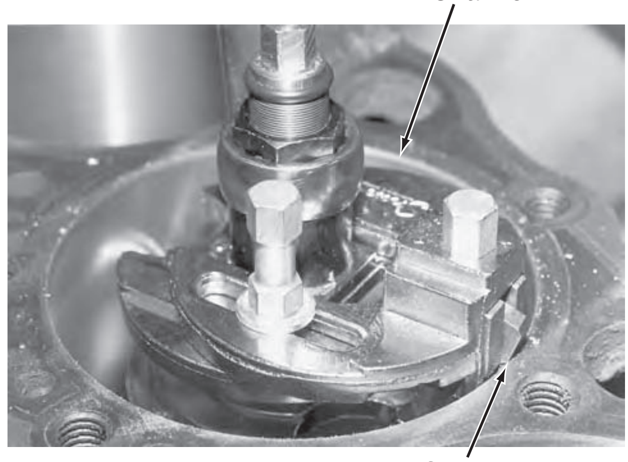


FIGURE 11.48 Chamfering the top of the bore after re-boring using a ridge reamer. *(Courtesy of Tim Gilles)*

Some aluminum blocks, including many Hondas, use cylinder bores of fiber reinforced metal (FRM), also called metal matrix composite (MMC). Aluminum is cast into a sleeve-shaped fiber matrix installed in the block. The result is a strong reinforcement with lower friction characteristics than cast iron. These engines are not typically rebored oversize more than 0.010", and reconditioning these bores should be done only by a machine shop qualified in this specialized work. Many sport compact enthusiasts choose to install iron cylinder sleeves in these blocks.

When hard sleeves are refinished, diamond stones are typically used for rough honing, followed by a finish process in which the hone stones are replaced with felt pads. The felt pads and cylinder bores are coated with silicone polishing paste (used without honing oil) to polish the cylinder wall, exposing silicon crystals in the surface of the metal. The silicon is very hard and provides a superior wear surface.

CYLINDER SLEEVES

Sometimes the block has a serious defect or a cylinder wall is cracked or rusted (see Figure 11.3). If all other cylinders are in good shape, the damaged one can be bored oversize to accept a dry **cylinder sleeve** installed with an interference fit. If the original bore is cracked, the crack must not go all the way to the top or bottom. The recommended interference fit is 0.0005" per inch of cylinder bore.

Thus, a 4-inch bore would require the block to be bored 0.002″ smaller than the outside diameter of the sleeve. The final cut with the boring bar should be less than 0.040" to ensure that the cylinder is round and true.

After a period of storage on the shelf, a sleeve will probably not be perfectly round.

- Measure the top of the sleeve at three places 120° apart.
- Repeat this at the bottom.
- Add the six measurements together and divide by 6 to find the average outside diameter of the sleeve.

Sleeves are available in ⅛" and 3⁄32" wall thicknesses and are available in precut sizes or in unfinished longer lengths. Uncut sleeves can be cut to slightly longer than their finished length before installation using a saw or a lathe (**Figure 11.49**). The outside edge of the bottom of the sleeve and the top edge of the cylinder bore should be chamfered or rounded to prevent sleeve galling during installation.

A sleeve can be cooled using dry ice (**Figure 11.50**) soaked in a bucket of kerosene or acetone—liquids that will not freeze unless subjected to very low temperatures. Shrinking the sleeve in this mixture simplifies installation.

- Chill the sleeve or heat the block to about 200°F (93°C).
- Apply a lubricant such as silicone spray when installing a dry sleeve.
- Pound or press the sleeve into the block.

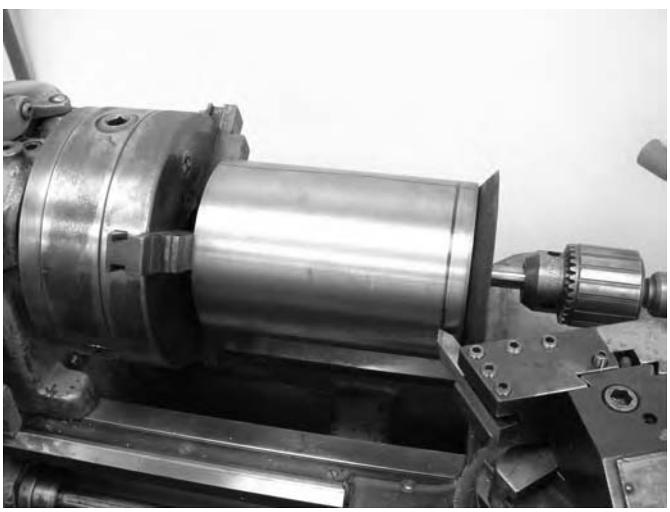


FIGURE 11.49 Using a lathe to cut a sleeve to length. *(Courtesy of Tim Gilles)*

FIGURE 11.50 This sleeve has been cooled in dry ice mixed with kerosene. *(Courtesy of Tim Gilles)*

With the block hot or the sleeve cold, the sleeve should fit easily into the hole in the block. It will become tight when the temperatures of the sleeve and block equalize. If the fit of the sleeve is a little too tight, it can be driven in quickly. A driving tool can be made out of an old rear-wheel-drive axle. Hydraulic-assist press installation tools are also available. Sleeves can be installed in a four cylinder block using a stationary hydraulic press.

After the sleeve has been installed, a small amount of material remains above the block deck surface (**Figure 11.51**). The top of the sleeve is finished flush with the block using a special cutter bit in the boring bar. Then the inside diameter of the sleeve is finished to size.

NOTE

The inside diameter (I.D.) of the sleeve is usually less than a standard bore, so it can be bored to original standard diameter.

One popular sleeving method is to make a step in the bottom of the bore by cutting the cylinder only to within ⅛" or ¼" of its bottom. The bottom of the sleeve will rest on this step (**Figure 11.52**). When the

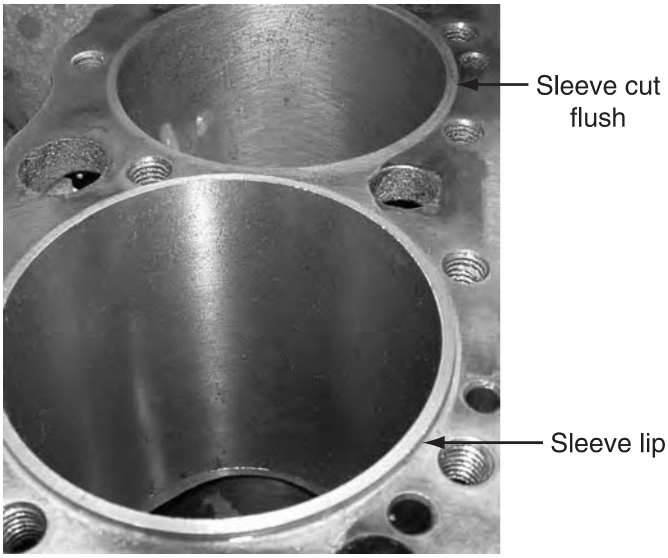


FIGURE 11.51 The lip of the sleeve will need to be cut. The top of the sleeve on the adjacent cylinder has already been cut. *(Courtesy of Tim Gilles)*

I.D. of the sleeve is bored to size, the line between the sleeve and step in the block will be almost impossible to see (**Figure 11.53**). Many machine shops use this procedure. Cylinders are often cut away at the bottom to provide clearance for the rod bolts or crankshaft counterweights. One advantage to cutting the bore to a ledge is that you will not need to spend additional time machining another clearance scallop on the bottom of the new sleeve.

Occasionally, more than one cylinder might be cracked, requiring sleeves. If the value of the block warrants the cost, *all* of a block's cylinders are sometimes sleeved. When the bores of a block are already at maximum oversize, a block can be salvaged by sleeving. Also, cylinder walls sometimes become too thin when a cooling system has been neglected and becomes corroded or has been run with salt water, as in a boat, for example. Some rebuilders of boat engines protect the inside of the water jackets with a ceramic coating on the thoroughly cleaned surface.

SHOP TIP

When all of the cylinders are to be sleeved, do not bore them in succession; do every other one to avoid straining and distorting the block.

LIFTER BORES

Lifter bores in cam-in-block engines must be clean to ensure that the lifters will spin. The bores

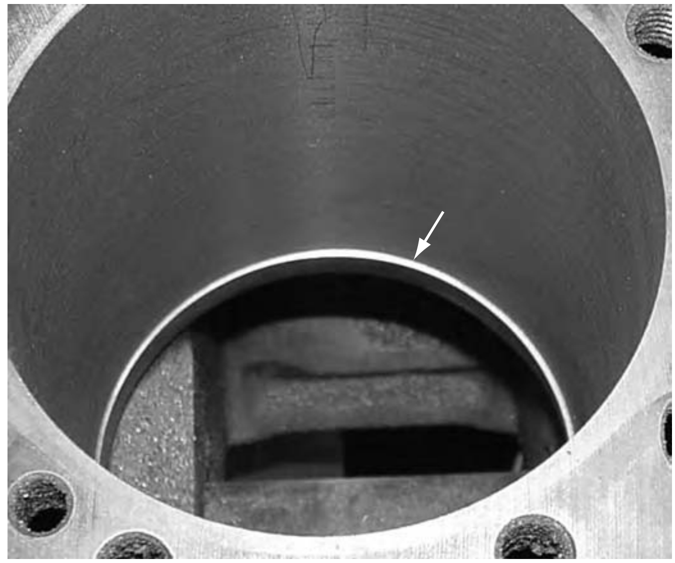


FIGURE 11.52 The sleeve will be pressed into the bore until it contacts the lip left during boring. *(Courtesy of Tim Gilles)*

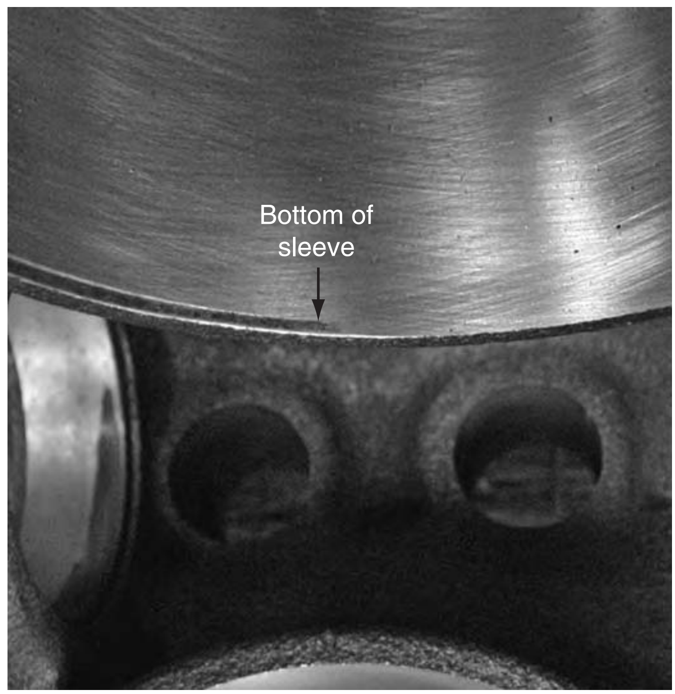


FIGURE 11.53 The lip at the bottom of the sleeve is only visible on part of this finish-honed cylinder. *(Courtesy of Tim Gilles)*

can be lightly cleaned with a brake Flex-Hone. Occasionally, a manufacturer will use a special oversize lifter in one bore to correct for an assembly line mistake that would ordinarily cause the block to be scrapped. Oversized bores are *usually* marked (**Figure 11.54**), but sometimes they are not. If you install a lifter that is excessively loose, the engine oil pressure will suffer. The old, oversized lifter can be reground and reused, or a new one *might* be available through the new car dealer.

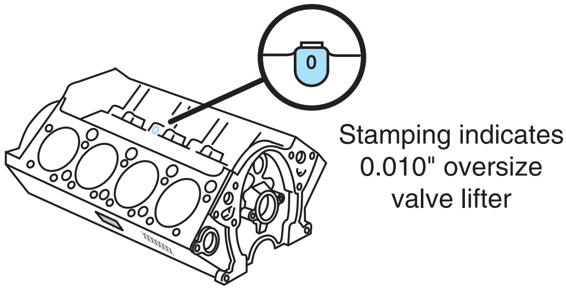


FIGURE 11.54 An oversized lifter bore is usually marked.

FINAL BLOCK PREPARATION

Clean the block with soap and hot water, as described earlier. Then lubricate it thoroughly. It is important to clean the bolt holes in the block. Failure to chase the threads can result in incorrect torque, which can lead to a leaking head gasket. Head bolt holes often run into water jackets, and rust sometimes accumulates at the bottom of the thread beneath the bolt. Threads can be *chased* with a thread chaser or the correct size tap (see Chapter 16). Rust is very hard so be very careful not to break a tap.

All bolt holes must be chased if the block is hot-tanked. A layer of corrosion builds up on the inside of the threads. *Use eye protection*, and blow out the holes with compressed air. If the surface of the block has been decked, chamfer the bolt holes at the top (**Figure 11.55**) to ensure that no burr is left above the block surface.

Clean oil galleries with a rifle brush before installing the gallery plugs (see Figure 11.6). This is extremely important. Failure to thoroughly clean the oil galleries often leads to an engine failure.

Oil Gallery Plug Installation

Threaded oil gallery plugs should be coated with sealer and tightened into the block (see Chapter 16). Be careful not to overtighten threaded plugs which have tapered threads that wedge tightly to the block.

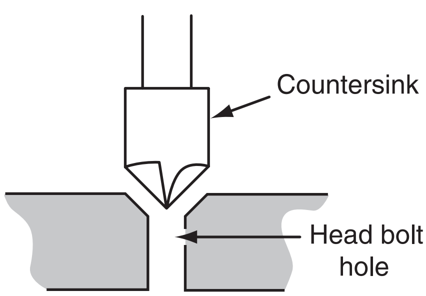


FIGURE 11.55 Bolt holes can be chamfered with a countersink.

If an oil gallery plug comes out of its bore, the engine will lose oil pressure. Oil gallery pressed-fit core plugs should be installed with red Loctite®. Cross stake the outside of the gallery holes with a cold chisel to prevent high oil pressure blowing the plugs out (**Figure 11.56**). A special oil gallery staking tool is also available.

Coolant Core Plug Installation

Before installing the core plugs, clean the core holes in the block with emery cloth (**Figure 11.57**).

- Core plugs are interference fit. Put sealer on the outside of a core plug (**Figure 11.58**) and drive it into the block (**Figure 11.59**).

FIGURE 11.56 Oil gallery core holes are cross-staked with a cold chisel. If the plugs come out, the engine will lose oil pressure. *(Courtesy of Tim Gilles)*

FIGURE 11.57 Clean the core holes in the block with emery cloth or sandpaper. *(Courtesy of Tim Gilles)*

FIGURE 11.58 Putting sealer on the core opening prior to core plug installation. *(Courtesy of Tim Gilles)*

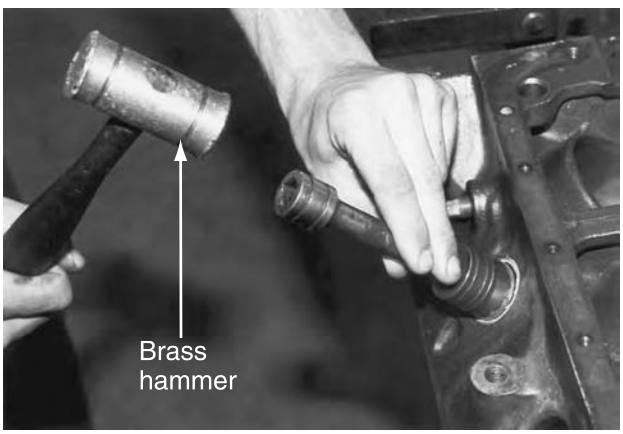


FIGURE 11.59 Drive in the core plug. Be sure to use a brass hammer to avoid damaging the tool. *(Courtesy of Tim Gilles)*

- A core plug is installed correctly when its lip is just past the chamfer on the block. Be sure to install core plugs to the right depth (**Figure 11.60**).

NOTE

Select a tool ⅛" smaller than the inside diameter of the core plug. A driving tool that is too small can distort the plug, causing it to leak; one that is too tight will get stuck in the core plug when the plug is driven into the block. The core plug shown in **Figure 11.61** was installed incorrectly by pounding on its outer sealing lip.

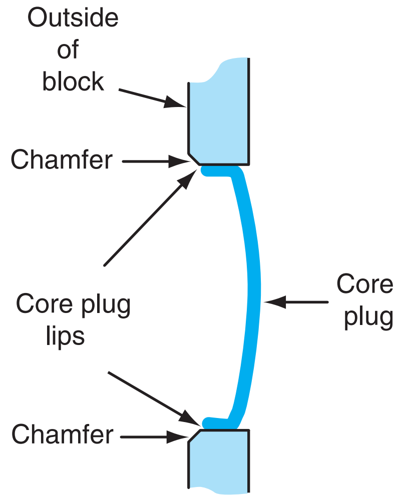


FIGURE 11.60 Install the core plug until its lips are past the chamfer in the block.

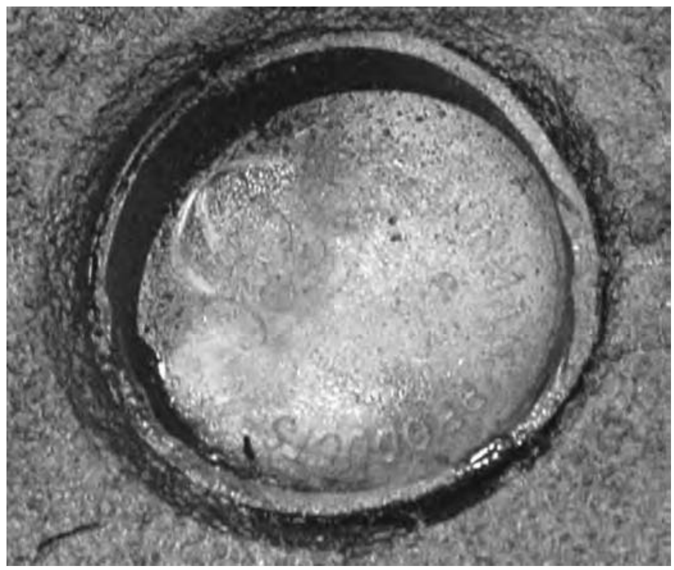


FIGURE 11.61 This core plug was installed incorrectly by pounding on its outer sealing lip. *(Courtesy of Tim Gilles)*

- Core plugs of the same diameter can have different depths (**Figure 11.62**). Be certain that you are installing the correct core plug.

Some engines have expansion plugs. This type of core plug must be expanded after installation by pounding on its center (**Figure 11.63**). A rule of thumb is to indent the center of the *expansion plug* by an amount equal to the curvature of the plug. GM recommends up to 0.020". Ford 6.9 and 7.3 liter diesels require a special installation tool.

FIGURE 11.62 These core plugs are the same diameter but have different depths. *(Courtesy of Tim Gilles)*

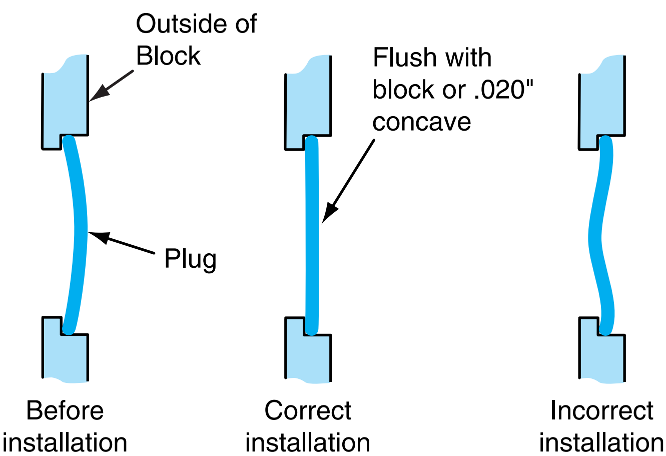


FIGURE 11.63 Installing an expansion plug.

CAM BEARINGS

Later model OHC heads are made of aluminum. Some have half-shell insert bearings, but most designs use the aluminum bore as a bearing surface. Cam-in-block (pushrod) engines have interference fit full-round bearing inserts that are pounded into bearing bores in the block. This section of the text refers to cam bearings in pushrod engines, most of which are made from seamless steel tubing with bearing lining material bonded to the inside. Heavy-duty cam bearings are made in flat strips. The layer, or layers, of lining material are bonded to the strip, and the strip is rolled to form the bearing. The seam is either interlocking or straight (**Figure 11.64**).

Cam bearing-to-cam journal oil clearance recommendations vary from 0.0015" to 0.0055".

Cam Bearing Installation

It is easiest to install the cam bearings in a pushrod engine *before* the crankshaft is installed so you can align the oil holes in the bearings to the corresponding holes in the block. It will also be easier to shave off any high spots on the bearing that occur during bearing installation. Before you install the cam bearings, be certain that the bearing bores are clean and that any high spots at the outer edges of the bearing bores have been deburred.

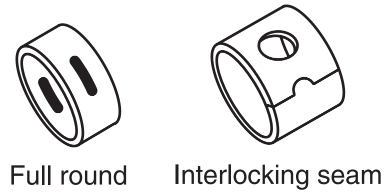


FIGURE 11.64 Cam bearings.

Cam bearings are interference fit; the outside diameters of the bearings are larger than their corresponding bearing bores in the block. When the journals on the camshaft are different sizes, the smallest is at the rear of the block. New bearings can be checked for approximate fit by putting them on cam bearing journals before installation.

Cam bearings are labeled with a part number stamped on the outside diameter (**Figure 11.65**). They are usually supplied in a box. Bearing positions in the block are printed on one of the box tabs (**Figure 11.66a**) or on a separate label (**Figure 11.66b**).

NOTE

A typical set of cam bearings is inexpensive. But if one bearing is accidentally ruined during installation, it will cost almost as much for a single replacement bearing as for an entire cam bearing set.

FIGURE 11.65 The part number for a cam bearing is stamped on its outside diameter. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Some vintage blocks were known for having incorrect cam bearing bore sizes. The inside diameters of the bearings in these blocks were machined at the factory after the bearings were installed in the block. Occasionally, replacement bearings are too tight and the bearing I.D. will need to be machined to provide the correct cam journal oil clearance. Measure the bearing I.D. while the bearing is installed in the block and compare this measurement to the size of the corresponding cam journal to determine how much metal should be removed from the bearing. A machine shop can cut the inside diameter of the bearings using a lathe.

CASE HISTORY

An apprentice was installing cam bearings in an in-line six cylinder mounted on a universal engine stand. After all of the bearings were installed, he attempted to install the camshaft in the block but it would not go in. Light was visible between one side of the cam journal and the cam bearing. The lead machinist suggested that the block be removed from the engine stand and rested on a workbench. After this was done, the camshaft went easily into the block. The block had been sagging under its own weight.

Cam Bearing Installation Tools

There are several ways of installing cam bearings. Some bearing driver sets have a number of individually sized mandrels. Others use a threaded tool to pull the bearing into place. The most popular style is a universal type that expands a mandrel and rubber O-rings to fit snugly against the cam bearing during installation (**Figure 11.67**). A large hammer is used to drive the bearing into position (**Figure 11.68**).

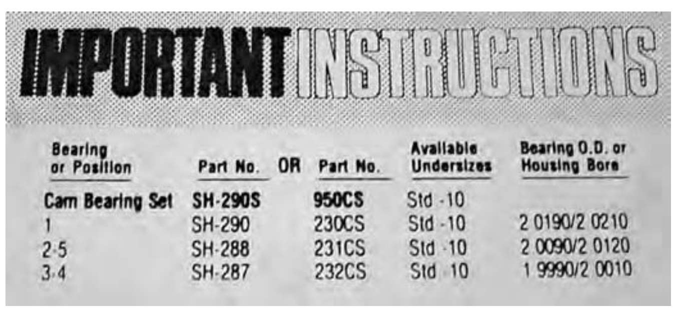
Be sure to lubricate the outside of the bearing before driving it into the block.

Universal Cam Bearing Tool

The following are concerns when using a universal cam bearing tool:

- A special washer must be used with the driver, or the tool's mandrel pieces may be ruined.

(a)



IMPORTANT INSTRUCTIONS

Bearing or Position	Part No.	OR	Part No.	Available Undersizes	Bearing O.D. or Housing Bore
Cam Bearing Set	SH-290S		950CS	Std -10	
1	SH-290		230CS	Std -10	2 0190/2 0210
2-5	SH-288		231CS	Std -10	2 0090/2 0120
3-4	SH-287		232CS	Std 10	1 9990/2 0010

(b)

FIGURE 11.66 (a) The tab on this box lists cam bearing part numbers and their positions in the block. (b) A cam bearing instruction label is sometimes included with a set of cam bearings. *(Courtesy of Tim Gilles)*

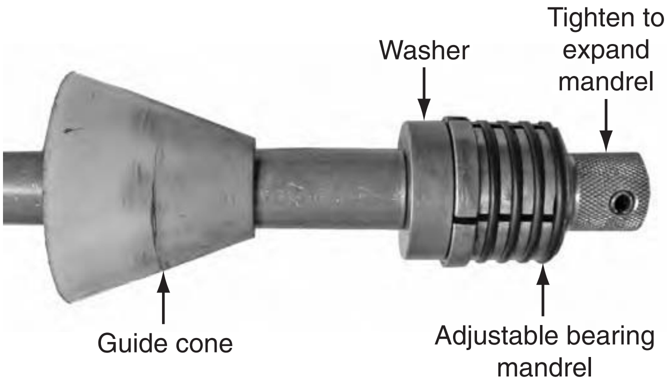


FIGURE 11.67 A universal cam bearing tool has an expanding mandrel and rubber O-rings. *(Courtesy of Tim Gilles)*

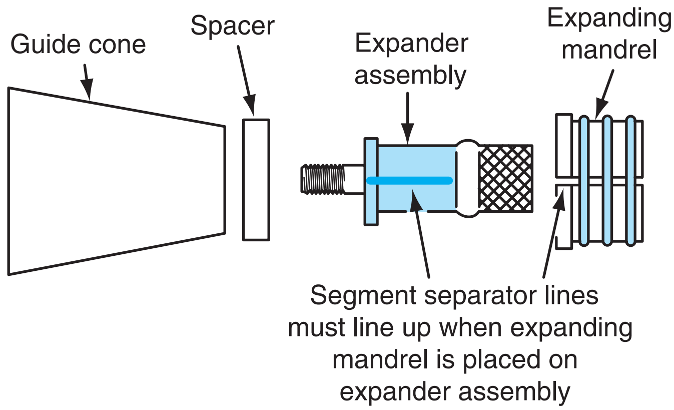


FIGURE 11.69 A universal cam bearing driver.

FIGURE 11.68 A large hammer is used to drive the cam bearing into its bore. Hold the guide cone tightly against the front bearing bore to align the tool. *(Courtesy of Tim Gilles)*

FIGURE 11.70 The cam bearing is assembled onto the tool after positioning it in front of the correct bearing bore. *(Courtesy of Tim Gilles)*

Washers of two different sizes are provided with the tool. Use the largest washer possible. Too small a washer can result in broken tool segments. Line the segments up with the spaces in the mandrel, as shown in **Figure 11.69**.

- Starting with the rear bearing, insert the cam bearing through the opening in the bottom of the block. Slide it onto the cam bearing mandrel and tighten it as shown in **Figure 11.70**. Be sure that the cam bearing is positioned against the shoulder of the mandrel as shown in **Figure 11.71.**
- When starting a bearing into a bore, tighten the tool as tightly as possible by hand. Give the tool one sharp rap with a large hammer, and then loosen the mandrel approximately one-eighth turn before continuing. Be sure to check this adjustment occasionally when driving the bearing into place because the tool will sometimes loosen, which can ruin the bearing.
- Hold the guide cone tightly against the front of the block as shown in Figure 11.68 and hold the cam bearing driver snugly against the bearing during installation so it does not bounce; otherwise the end of the bearing can be damaged.

Figure 11.71 shows a cam bearing as it is first being pounded into its bore and **Figure 11.72** shows the bearing after installation is complete.

FIGURE 11.71 Start the bearing into its bore. Then loosen the mandrel bolt ⅛ turn. Be certain the bearing is positioned against the shoulder of the mandrel. *(Courtesy of Tim Gilles)*

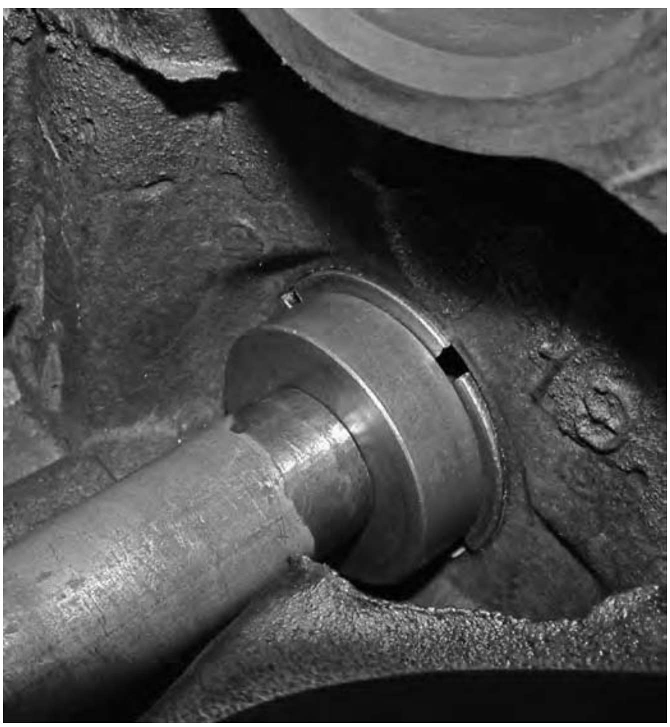


FIGURE 11.72 The cam bearing is fully installed in its bore. *(Courtesy of Tim Gilles)*

Although cam bearings are usually chamfered on the outside edges of both sides, some are chamfered only on one side. Be certain that the chamfer is facing the bore before installing a bearing. The interference fit is approximately 0.002" to 0.003" to prevent rotation of the bearings in the block while the engine is running. A large hammer is needed to overcome this interference fit. Lubricating the outside of the bearing with 90- or 140-weight oil makes installation much easier.

SHOP TIP

Chamfer the inside edge of the bearing with a scraper if it is not already chamfered (**Figure 11.73**).

NOTE

Installation of straight seam cam bearings is difficult, if not impossible, with an expanding mandrel (**Figure 11.74**).

Positioning the Oil Hole. Follow the manufacturer's recommendations when positioning the oil hole. When there is an oil groove around the total cam bore in the block (see Figure 11.2) Federal-Mogul recommends that you install the bearings with their oil holes positioned between two o'clock and four o'clock when the engine is viewed upright from the front (**Figure 11.75**). This oil hole placement allows oil to enter the bearing easily and to float the cam as it rotates.

FIGURE 11.73 Chamfer the inside edge of the cam bearing with a bearing scraper before installation if the chamfer is missing. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Some engines, such as the small block Chevrolet V8, have a rear cam bearing bore that is wider than the bearing and must be pounded past the edge of the bore to correctly center the lubrication hole (**Figure 11.79**). The engine can suffer a total loss of oil pressure if the bearing oil hole is not aligned with the block oil groove.

A student rebuilt a small block Chevrolet and installed it in the vehicle. When the engine was started it had no oil pressure at idle, although raising the engine speed produced normal oil pressure.

The engine was removed and disassembled to determine the cause of the problem. The rear camshaft bearing had been installed flush with the front of the bearing bore, but the alignment of the oil hole had not been confirmed using a piece of wire. The oil groove that is supposed to line up with the oil hole in the bearing was partially uncovered because the bearing had not been installed all of the way into the bore. This resulted in a loss of engine oil pressure that returned to normal when the engine was revved high enough for the oil pump to produce enough volume to fill the leak and build pressure.

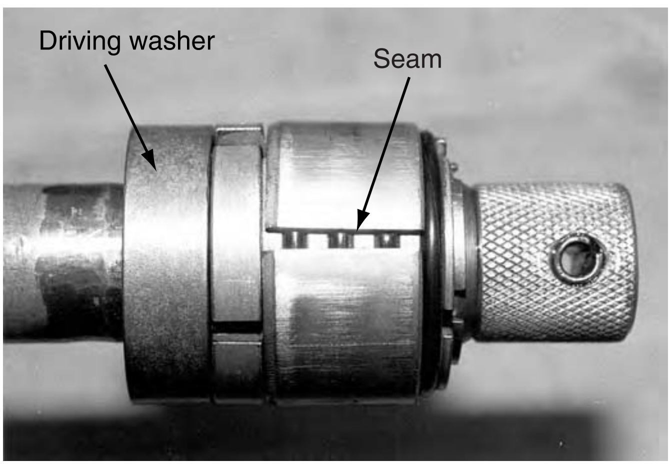


FIGURE 11.74 An expanding mandrel driver with straight seam cam bearing. Note the opening at the seam, which makes installation into the block impossible. *(Courtesy of Tim Gilles)*

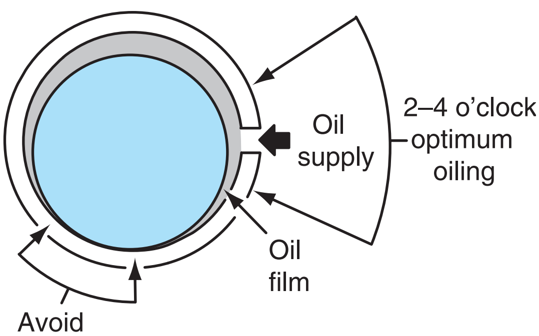


FIGURE 11.75 Position the oil hole so that oil is carried under the cam as it rotates.

Avoid positioning the oil hole between the five o'clock and eight o'clock positions because the camshaft rests against the bottom of the bearing until the oil film lifts it. **Figure 11.76** shows typical cam bearing wear at the bottom on a pushrod engine.

Double-check the alignment of the oil hole using a mirror (**Figure 11.77**) and a piece of bent wire or welding rod (**Figure 11.78**). Some installations are especially difficult to see. You can file a notch on the

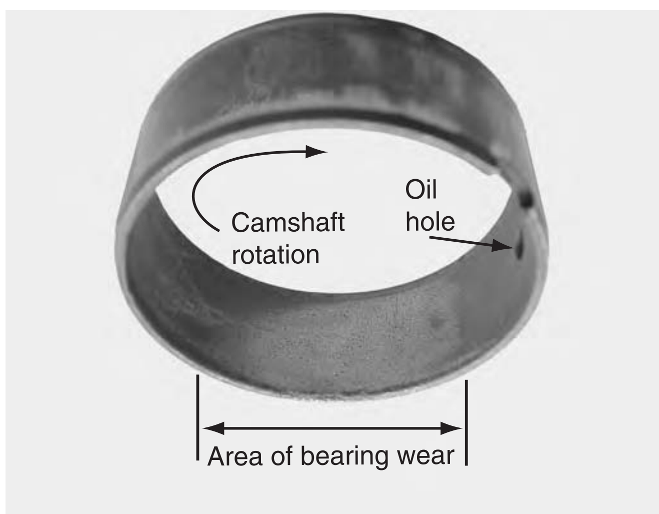


FIGURE 11.76 Typical cam bearing wear is at the bottom. Note the location of the oil hole. Was this bearing correctly installed? *(Courtesy of Tim Gilles)*

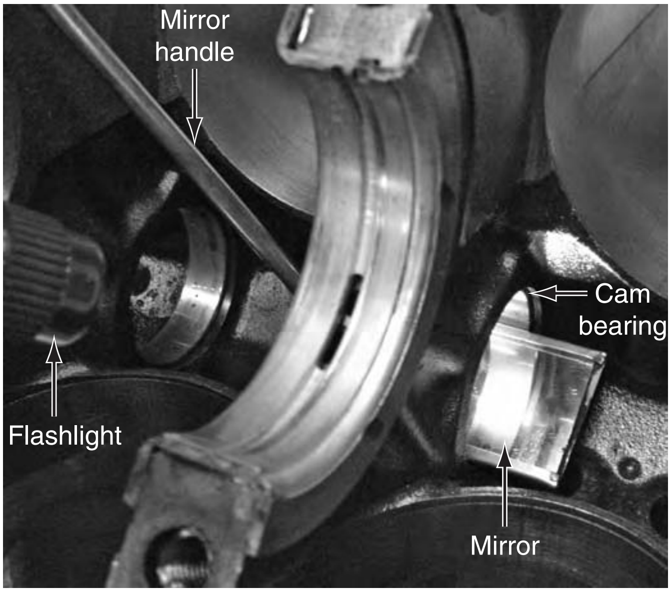


FIGURE 11.77 Verify cam bearing oil hole alignment with the oil gallery in the block.

FIGURE 11.79 Correct installation of this cam bearing called for pounding it past the outside edge of the bearing bore. Note the bearing hole correctly positioned at three o'clock. (Remember, this engine is upside down.) *(Courtesy of Tim Gilles)*

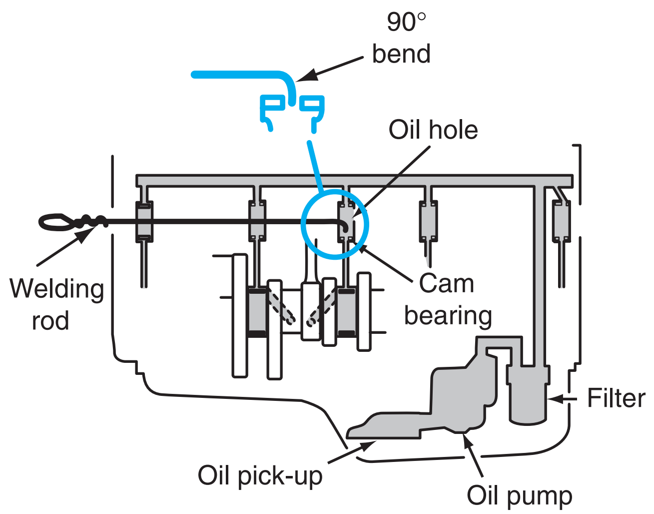


FIGURE 11.78 Using a bent welding rod to check oil hole alignment.

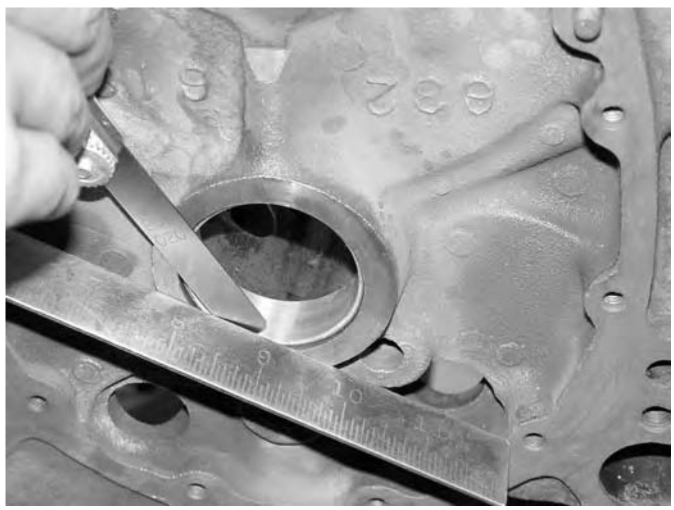


FIGURE 11.80 Install the front cam bearing below the front of the block surface to allow for timing chain oiling. *(Courtesy of Tim Gilles)*

outside edge of the cam bearing even with the oil hole, or use a felt marker or white correction fluid to mark the location of the oil hole on the block. If the bearing is accidentally driven beyond the oil hole, drive it the rest of the way through the bore and then reinstall it.

Front Cam Bearing Installation. The timing sprockets and chain are lubricated from the front cam bearing, which is often installed past the block surface (**Figure 11.80**). This creates an oil channel at the rear of the cam sprocket, which throws oil onto the timing chain. When a front cam bearing has a notch cut into it (**Figure 11.81**), the bearing is installed with the notch facing the cam sprocket.

Checking Bearing Fit. Following cam bearing installation, check for any high spots and shave them off the bearing surface using a suitable scraper or knife (**Figure 11.82**). A high spot can sometimes be located by painting the bearing with Dykem blue and then

FIGURE 11.81 Some front cam bearings have an oil groove to provide oil to the timing sprocket and chain. *(Courtesy of Tim Gilles)*

installing the camshaft and rotating it. The high spot will become polished.

NOTE

Do not sand bearings with emery cloth because pieces of emery grit can become embedded in the bearing surface (see Chapter 12).

- You can make a cam bearing reamer by grinding grooves into the journals of an old cam core.

FIGURE 11.82 This bearing scraper, made by hollow-grinding and sharpening a triangular file, is being used to scrape a burr from the outer edge of the front cam bearing. *(Courtesy of Tim Gilles)*

As the tool is turned, it shaves off any high spots from the bearing.

- A Flex-Hone is available for honing small amounts from the cam bearing surface.
- You can use 1500-grit wet or dry sandpaper or crocus cloth to polish cam bearing surfaces if necessary.

Key Terms

choke bore
crosshatch
cylinder sleeve
decking a block
glazed
line boring or honing
microinches
plateau honing
rigid hone
torque plate

Study Questions

1. After hot-tanking and rinsing a block, what should be done to all machined surfaces?
2. Where would NPT threads be found on a cylinder block?
3. What kind of socket can be used to remove a male gallery plug?
4. Besides taper, what is another type of cylinder bore wear?

5. What is the maximum amount of bore taper allowed in cylinders using conventional cast iron rings?
6. To check cylinder taper using a piston ring and feeler gauge, you measure the ring gap at the top and bottom of the cylinder. Then what do you do?
7. What is the name of the shiny area where the rings rub against the cylinder wall?
8. What is the name for the 20° to 60° crisscross pattern left during cylinder wall honing?
9. When a cylinder is bored and honed 0.030" oversize, how much metal is removed from the surface of the cylinder wall?
10. What can happen to cylinders if they are rebored while the block is mounted on a conventional engine stand?
11. When a very fine grit hone set is used after initial honing of a cylinder, this is called _____ honing.
12. With how much interference is a cylinder sleeve installed?
13. How far into the block are cup-type core plugs installed?
14. When using the universal cam bearing installer, give the tool one hard rap to start the bearing into the bore. What should be done to the expanding mandrel before continuing?
15. What can be put on the O.D. of the bearing to make cam bearing installation easier?

ASE-Style Review Questions

1. Technician A says that a cracked cylinder bore cannot be repaired. Technician B says that when finish-honing after boring, stroking the hone out of the top of the cylinder bore will produce a taper that is hard to correct. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. Technician A says that a main bearing that has burned will often cause the main bearing bore diameter to become smaller in some places. Technician B says that main caps should be torqued in place before reboring the block. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. A block from an early 1970s car has 0.012" of bore taper. Technician A says to rebore oversize and use a new piston and rings. Technician B says to use 0.010" oversized rings. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. Technician A says that some manufacturers recommend against breaking the cylinder glaze with a glaze breaker when re-ringing an engine that has not been removed from the car. Technician B says that a Flex-Hone is used to help break the cylinder glaze so new rings can seat more easily. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. Technician A says that the amount of taper a cylinder bore has can be determined using a piston ring and a feeler gauge. Technician B says that the greatest cylinder bore out-of-round

wear will occur at the wrist pin ends of the piston. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

6. Technician A says that removing 0.015" of material from the cylinder wall will result in a bore that is 0.030" larger. Technician B says that a 0.030" oversized cylinder has a wall thickness that is 0.015" thinner than stock. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that oil gallery plugs and heater-hose connections usually have NPT threads. Technician B says that a ⅜" to ¼" socket adapter is used to remove oil gallery plugs. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says that a pressed-fit cylinder sleeve usually has an I.D. that is smaller than the original bore size. Technician B says to clean the block thoroughly with solvent after honing. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that if the camshaft is too tight after new cam bearings are installed, the bearing can be sanded with emery cloth. Technician B says that the front cam bearing is always installed flush with the front of the block. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Two technicians are discussing chamfering the top of recently rebored and honed cylinders. Technician A says to use a ridge reamer or special cutter in the boring bar. Technician B says that chamfering the cylinder is unnecessary. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 12

Crankshaft, Bearings, and Engine Balancing

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Analyze wear and damage to the crankshaft and bearings.
- Select the most appropriate crankshaft repairs.
- Explain the theory of engine balancing.
- Describe the related theory of the bearings, crankshaft, and related parts.

Introduction

The crankshaft assembly is the part of the engine referred to as the *lower end*. This chapter deals with these lower end parts, various service procedures performed on them, and diagnosis of part failures.

CRANKSHAFT DESIGN

The crankshaft converts the up-and-down (reciprocating) motion of the pistons to rotary motion. The polished bearing surfaces are called *journals*. The journals that support the crankshaft as it turns in the block are called *main bearing journals*. Bearing journals that are in line on the same axis as the front and rear main journals are all mains. Journals that are offset from the *main bearing journal* centerline are called rod journals (**Figure 12.1).**

Connecting rod journals transfer up-and-down motion between the crankshaft and connecting rod. Rod journals are also known as *crank pins.* As described in Chapter 1, connecting rod journals are offset at 90° angles for eight cylinders, 120° angles for even-fire six cylinders, and 180° angles for four cylinders.

The crankshaft has oil passages drilled from the main journals to the rod journals. Each crankshaft journal has a radius (rounded area) at its edge for added strength (**Figure 12.2**). Some crankshafts are induction hardened and, with proper maintenance, should last until an overhaul with very little evidence of wear.

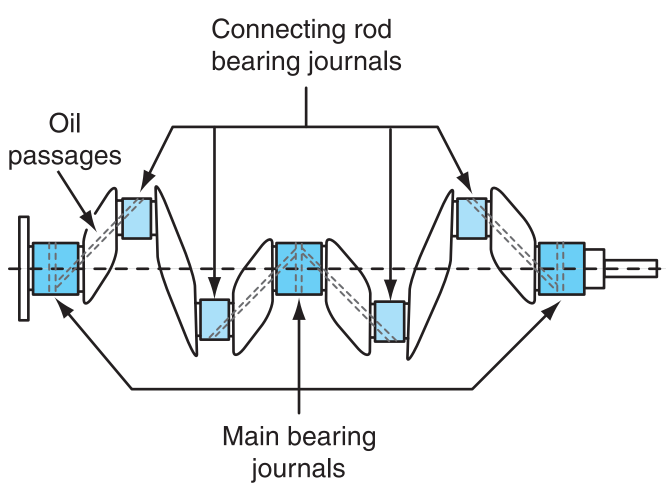


FIGURE 12.1 Crankshaft parts and oil flow.

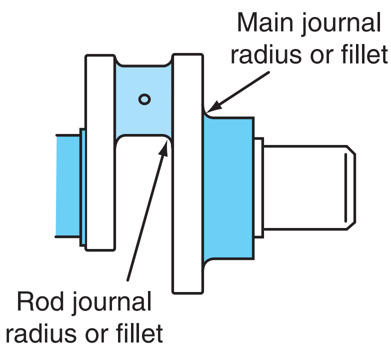


FIGURE 12.2 The radius, or fillet, on the sides of the main and rod journals.

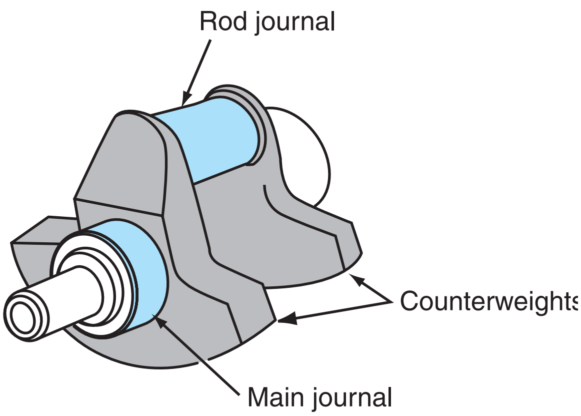


FIGURE 12.3 A counterweight is located opposite each rod journal.

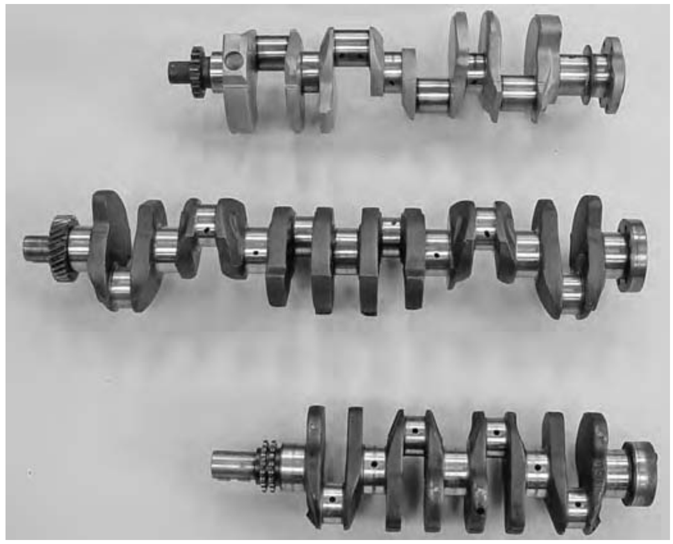


FIGURE 12.4 Crankshaft design differences. From top to bottom: a V8 crankshaft, an in-line 6 crankshaft, and an in-line 4 crankshaft. (*Courtesy of Tim Gilles*)

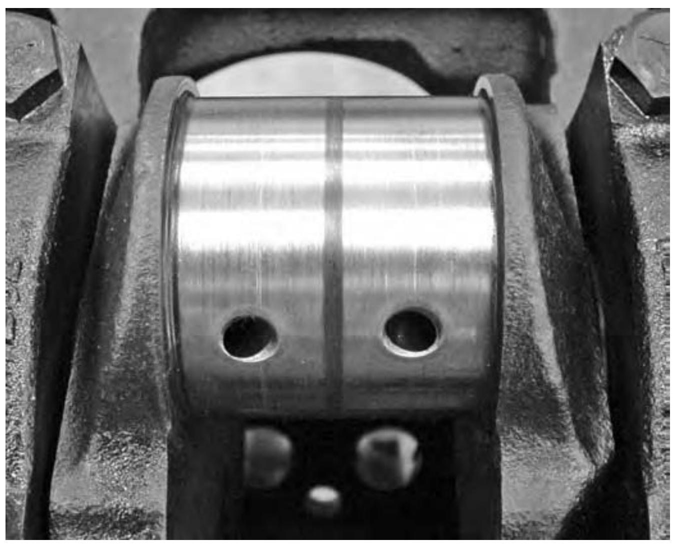


FIGURE 12.5 Wear pattern on a crank pin used on a V-type engine. (*Courtesy of Tim Gilles*)

Counterweights

Opposite each rod journal is a *counterweight* that precisely balances the combined rotating mass of the offset rod journals and the rod (**Figure 12.3**). The counterweight is much heavier than the rod journal to compensate for the weight of the connecting rods, bearings, and piston assembly.

An eight cylinder, V-type crank sometimes has fewer main bearing journals than an in-line six cylinder. **Figure 12.4** compares the crankshafts of an in-line four, an in-line six, and a V8. V8 engine rod journals are wide enough for two connecting rods. The photo in **Figure 12.5** shows the wear pattern caused by two connecting rods on a V8 crankpin.

The smaller V6 design, with 60° between the cylinder banks, is even-fired; one cylinder fires every 120° of crankshaft rotation. With the larger 90° V6 block design, achieving an even-firing 120° requires that the crankpins be offset or that there be individual journals for each connecting rod. The amount of journal offset varies among manufacturers because some design engineers believe that offsetting journals the full 30° necessary to achieve even-firing will weaken the crankshaft beyond acceptable limits.

NOTE

Rod journal offsets differ among the various V6 engines, so be sure that the replacement crankshaft is the proper one when working on one of these engines.

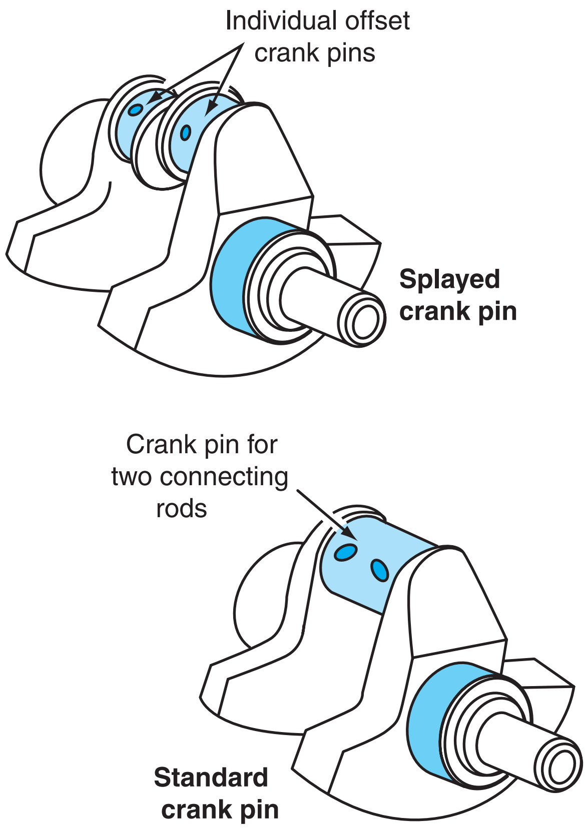


FIGURE 12.6 Comparison of crankshafts for the V6.

Figure 12.6 shows an offset rod journal design found on some V6 engines. The earlier General Motors V6 did not use the offset, or *splayed*, design. The engine was originally designed as a V8. To make a V6, two cylinders were chopped off, so it could be manufactured using existing V8 machinery and parts. The result was an odd-fire engine that had a rough idle and was hard on timing chains.

Cast or Forged Cranks

Crankshafts are either cast or forged. Forged crankshafts are stronger but more costly. Cast cranks are of high enough quality to do an adequate job.

NOTE

The cast crankshaft has a very narrow parting line where the casting mold halves were joined. The forged crankshaft has a wider, ground-off area. The difference between the two types can be seen in **Figure 12.7.**

Cast crankshafts must have larger counterweights because cast metal is not as dense as forged metal, so, therefore, it is lighter. Cast crankshafts sometimes use a balanced vibration damper and torque converter flexplate. On these crankshafts, there might not be any balancing done on the crankshaft counterweights. Forged crankshafts are usually balanced internally by drilling holes on the counterweights. Balancing is discussed later in this chapter.

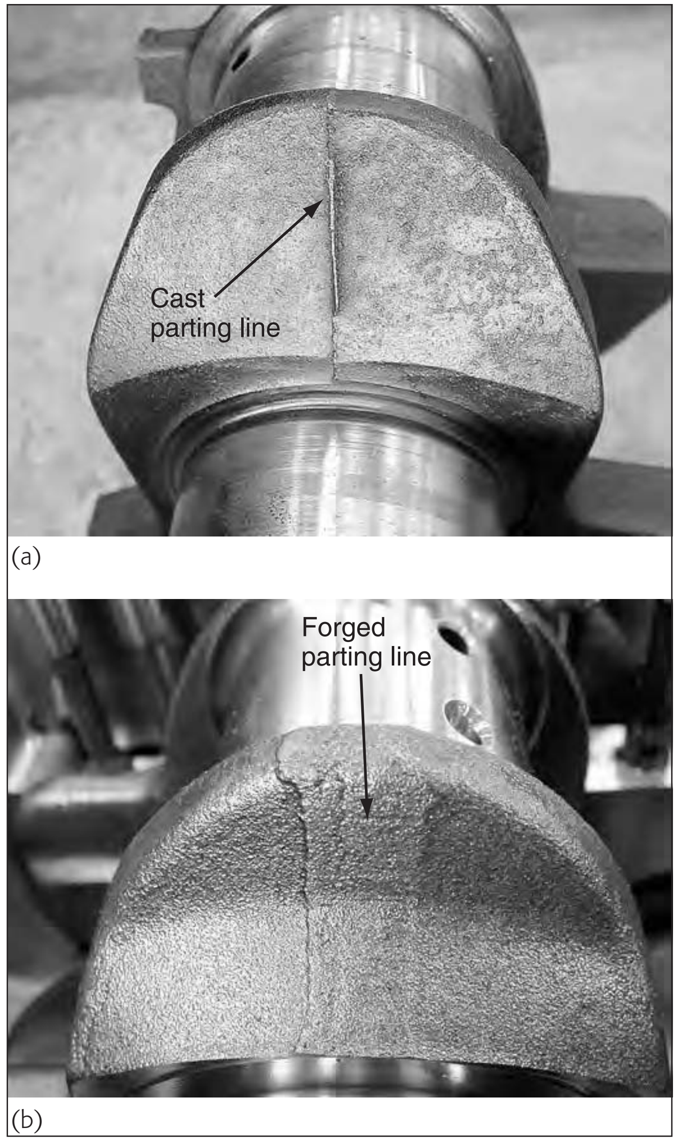


FIGURE 12.7 (a) Case crankshaft. (b) Forged crankshaft. (*Courtesy of Tim Gilles*)

CASE HISTORY

A technician rebuilt a 440 Dodge engine for a motor home using spare parts from the shop inventory. He used the existing engine's torque converter and vibration balancer. When the

engine was started, a serious vibration was evident. The crankshaft used in the rebuilt engine was forged and the one in the engine that was removed was cast. One of the crankshafts was externally balanced, requiring a special vibration damper and weights on the torque converter.

CRANKSHAFT END THRUST

The crankshaft can be pushed forward by pressure in the torque converter or by the release spring pressure of the clutch. This is called **end thrust**. One of the crankshaft main bearings has precision bearing surfaces ground on its sides, called thrust surfaces (**Figure 12.8**). A flanged thrust bearing fits between the crankshaft thrust surfaces (**Figure 12.9**), controlling back and forth movement (end thrust). Sometimes thrust insert half washers are used instead of a flanged bearing (**Figure 12.10**).

CHECKING CRANKSHAFT CONDITION

Keep bearings in order during disassembly so that the cause of unusual wear conditions can be diagnosed. A bent crankshaft can be indicated when one bearing wears more than others (**Figure 12.11**). The resulting bearing wear is usually worse at the center. Do not confuse this wear with that caused by a warped crankcase (see Chapter 11).

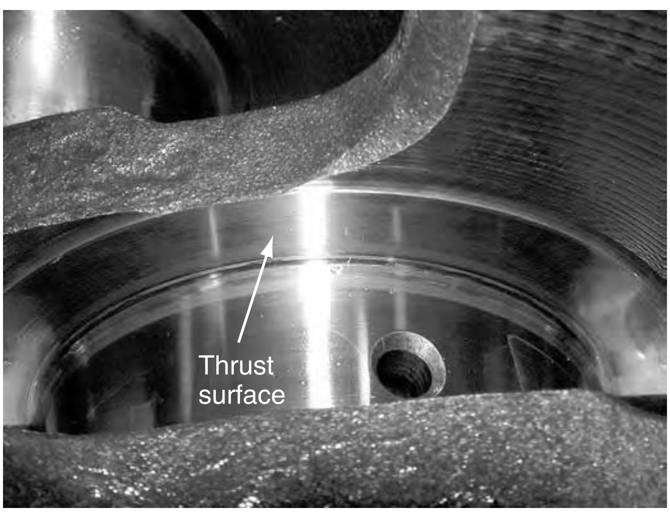


FIGURE 12.8 Crankshaft thrust surface. (*Courtesy of Tim Gilles*)

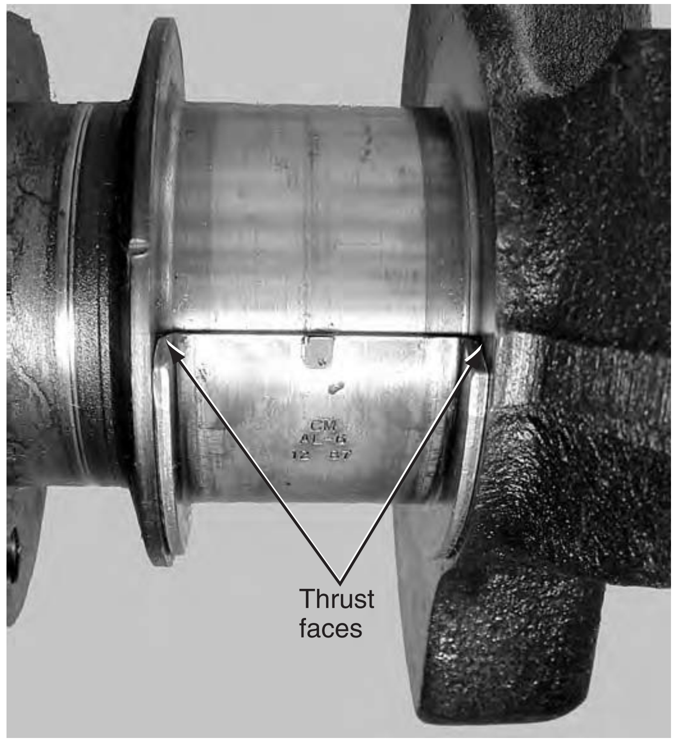


FIGURE 12.9 The thrust insert limits crankshaft end play. This main bearing has thrust faces on its side and is commonly referred to as a flanged thrust bearing. (*Courtesy of Tim Gilles*).

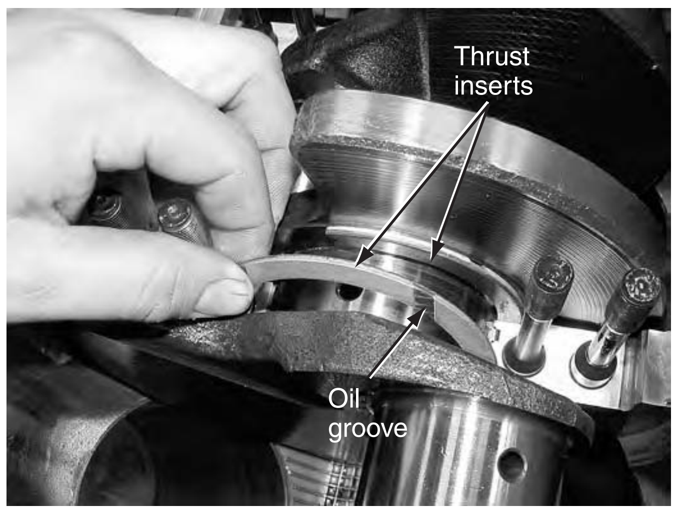
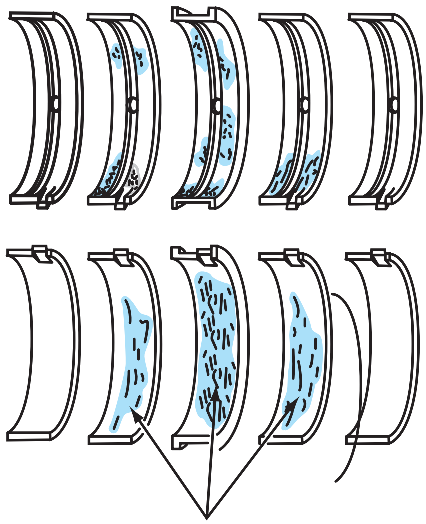


FIGURE 12.10 This engine uses thrust bearing inserts, or thrust washers, installed next to one of the main bearings. The oil grooves face toward the crankshaft thrust surfaces. (*Courtesy of Tim Gilles*).

Straightening a Crankshaft

Crankshafts are checked for warp before grinding.

- A forged crankshaft that is bent can be straightened.
- A bent cast crankshaft is typically replaced.



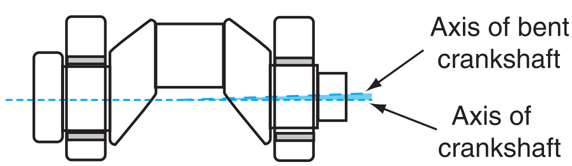


FIGURE 12.11 Crankshaft misalignment. Main bearing wear caused by a bent crankshaft.

NOTE

Sometimes a crankshaft that is bent will not cause wear on bearings. The theory is that if oil clearance is correct, the oil film actually bends the crankshaft straight when the engine runs.

A pair of machined V-blocks (lined with brass or paper to protect the journal) can be used with a dial indicator to check for a bent crankshaft (**Figure 12.12**). The block and the two end bearings can also be used as "V-blocks."

A bent crankshaft should be straightened and reground by a machine shop.

SHOP TIP

A favorite straightening technique is to peen the shaft in the **fillet radius** area (see Figure 12.2). The fillet area is peened with a chisel ground to match the fillet radius. This relaxes the shaft, allowing it to settle back to straight, rather than forcing it against the "set" it has assumed. Crankshafts with severe warpage (0.060") have been successfully straightened using this method.

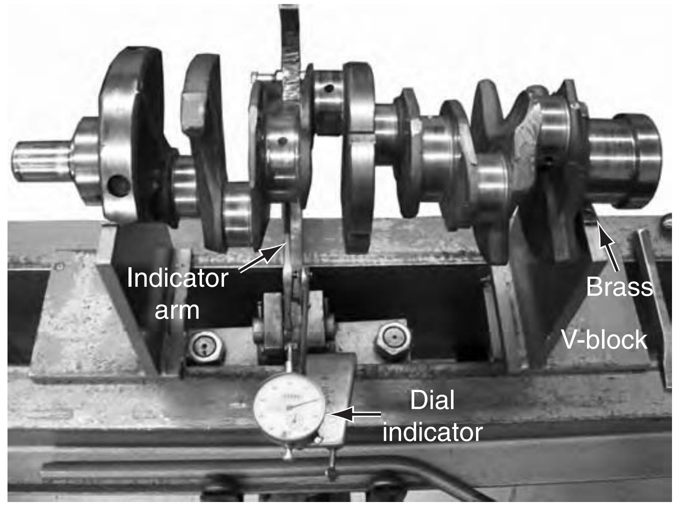


FIGURE 12.12 Checking straightness on a crankshaft resting on V-blocks lined with brass.

The crankshaft can be brought very close to straight and then reground. Peening with a ⅛" radius punch is the method of choice for straightening cast crankshafts. Position the bend so it faces down, and peen the top of the fillet radius of the bearing journal that burned and caused the crankshaft to warp (**Figure 12.13**). This method requires some practice to be able to straighten a crankshaft in a timely manner. Therefore, many shops do not

FIGURE 12.13 Straightening a bent crankshaft by stress relieving Position the bend downward and peen the topside of the fillet of the burned journal. (*Courtesy of Butch Reilly, Spokane Community College*)

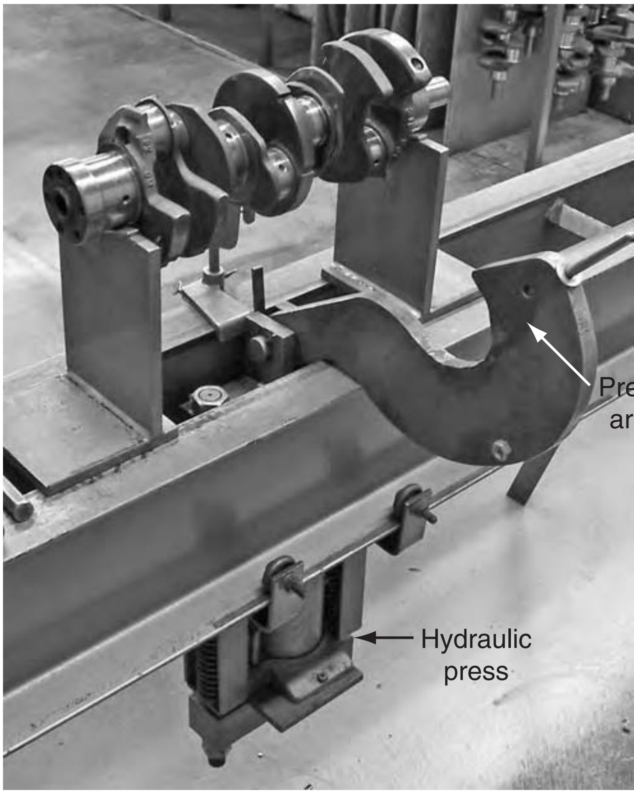


FIGURE 12.14 A crankshaft straightening press used to correct a bend in a forged crankshaft.

attempt it because they find it more economical to replace the crankshaft.

Another method of straightening crankshafts is with a special press (**Figure 12.14**). The press will work with forged crankshafts but will likely break a cast crankshaft.

A crankshaft that is only slightly bent can often be reground straight, but this has its limitations. Rebuilders sometimes insist on receiving a crankshaft core that is standard or 0.010" under to allow for the possibility that a crankshaft slightly out of alignment can be corrected by regrinding.

Checking for Cracks

When a crankshaft is severely worn, it will have suffered pounding because the engine was operated with excessive clearance. There is a higher likelihood this crankshaft to be cracked. A crankshaft burned from oil starvation is not as likely to be cracked.

A crankshaft can be checked for obvious cracks by "ringing" the counterweights with a light tap of a hammer (**Figure 12.15**).

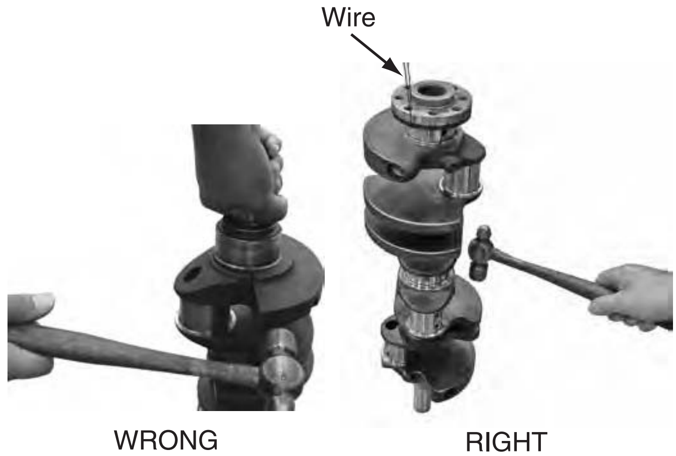


FIGURE 12.15 Ringing a crankshaft to check for cracks. A dull sound indicates a crack. Suspend the crankshaft with wire. Holding it with your hand will invalidate the test. (*Courtesy of Tim Gilles*).

NOTE

When ringing a crankshaft, the sprocket or gear must be removed first, or the crankshaft will sound like it is cracked.

Hang the crankshaft by a wire. Holding it by hand will deaden the sound.

A dull sound indicates the presence of a crack. A forged crankshaft will have a sharper sounding ring than a cast crankshaft.

NOTE

Some crankshafts require very careful handling. If you damage a tone ring for a crankshaft position sensor like the one shown in **Figure 12.16**, you can cause a drivability problem due to the confusing signals received by the PCM.

A more accurate way to check for cracks is the wet Magnaflux® magnetic particle inspection method (**Figure 12.17**).

- A magnetic field is induced in the crankshaft by spraying the crankshaft with a mixture of iron particles suspended in a liquid.
- Then a black light is used to detect the cracks.

NOTES

Magnaflux will not locate pinholes and casting defects. It only works for cracks.

Before checking a burned crankshaft for cracks with Magnaflux, grind it first.

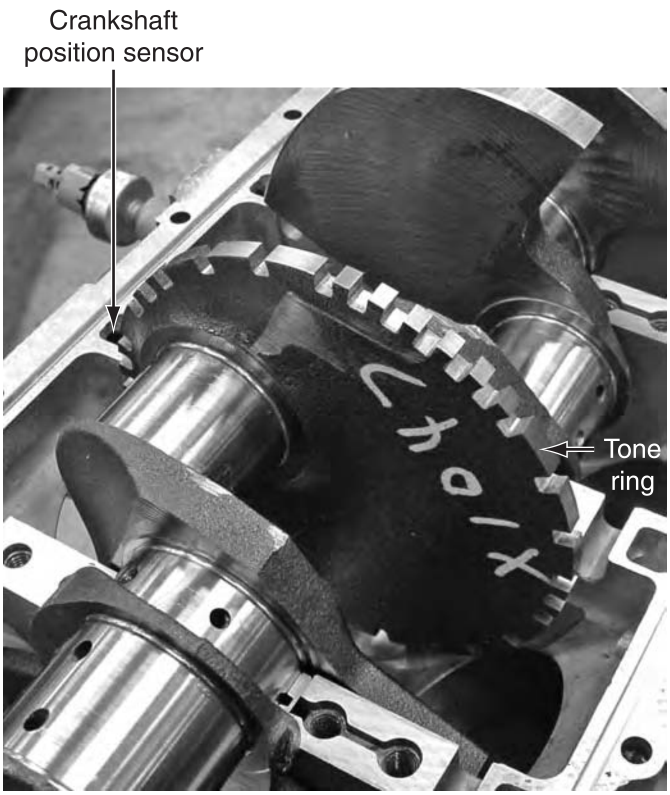


FIGURE 12.16 Damage to the sensor ring that is part of this crankshaft can result in computer control problems. (*Courtesy of Tim Gilles*).

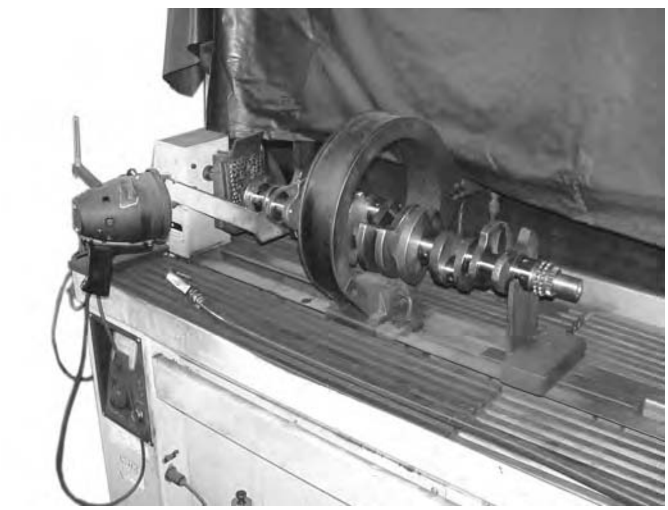


FIGURE 12.17 A large Magnaflux crack detector. (*Courtesy of Tim Gilles*).

Vibration Damper

During combustion, the force on the piston twists the crankshaft and the crankshaft tries to straighten itself. It overcorrects, twisting back in the other direction. Like a tuning fork, these oscillations occur for several cycles before fading out. When oscillations from several cylinders are occurring at the same time, **torsional vibrations** can cause the crankshaft to break (**Figure 12.18**). Timing chain and

FIGURE 12.18 When a crankshaft breaks, the cause is often a loose vibration damper or flywheel. Replace the damper to prevent the problem from recurring. *(Courtesy of Tim Gilles)*.

sprocket wear can also result. Most of the vibration occurs at the front of the crankshaft because the flywheel is resistant to oscillations.

The part that dampens torsional vibration at the front of the crankshaft is called the *vibration damper* or *harmonic balancer*. It has a heavy outer inertia ring and an inner hub separated by a synthetic rubber strip. The two parts stretching against the rubber strip absorb vibrations. Four cylinder engines usually have only a pulley and do not use a damper. Six and eight cylinder engines almost always have dampers.

Checking the Vibration Damper. If a crankshaft is broken, be sure to check the vibration damper for obvious signs of damage (**Figure 12.19**). The

FIGURE 12.19 Defective vibration dampers. (*Courtesy of Tim Gilles*)

following are some additional vibration damper considerations:

- The outer ring of the damper (see Chapter 6) can slip, causing an out-of-balance condition. With the cylinder head removed and the piston at TDC, make a visual comparison. Do the timing marks for TDC on the timing cover and damper appear to be accurate?
- Be sure the damper is the correct one for the vehicle. The wrong one can be worse than none at all.
- Sometimes a damper can become loose on the crankshaft. Check the keyway for wear that can result from improper damper installation, the wrong size key, or a loose damper hub to crankshaft fit. A case history in Chapter 9 describes the results of a loose damper (see Figure 9.101).
- Be sure all pulleys are straight. A damaged pulley can force a crankshaft to bend during engine operation.
- Sometimes the front oil seal wears a groove into the outer surface of the snout of a crankshaft pulley or damper (**Figure 12.20**). A thin metal sleeve can be installed over the worn area to correct the problem. See Chapter 16 for this simple, inexpensive repair procedure.

Crankshaft Wear

The crankshaft sometimes experiences excessive wear because of abrasives in the oil. Journals can wear out of round and tapered. **Figure 12.21** shows how to evaluate crankshaft journal measurements.

FIGURE 12.20 Wear to the sealing surface of this damper resulted from dirt on the outside of the engine and friction from the seal. (*Courtesy of Tim Gilles*)

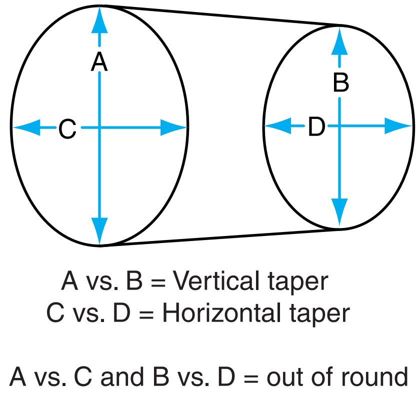


FIGURE 12.21 Crankshaft journal measurements.

Out-of-Round Wear. Crankshaft main bearing journals wear out of round. When the engine is first cranked by the starter after sitting for a period of time, there is little or no lubrication between the crankshaft and the lower main bearings. The result is that the lower main bearing wears excessively and the main journals wear out of round.

NOTE

When a starter motor drive fails, the ring gear on a flywheel or flexplate will become worn in only one section of its teeth (see Figure 4.118). This is because the pistons always tend to stop either halfway up or halfway down in their travel in the cylinders when the engine is shut off. The ring gear on an eight cylinder engine wears at 90° intervals, whereas a six cylinder engine ring gear wears at 120°. Chapter 4 discusses worn starter ring gears and their replacement.

Tapered Wear. Rod journals sometimes suffer taper wear. The presence of uneven rod bearing wear, and sometimes piston skirt wear, usually indicates taper. Connecting rods should be checked for misalignment whenever uneven wear is found.

Crankshaft Journal Tolerance. Wear specifications for crankshaft journals are found in repair manuals. An example specification might be 2.2552–2.2560; this range is called the *tolerance,* which in this case is 0.0008". When the crankshaft is worn only slightly and is still within tolerance, it can be reused.

If a crankshaft is in good condition, it is sometimes desirable to have it polished. This is a relatively inexpensive operation. Check the crankshaft bearing surface for excessive roughness by rubbing

VINTAGE ENGINES

When most vehicles had manual transmissions, the flywheel had a replaceable ring gear. A backyard mechanic trick was to simply heat the ring gear to loosen it from the flywheel, and then turn it 90° so that an unworn section of the gear would meet the starter.

Connecting rod journals also wear out of round, wearing on their top sides because of excessive loads during the power stroke. Excessive loads are caused by lugging the engine or by abnormal combustion. The oil film does not hold up, and the result is wear. Lugging occurs when the load on the engine is greater than the rpm needed to develop the horsepower needed to pull the load. Measure the rod journal horizontally and vertically to check for out-of-round wear. Crankshaft journals are miked (measured with a micrometer) at 90° angles to check for out of round wear, which should be less than 0.0005".

a copper penny on it. If the journal picks up copper, the surface is too rough (see Chapter 6).

Nicks in the Crankshaft. When there is a nick in the crankshaft journal surface, it could be a high spot or a low spot. A low spot does not usually present a problem. However, a nick that results in a high spot must be lowered with a small jeweler's file or it will wear a groove in the bearing. To determine whether a nick is causing a high spot, use a micrometer (**Figure 12.22**).

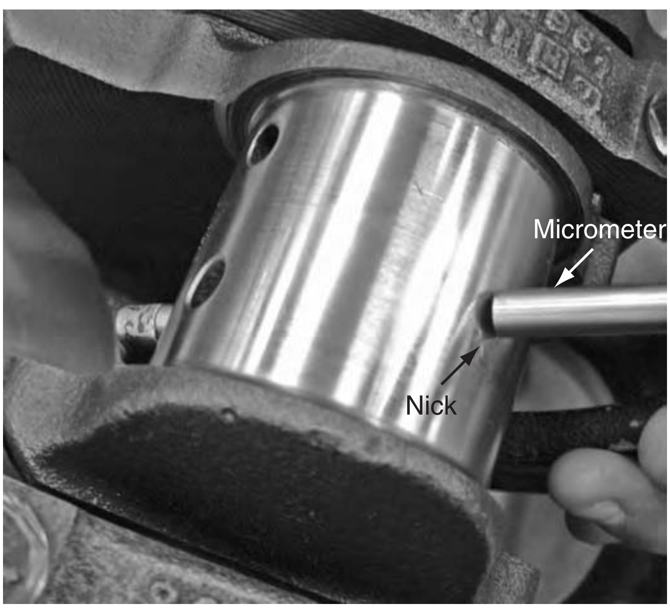


FIGURE 12.22 This crankshaft journal has a nick. Use a micrometer to determine that it is not higher than the surrounding surface. (*Courtesy of Tim Gilles*)

Oil Groove Wear. Another kind of wear to the crankshaft journal results from the void left by a bearing oil groove. The area that corresponds to the groove will be unworn, whereas the bearing support areas on both sides exhibit wear (**Figure 12.23**). When the oil groove is in both the top and bottom bearing halves, the amount of crankshaft wear can be determined by comparing the sizes of the two areas using a micrometer.

Shot Blasting a Crankshaft

Shot blasting a crankshaft strengthens it and relieves stress. It is sometimes done in heavy-duty and racing applications. Certain precautions are necessary when shot blasting a crankshaft. Grinding the journal surfaces after blasting will result in a smooth surface, but the oil seal and thrust bearing surfaces must be protected from the shot. Before blasting a crankshaft, protect the rear oil sealing surface with duct tape. Failure to do this can result in a rear seal leak. Taping an old thrust bearing to the journal can protect the thrust surfaces during blasting.

Regrinding the Crankshaft

Crankshafts are reground by an experienced machinist with a crankshaft grinder (**Figure 12.24**); 45 minutes is the typical time required. **Figure 12.25** shows a reground crankshaft. Automotive crankshafts are usually reground to 0.010", 0.020", or 0.030" undersize.

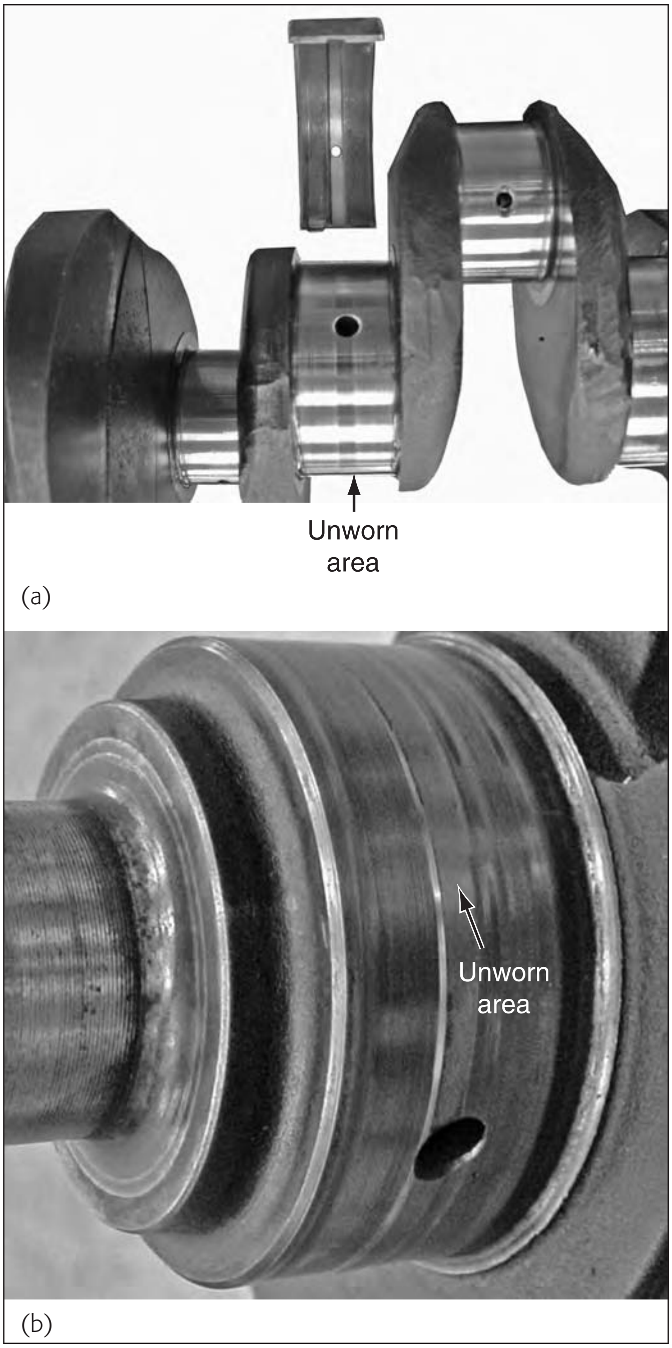


FIGURE 12.23 (a) The area of a bearing journal that mates with the oil groove in a bearing will not wear. The amount of crankshaft wear can be determined by comparing the sizes of the two areas using a micrometer if there is an oil groove in both the top and bottom bearing halves. (b) The unworn area on this main bearing journal corresponds to the groove in the main bearing. (*Courtesy of Tim Gilles*)

NOTE

A 0.020" undersized crankshaft actually has only 0.010" of metal removed from its surface. Because metal is removed from both sides when the crankshaft is ground, the crankshaft will be 0.020" undersize.

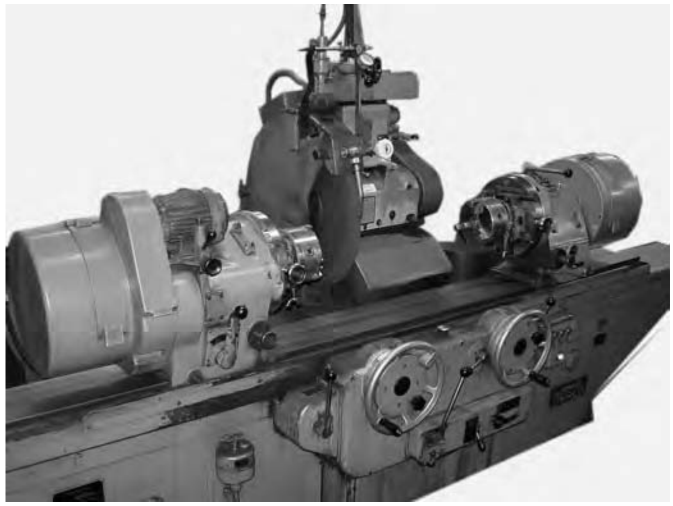


FIGURE 12.24 A crankshaft grinder. (*Courtesy of Tim Gilles*)

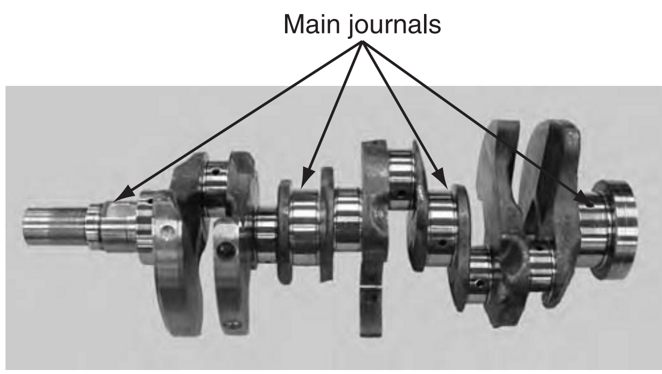


FIGURE 12.25 A reground crankshaft. (*Courtesy of Tim Gilles*)

Sometimes, rod journals and main journals are ground to different undersizes. In this case, the rod journal size is traditionally listed first—for example, 0.010–0.020". The main bearing size is 0.020". This is not always the case, however. Always measure the diameter of the crankshaft journals before ordering new bearings.

Some imported vehicles use replacement thrust bearing inserts that are wider. In those instances, the crankshaft thrust surfaces must be ground to compensate for the greater bearing width.

Main and Rod Journal Grinding. Grinding the main bearing journals is relatively easy, like using a lathe. The crankshaft grinder must dial indicate off where the sprocket and seal ride in the front and where the rear seal rides in the rear. Main bearing journal out-of-round *cannot* be corrected or the crankshaft seals would not run true to the crankshaft. Grinding connecting rod journals is

VINTAGE ENGINES

Crankshaft journals on old engines were of smaller diameter. The Model T Ford had journals of 1.250" or 1.500". The slower surface speed associated with smaller journals resulted in less heat generation, which was a problem with these engines. During the dust bowl migration from Oklahoma to California in the 1930s, people often drove their cars at night to avoid crankshaft bearing failures. This problem was more acute on these engines than the later ones because they did not have a pressurized lubrication to help carry away the heat. Compare the 1.500" bearing journal size to the 401 cubic inch (6.6L), which has a main bearing journal diameter of 3.125". When multiplied by π (3.14159…"), the surface of the crankshaft journal is ¾ foot. When this engine turns at 4000 rpm, the bearing speed is about 3000 feet per minute, which is over 30 miles per hour. The smaller bearing journals of yesteryear moved much slower, creating less heat.

more complex than grinding main journals. Because the crankshaft grinder is adjustable in both directions, out-of-round connecting rod journals *can* be corrected.

SHOP TIPS

The following shop tips apply to crankshaft grinding:

- The wheel goes out of balance at night from moisture. Run the wheel for 20 minutes without coolant so it does not have a heavy spot from wetness.
- Warm up the wheel carefully. Cold coolant combined with the heat from grinding can push the stone into the crankshaft.
- Crankshaft grinding wheels are narrow in width and large in diameter. The possibility of grinding wheel breakage is a serious safety concern. To protect the machinist, the wheel guard on a crankshaft grinder is steel, not cast iron. Before grinding, check the grinding wheel by tapping it lightly on one side with a small wrench. While it rings, put your hand on it. If the sound does not change, the wheel is cracked and you should not start the grinder.

NOTE

A wheel must be mounted to the crankshaft grinder or the ring test will not work.

- Be careful of oil holes in bearing journals. Your indicator can get stuck in them.

CRANKSHAFT GRINDING WHEEL NOTES

- Grinding wheels come in many different types and qualities. CBN, or cubic boron nitride, is a grinding material that removes material 3 or 4 times faster than an ordinary stone wheel and has a lifetime that is said to be 10 times longer. Cutting tools are also made of CBN.
- A grinding wheel's top speed is limited to 5500 ft/minute or less. This is faster than 60 mph, which is 5280 feet per minute. During manufacture, grinding wheels are tested at very high speed (2000 rpm). Grinding wheel speed is controlled by pulleys.

Sharpening a Grinding Wheel. When it is spinning, a sharp wheel looks flat. A dull wheel has a waxed appearance because the grain has been flattened on its surface. When attempting to quickly remove metal from the journal surface, a dull wheel will burn the crankshaft, turning it black.

A grinding wheel does not wear appreciably. It is a forming stone and its size becomes smaller due to truing with a diamond. Over time, the tip of a diamond will wear flat. Before truing the grinding wheel, use a 20 power magnifier to inspect the diamond tip so you can twist the diamond to present its sharp spot.

Crankshaft Rotation when Grinding

Automotive engines typically rotate counterclockwise when viewed from the flywheel end.

VINTAGE ENGINES

All crankshaft grinders use a steady rest to follow the grinding wheel and support the bearing journal when grinding. The Nash Straight Eight, with nine main bearing journals, was especially difficult to grind.

When a crankshaft is installed into the crankshaft grinder, it must be positioned correctly so it will turn normally when grinding. The correct position is with the crankshaft nose, or snout, chucked to the left in the grinder's headstock with the crankshaft rotating toward you. A few engines (including some Honda and marine), rotate in the opposite direction. For these crankshafts, the flywheel flange is chucked on the left with the snout on the right.

Crankshaft grinders are unique and a machinist must acquire a feel for each one. One machinist trick is to "bend" the machine to correct 0.0002" of runout. This is accomplished by pressing lightly at the correct time on the tailstock with the palm of your hand.

Oil Passage Chamfer

When a crankshaft is reground, rough edges occur around the bearing journal oil holes. These rough edges can result in high spots that can scratch the new bearings and leave a place where cracks could begin to form. Prior to polishing the crankshaft, a machinist will *chamfer* the oil holes with a die grinder and grinding wheel or a slower motor with a countersink. If the holes are chamfered after polishing, the journals will have to be polished again. **Figure 12.26** shows a chamfered oil hole.

FIGURE 12.26 Oil holes in the crankshaft are chamfered before the journals are polished. (*Courtesy of Tim Gilles*)

Polishing a Crankshaft

After a crankshaft has been ground, a copper penny rubbed on the journal surface will deposit copper. You can feel this with your fingernail. After grinding, the journals are polished approximately 0.0002" with a polishing belt (**Figure 12.27**). This promotes longer bearing life because the microscopic peaks formed during polishing follow the direction that the crankshaft rotates in the bearing (**Figure 12.28**). Machinists say that polishing a crankshaft backwards is "like stroking a cat backwards." To achieve a super smooth journal surface, some machinists put pumice stone or rottenstone polishing powder, or jeweler's rouge on the surface of the journal with some cutting oil before polishing with the belt. Another trick for achieving a very smooth surface is to "kill" a new belt with a silica stick before using it.

SHOP TIP

To prevent bearing wear during engine assembly, it is a good practice to only rotate the crankshaft in its normal direction of rotation.

Surface Roughness. Surface roughness is measured using the "*Ra*" or roughness average standard, which has replaced the older root mean square (RMS) standard. To find the RMS equivalent, 11% is added to the Ra meter reading. A profilometer is used to determine surface roughness. It has an electromechanical stylus tracer with a 0.0004" radius diamond tip. A popular test is the fingernail test. But a fingernail is 0.025" thick, whereas the tip of a profilometer is only 0.004". For stock engines, traditional belt polishing must leave a surface finish of 15 microinches Ra or smoother. A surface finish

FIGURE 12.27 A crankshaft polisher. (*Courtesy of Tim Gilles*)

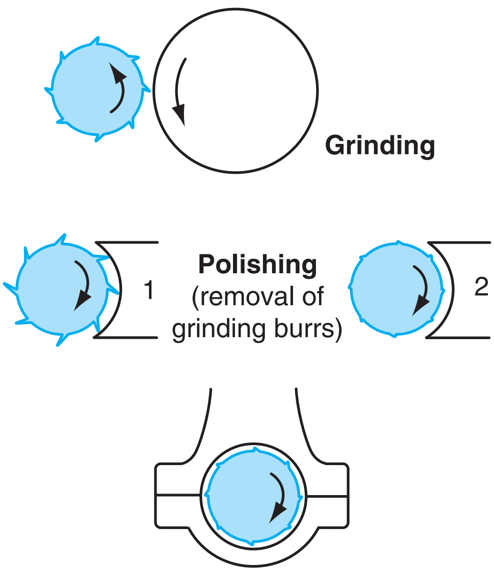


FIGURE 12.28 Direction of peaks of metal after grinding and polishing a crankshaft.

of less than 10 Ra is needed for high-performance and heavily loaded engines like diesels. Very smooth bearing surfaces, sometimes less than 6 Ra, are often specified for engines with reduced bearing clearance that use low viscosity oil like 5W-30 or 0W-30. General Motors specifies a 5 Ra finish on some of its engines.

A faster and better finish is possible if grinding is done to the best possible surface finish using the correct speeds and a true and clean grinding wheel of the correct width and grit. Polishing must not remove more than 0.0002" of material from the journal surface. Because polishing does not get below the level of grind, the size of the journal is not appreciably reduced. However, immediately after polishing a crankshaft, it will be larger in diameter due to heat.

Polishing is a two- or three-step process. The first step uses a 280-grit belt, as the shaft is rotated in the opposite direction from the direction shown in **Figure 12.28**. The second step uses 320 grit with the crankshaft rotating in the correct direction. To get a very fine finish, a final polishing step can be accomplished using a 400-grit belt. According to AERA, if the thrust surface is scratched, it must be polished to a 12 Ra finish or less.

Polishing with a belt requires a higher degree of operator expertise to achieve consistent results and an even bearing surface. As the belt wears, the finish changes and the best belt choice is one that matches the width of the crankshaft journal. But main and rod bearing journals are typically of different widths. Achieving a smooth, even bearing surface with a narrow belt takes some skill, is relatively inconsistent, and can leave overlap marks in the middle of the journal.

Cast nodular iron crankshafts require extra care in grinding and polishing. Graphite nodules reside along the surface of the bearing journal. Grinding the surface opens the nodules and creates jagged edges that must be polished in the correct direction to remove them and prevent them from damaging the new bearings.

Microfinishing

Original equipment manufacturers use special automated equipment to polish their crankshafts. The process is called microfinishing or micropolishing. Some aftermarket rebuilders also use microfinishing equipment because it is very consistent and does not require a high skill level to use correctly. Polishing is done in two directions using abrasive tape that can be obtained in different micron finishes and widths. The tape is clamped around the journal and evenly supported all around. Polishing time, pressure, and direction are automatically controlled and the micron tape automatically advances to provide a fresh abrasive surface for each journal. A very smooth and consistent finish is the result. An attachment is used to polish the thrust surfaces to a very fine finish as well.

NOTE

The shiny surface of a used crankshaft is very smooth and will cause less bearing wear if it is not polished with an abrasive such as emery cloth or sandpaper. Occasionally, you will you need to clean minor rust from a journal surface using very fine (600 grit) wet-or-dry sandpaper (**Figure 12.29**). This method works best when used with solvent.

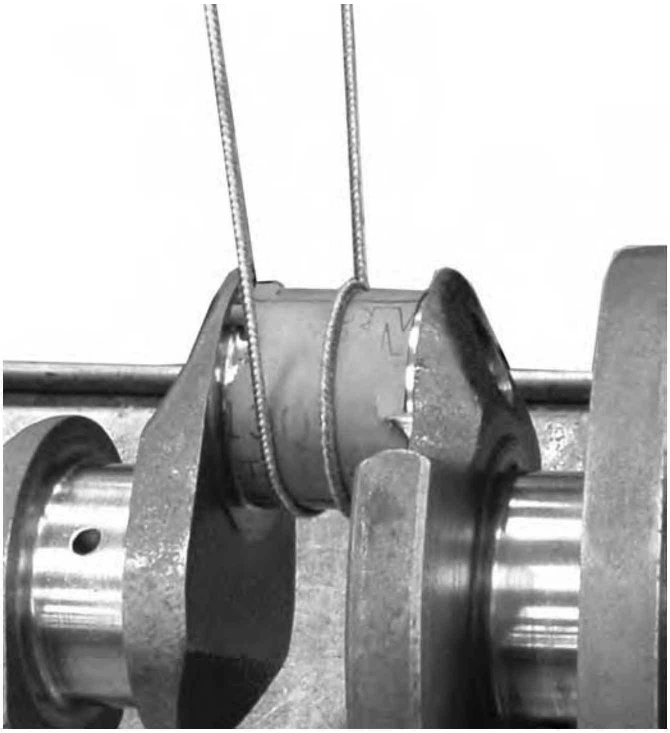


FIGURE 12.29 A method for removing light surface rust using fine wet-or-dry sandpaper and a shoe string. (*Courtesy of Tim Gilles*)

For very fine polishing use *crocus cloth*, which is 1200-grit jeweler's rouge abrasive on a cloth backing.

NOTE

Surface Finish Recommendations

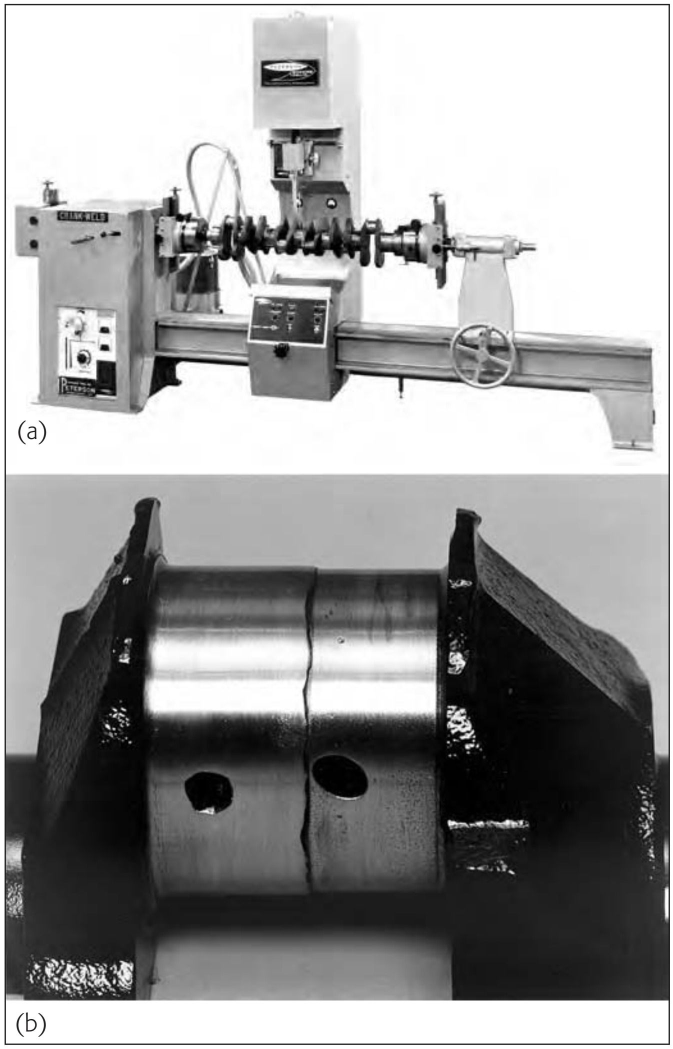
Crankshaft	5–25 microinches
Main bearing bores	63–200 microinches
Camshaft	16–25 microinches

Storing the Crankshaft

If a crankshaft is to be stored for a period of time, it should be oiled and put in a plastic bag to prevent rust. A reground crankshaft is sometimes coated with a preservative or rust preventive, like Cosmoline, which must be washed off with solvent before using the crankshaft. The crankshaft should be properly supported or hung in a crankshaft storage rack to prevent it from being knocked over and/or damaged. This practice also provides machine shops with more floor space.

Welding Crankshafts

Burned or severely worn crankshaft journals can be built up on a crankshaft welder before regrinding (**Figure 12.30**). Before attempting to weld a



(a)

(b)

FIGURE 12.30 Crankshaft welding. (a) A crankshaft welder. (*Courtesy of Peterson Machine Tool Inc.*) (b) This journal was built up on the left side and then ground for demonstration purposes. (*Courtesy of Gleason Engineering Industries, Inc.*)

VINTAGE ENGINES

The practice of storing crankshafts by standing them on end is left over from the days of the Model A Ford, whose crankshafts would warp when laid down for storage.

crankshaft, care must be taken to ensure that it is extremely clean. Soak it in a hot caustic solution. Then preheat it until it turns blue to boil off any oil that might remain below the surface. Preheating also helps prevent thermal shock and stress cracks. When welding, do not stop welding. You need to keep the heat going.

NOTE

Welding is a satisfactory method of repair for worn journals, but it is not an acceptable repair for cracked crankshafts.

Crankshaft Hardness

Crankshafts used by some manufacturers (mostly imports and heavy duty) are specially hardened. If these crankshafts are reground, the manufacturers recommend that they be rehardened. Crankshafts that have *not* been previously hardened can suffer misalignment if they are subjected to hardening. Special stress relieving procedures should be followed if crankshafts are to be hardened.

Crankshafts can be surface hardened. Two common hardening processes are *gas nitriding* and *tufftriding*™. Both processes harden the surface by causing iron nitride formation at temperatures near 1000°F (538°C).

When nitrogen is absorbed into steel its surface becomes very hard. The hardened metal has a very thin surface layer of extra hard material called a white layer. The white layer is very brittle. To maintain the strength of the part, the depth of the white layer is kept to a minimum during the heat treating process. The surface of the part is machined to the desired size before hardening. Hardened crankshafts are polished lightly with a crankshaft polisher before use. Only 0.00005" to 0.0001" of metal is removed during this polishing operation (count the zeros). The desired white layer of a hardened surface is only about 0.0005" to 0.002" thick.

Tufftriding is a liquid process that uses molten salt; nitriding is a gaseous process that uses nitrogen (ammonia). Gas nitriding has been used in industry for many years. The Tufftride® process has been used in the United States since 1960. The surface of a tufftrided crankshaft is gray in color.

To test a crankshaft for tufftriding, file a nonbearing surface. The file should cut easily if the crankshaft has not been hardened; tufftriding hardens the entire crankshaft, not just the journals. Tufftride is so effective that even a hardened surface that is only 0.001" deep will improve wear resistance.

Tufftriding is effective on all ferrous metals; nitriding works well only on high-grade steels. Nitriding is also more expensive.

SHOP TIP

Shops that do hardening generally charge a minimum amount, and then charge by the pound for handling; therefore, three or four crankshafts can often be done for the price of one.

Crankshaft Hard Chrome Plating

Hard chromium plating or industrial chrome plating, commonly known as *hard chrome,* is when a relatively thick layer (approximately 0.0002"/ 0.00508 mm – 0.030"/0.76 mm) of chromium is electrodeposited on metal, usually from a hexavalent plating bath. Chromium plating is used to provide a hard, corrosion resistant, low friction surface like on a crankshaft journal or piston rings. Hard chrome has a metallic appearance. This is not the same as *decorative chromium plating* or *bright chrome plating*, which would be found on automotive trim like a bumper or wheel rim. The very thin bright chrome layer can be as little as 50 millionths of an inch, deposited over a layer of nickel or copper/nickel.

Hard chroming is used in the heavy-duty industry to restore worn or poorly machined crankshaft journals to their original size. It is relatively expensive for smaller, automotive engines and is done only by specialty plating businesses.

NOTE

Most crankshafts are not specially hardened, but they tend to work-harden as they are used. Nickel in the crankshaft comes to the surface. A used, polished crankshaft will have a yellow tint because of this nickel.

Measuring Crankshaft Hardness

Hardness of a material can be accurately tested with several types of hardness testers. The following measure the resistance of a material to penetration:

- The Brinell hardness tester measures the diameter of an impression left by a hardened steel ball.
- The Rockwell hardness tester measures the depth of an impression.
- The Vickers tester is like the Brinell tester but uses a diamond pyramid. The impression left by the diamond is easier to read.
- The portable Shore scleroscope tester measures the height of the rebound of a dropped ball. The impression left by the ball is very light.
- Electronic hardness testers measure both penetration and changes in frequency.

Most manuals list hardness specifications in the **Rockwell "C" scale**. Four measurements of crankshaft journal hardness are taken at 90° to each other because hardness may not be uniform.

Crankshaft Strength

Crankshafts and connecting rods can be made stronger by shot peening (see Chapter 2). For maximum strength, the crankshaft is ground first. Then the journals are masked before shot peening. Shot peening relieves stress that could otherwise cause small cracks to start and then spread. The fillet or radius of the crankshaft main bearing journal (see Figure 12.3) is the area of a forged crankshaft that is stretched the most during manufacturing. Shot peening is especially helpful in strengthening the crankshaft by relieving stress raisers in the fillet area.

Forged and Billet Crankshafts

High-performance crankshafts are either forged or made from a billet of steel. A billet is stronger than a forged crankshaft, but forged cranks are less expensive.

Forged Crankshafts. During forging, the crankshaft is stamped into a rough shape prior to machining. **Figure 12.31** shows a rough forging of a crankshaft. The forging process stretches the metal in some places but retains the grain structure of the metal. The aim in designing a forged crankshaft is to twist the metal as little as possible. A forged crankshaft is also very strong but it is less expensive than a billet.

FIGURE 12.31 A rough forged crankshaft. (*Courtesy of Tim Gilles*)

FIGURE 12.32 Steps in making a high-performance crankshaft from a billet of steel. (*Courtesy of Tim Gilles*)

Billet Crankshafts. A billet is a cylindrical bar of continuous grained steel. The billet is machined, but not bent like a forging, so it retains its uniform grain structure. **Figure 12.32** shows the transformation of a billet into a crankshaft at the manufacturing plant of SCAT, a high-performance crankshaft producer.

OTHER CRANKSHAFT MODIFICATIONS

In the aftermarket, performance modifications are sometimes made to crankshafts. These include "stroker crankshafts" and "knife edging" the counterweights.

Stroker Crankshafts

Sometimes a change in stroke is desired when building a racing engine. A crankshaft is stroked by offset grinding the journals to a smaller diameter (**Figure 12.33**) or adding additional metal to the jour-

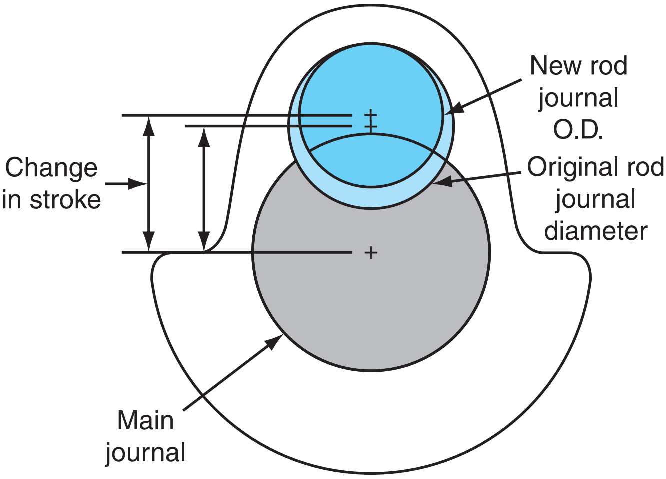


FIGURE 12.33 Changing the stroke can be accomplished by offset grinding the rod journals to a smaller diameter.

FIGURE 12.34 This rod journal was welded on the top side to change the crankshaft stroke. (*Courtesy of Gleason Engineering Industries, Inc.*)

nal with a welder prior to grinding it (**Figure 12.34**). Most of the time, changing the stroke requires connecting rods with a different big end to small end center-to-center distance. New pistons with a different compression height might also be required.

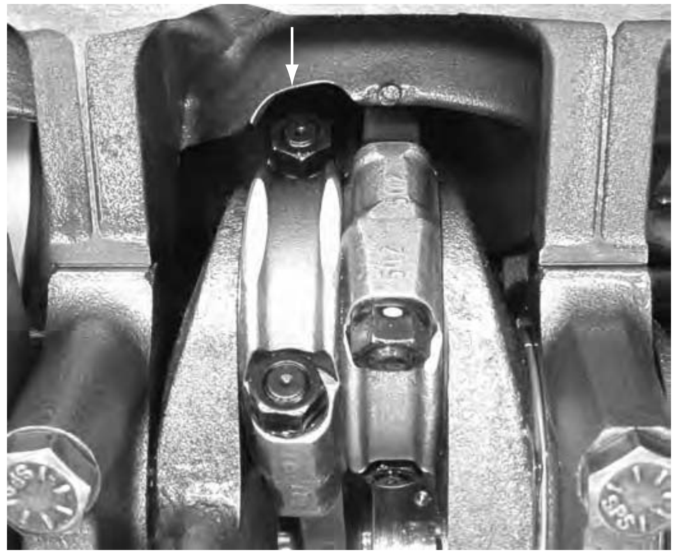


FIGURE 12.35 The cylinder walls in this block were notched to allow clearance for the rod bolts after the crankshaft stroke was changed from stock. (*Courtesy of Tim Gilles*)

Figure 12.35 shows a block with modifications to the bottoms of the cylinders to allow for clearance of the connecting rod bolts at their new position after installation of a stroker crankshaft.

Oversquare Engines

When the two dimensions in the ratio between the diameter of the bore and the length of the stroke are equal, the engine is called "square." When the stroke is a larger number than the bore, the engine is *undersquare;* when the bore is larger than the stroke, the engine is *oversquare*.

Oversquare engines have an advantage when it comes to breathing because larger valves can be used and airflow will not be obstructed as much by the cylinder walls. Probably the biggest advantage to oversquare engines is the cost advantage when it comes to increasing displacement; it is much easier to increase the bore appreciably than it is to increase the stroke.

VINTAGE ENGINES

Early piston engines were undersquare, often by a large amount. Before the 1950s, British vehicles were taxed according to the size of the cylinder bore, no doubt leading to their longer strokes and smaller bores.

An undersquare engine will have more torque due to the longer rod throw. But its top engine rpm will be lower, so it can have less valve port area and/or fewer valves. A four valve per cylinder oversquare racing engine might have a top rpm of 13,000, whereas an undersquare engine of similar displacement could have an rpm limit of 5500. Longer stroke engines tend to produce more torque and rev slower, and short stroke engines are the opposite.

Counterweight Modifications

In the hot rod days of the 1970s, reducing the drag of a rotating crankshaft became popular. A big concern was to control misting or fogging of the oil in the crankcase. Windage trays (see Chapter 14) and dry sump oil systems became popular, as did *knife-edged* counterweights. Early knife edging was done to the leading edge of the counterweight. But according to aerodynamic theory, the *trailing* edge of the rotating part is responsible for most of its drag. Therefore, both ends of the counterweight were knife edged, making the counterweight the shape of a teardrop (**Figure 12.36**).

High-speed engines use lighter pistons and connecting rods. This allows for smaller counterweights, which makes a quicker responding engine. Reducing the diameter of the counterweights can be done during engine balancing, covered later in this chapter. **Figure 12.37** shows a crankshaft with counterweights of smaller diameter than a stock crankshaft.

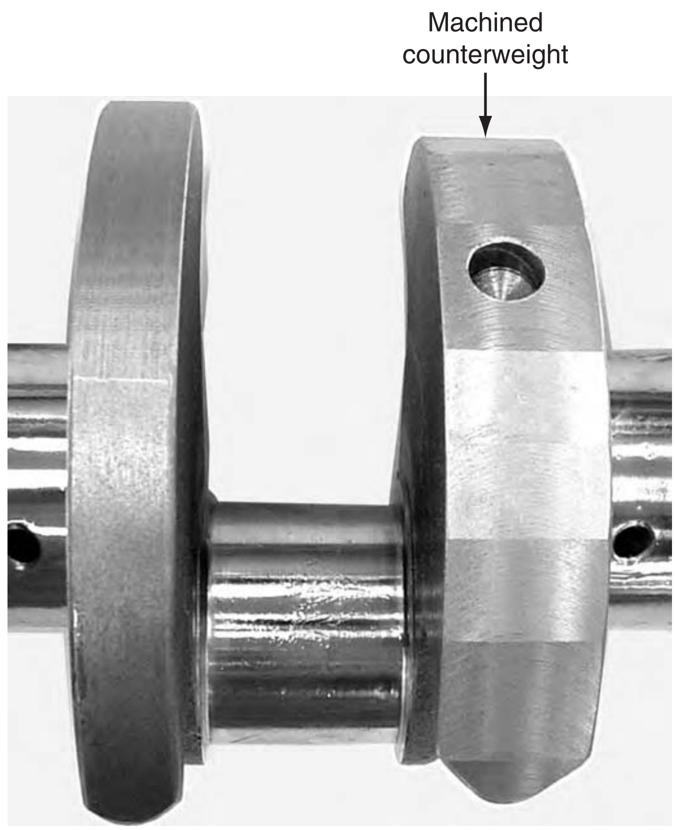


FIGURE 12.37 The counterweights on this crankshaft were reduced in diameter during the balancing process. (*Courtesy of Tim Gilles*)

FIGURE 12.36 The counterweights on this crankshaft are knife edged on the leading and trailing ends. (*Courtesy of Tim Gilles*)

Rod Angle

The length of the connecting rod throw determines the stroke and affects the performance of the engine. When the crankshaft pushes the piston and rod to TDC, the direction of movement must change. The piston remains still at TDC while the crankshaft continues rotating for several degrees. This period is called *piston dwell time*. Dwell time (see Figure 10.58) is longer with a long stroke due to its lesser rod angle. The piston moves slower and because it rests longer at TDC, more air and fuel can be pulled into the cylinder during valve overlap.

Compare the rod angles of a short stroke and long stroke engine when the rod throw is at 90° (**Figure 12.38**). When the connecting rod is at 90°,

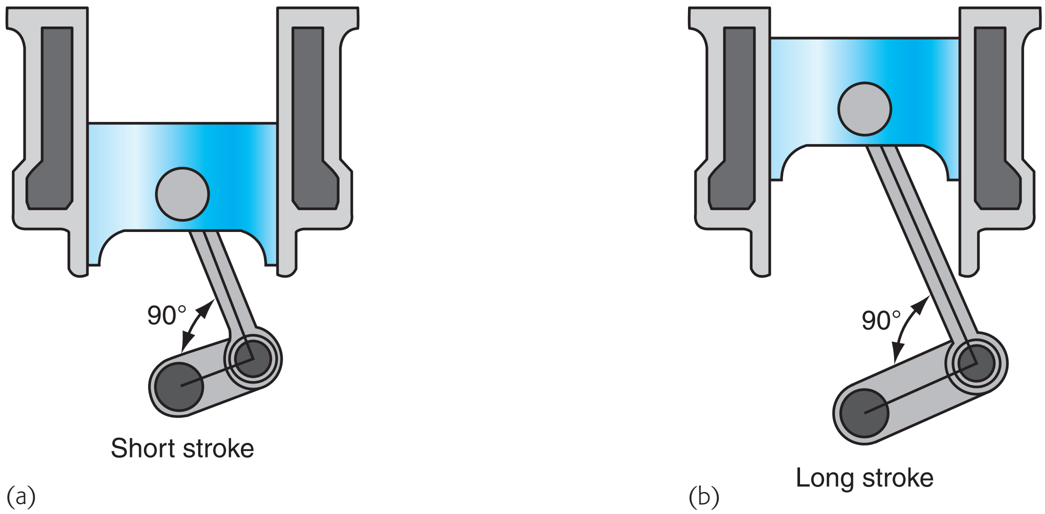


FIGURE 12.38 Comparison of rod angles between short and long stroke engines. Piston velocity is greatest at 90° of rod angle.

this is the point of highest piston velocity. This is of particular note to camshaft designers, who understand that this is the point where the piston will take its biggest gulp of air. Short stroke engines are more susceptible to cylinder wear because their increased rod angle tends to push the pistons against the cylinder walls. On longer stroke engines, the angle of the connecting rod pushes harder on the connecting rod and center of the piston. This causes less pressure on the maximum thrust side of piston, resulting in less friction, temperature, and bearing load.

Short stroke engines have several advantages. They can have more camshaft duration because the faster moving piston stays out of the way of valves that are open farther during valve overlap. Operating with an increased rod angle also applies more leverage on the crankshaft for a longer period of the power stroke. A shorter stroke means the cylinder block can have a lower deck height. This allows designers to lower the hood height, reducing wind resistance and improving fuel economy.

Piston velocity governs engine rpm. This is not a concern where rpm is not a factor, as in industrial engines, which run at very low rpm and have a very long stroke. The stroke affects the speed of piston movement, which is stated in feet (or meters) per minute. On an engine with a 2-inch stroke (50.8 mm), piston movement from BDC to TDC is 2 inches. In one complete crankshaft revolution, the piston will move 4 inches. At 6000 rpm, the piston will move 24,000 inches (609,600 mm) or 2000 feet (609.6 m) per minute.

Cross Drilled Main Journals

Cross drilling is when holes are drilled completely through the main bearing journals at 90° to each other to provide two intersecting oil galleries. At first glance, this would appear to expose the passages to the rod journals to full oil pressure at all positions of crankshaft rotation. Cross drilling has been a popular high-performance upgrade. It has been found, however, that centrifugal force impedes the oil flow at high rpm or under rapid acceleration. Overcoming centrifugal force calls for increased oil pressure. A newer theory calls for drilling the holes between the main bearings and rod throws at an optimum angle so oil can enter the main journal oil passage somewhere near the 8 o'clock position and exit the rod throw somewhere near 2 o'clock. Oil flow continues with crankshaft rotation, rather than against it and centrifugal force is not a factor with increased rpm.

NOTE

In very heavy-duty uses, it is said that rolling fillets with a special hydraulic roller can increase the strength of crankshafts by 30–40%.

CHECKING BEARING CLEARANCE

There are different methods for checking bearing oil clearance, including measuring and using Plastigage.

Plastigage

Bearing clearance is easily checked using Plastigage®, a thin plastic strip that is soluble in oil. Plastigage is available in different thicknesses denoted by color. The one used in engine repair is green and is for clearances from 0.001" to 0.003". Plastigage for larger clearances is red in color. The following describes the process:

- First, oil the surface of the bearing so the Plastigage does not stick to it but will stick instead to the crankshaft where it can be removed more easily.
- Remove the Plastigage from its wrapper (**Figure 12.39**). Apply it to the bearing journal between the bearing and the crankshaft (**Figure 12.40**), and torque the bearing cap. When the cap is torqued, the plastic string flattens. Do not turn the crankshaft.
- Loosen the bearing cap bolts, remove the bearing cap and look at the flattened Plastigage. The wider the flattened string, the less clearance there is.
- Look for variations in the thickness of the Plastigage during the test, which can indicate a tapered journal.
- Measure the widest part of the Plastigage to determine the minimum clearance.

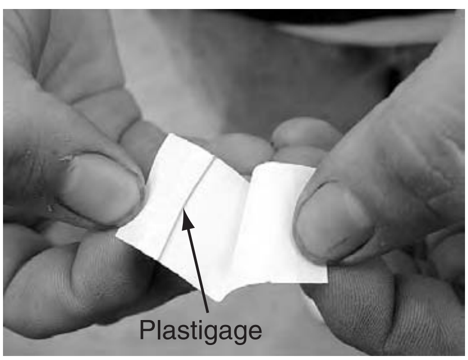


FIGURE 12.39 Open the wrapper and remove the piece of Plastigage. (*Courtesy of Tim Gilles*)

Plastigage measures total bearing clearance. Always position the Plastigage on the "no-load" side of the bearing journal when measuring (**Figure 12.41**). When performing a Plastigage check on an engine that is in the vehicle, jack up the crankshaft against the upper bearing, or an inaccurate reading (with too little clearance) will result.

SHOP TIP

To jack up the crankshaft, temporarily insert a piece of paper between a neighboring lower main bearing insert and its crankshaft main bearing journal. When the main bearing capscrews are tightened, the crankshaft will be raised.

Plastigage should not be used at temperatures above 100°F (38°C) or below freezing, because it may not give an accurate reading at extreme temperatures.

Measuring Clearance. Bearing clearance can also be calculated by measuring the *wall thickness* of the bearing insert. Measure the bearing at the center,

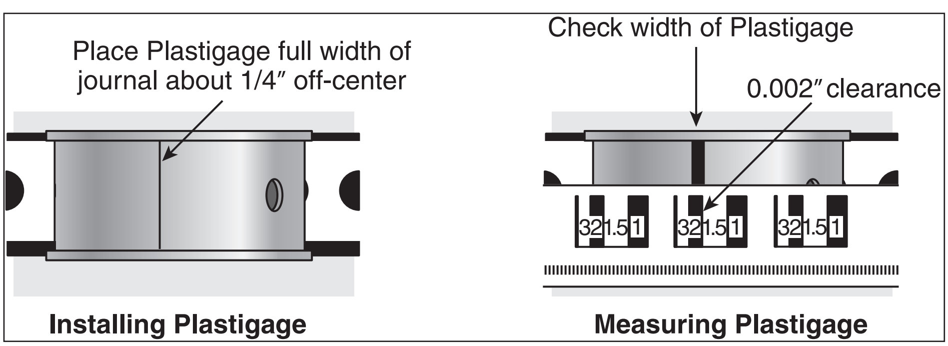


FIGURE 12.40 Checking bearing oil clearance with Plastigage. This is green Plastigage that measures clearance from 0.001" to 0.003". The opposite side of the wrapper provides metric measurement.

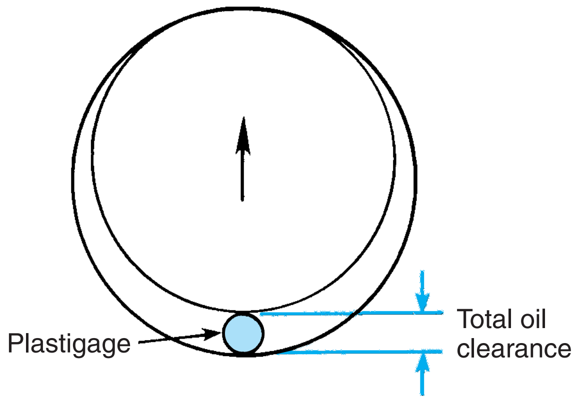


FIGURE 12.41 If the engine is right-side up in the chassis, raise the crankshaft and measure on the unloaded side of the bearing.

because bearings are sometimes tapered. Tapered bearings have 0.0005" to 0.0015" more clearance at their parting lines to help build an oil film under the bearing.

- Use a dowel, or a ball bearing and piece of hose, to make the measurement. Then double the measurement, because there is an insert on each side of the journal. Specialty ball mikes are also available for this purpose (**Figure 12.42**).
- Mike the journal, and then determine the total clearance by subtracting all of these figures from the bore diameter.

NOTE

The oil clearance will actually be about half the total clearance measurement, because oil is present on both sides of the shaft (**Figure 12.43**).

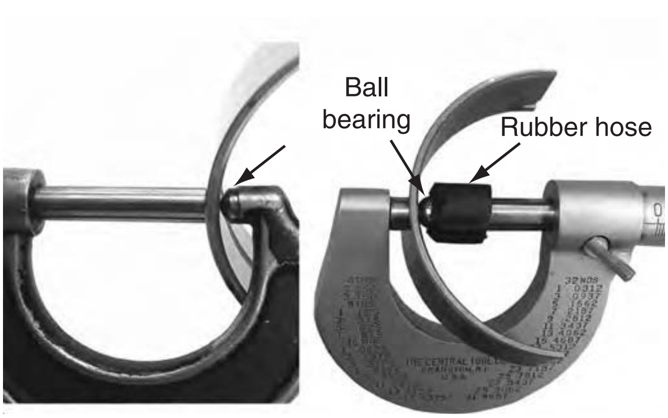


FIGURE 12.42 Measuring the wall thickness of an insert bearing. The micrometer on the left is a specialized ball micrometer. A ball bearing can be used with a regular micrometer by subtracting its thickness from the total measurement. (*Courtesy of Tim Gilles*)

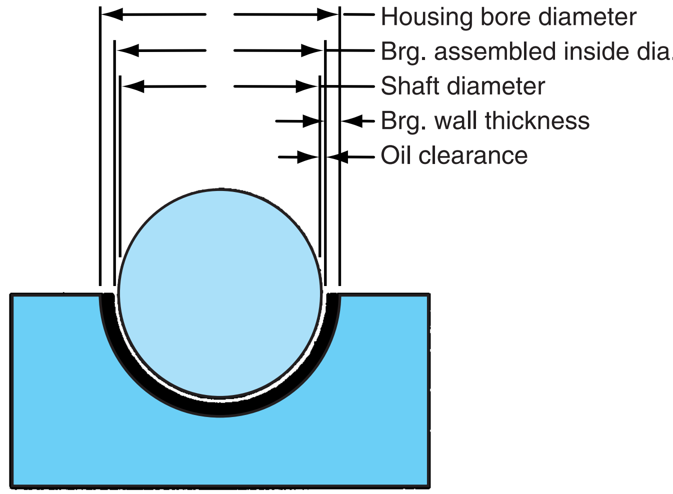


FIGURE 12.43 Determining oil clearance. Be sure to measure at the center of the bearing because the bearing will be tapered at the parting line.

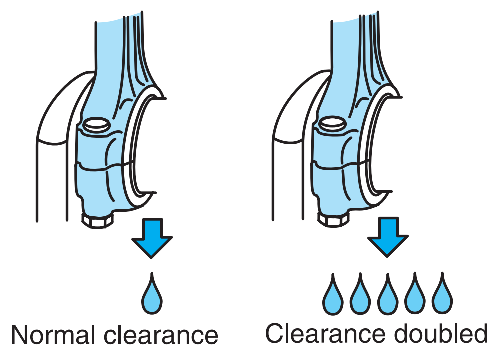


FIGURE 12.44 When oil clearance is doubled, five times as much oil will be thrown from the connecting rods.

Normal oil clearance on a new journal is 0.0007" per inch of diameter. In the past, oil clearance was about 0.001" for each inch of shaft diameter, but newer engines have tighter oil clearance specifications. An engine with double oil clearance will throw off five times as much oil onto the cylinder walls (**Figure 12.44**), causing increased oil consumption.

Some say it is best to use the wide side of a bearing's oil clearance tolerance. If there is too little bearing clearance, not enough oil will be thrown from the rods to the cylinder walls, where lubrication of the rings is especially important right after the engine starts. Be careful not to allow too much clearance, however. A front bearing with excessive clearance will knock (see Chapter 3). Excessive clearance can also cause low oil pressure at idle.

Select-Fit Bearings

Some manufacturers use select-fit bearings. Bearings are matched to the finished crankshaft size, according to the machining tolerance achieved at the factory. With some manufacturers, such as Honda, bearings are selected according to colored marks on the block that match corresponding marks on the sides of the bearing inserts (**Figure 12.45**). In the aftermarket, it is common to use unsized bearings during an overhaul. Other manufacturers use a numbering system to select bearings. For instance, on some of its engine lines Ford uses a three-grade select-fit system to match each bearing with its specific crankshaft journal. There is one seven-character number string on the block and another on the crankshaft. Numbers from each are cross-referenced on a select-fit chart in the service literature to determine which size bearing to use.

Bearing Inserts

Bearing inserts are made of many different materials. Dissimilar metals slide against each other with lower friction than similar metals, so bearings usually have a steel back with a soft alloy surface. Bearings have been made with surfaces of babbitt, copper-lead, or aluminum alloy.

- The copper lined bearings are premium bearings.
- Some bearings are made of solid aluminum alloy with no steel backs.
- Multilayered bearings have steel backs with one or more layers of lining material (**Figure 12.46**).

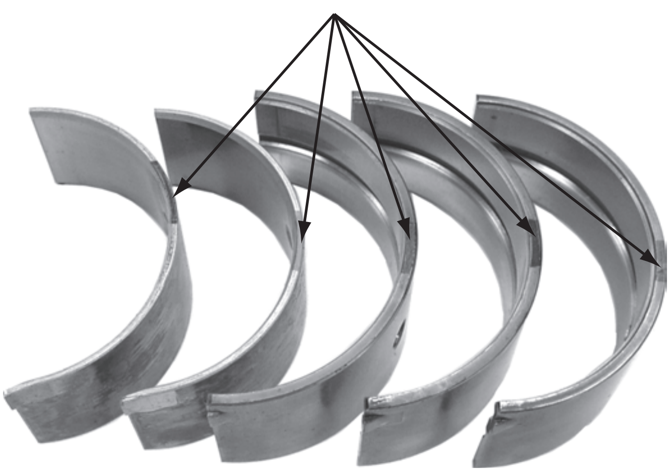
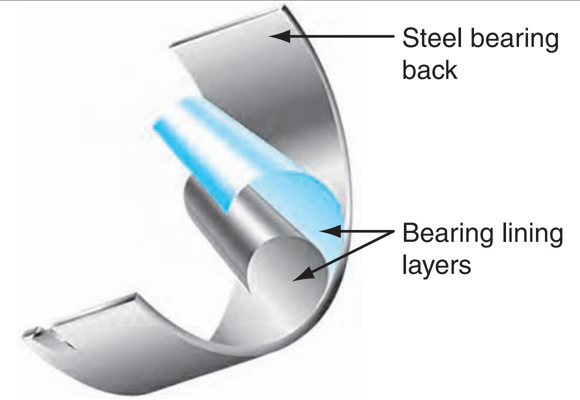


FIGURE 12.45 Color-coded bearing inserts for selective fit of bearing oil clearance. (*Courtesy of Tim Gilles*)



(a)

Bearing Lining Material	Bearing Use
• layer lead or tin based babbitt	light duty
• layer copper-lead alloy	heavy duty and extra H.D.
• layer copper-lead	medium duty
• layer aluminum-lead or aluminum-tin	medium duty
• layer aluminum-cadmium	heavy duty and extra H.D.

(b)

FIGURE 12.46 Bearing lining materials. (a) Multilayered steel-backed bearings. (b) Chart of lining materials.

Figure 12.46 shows the various part number codes of bearings from one manufacturer.

Bearing Properties

The bearing surface has three primary properties that make it suitable for use in an engine (**Figure 12.47**). When foreign particles are forced between the bearing and journal, they are absorbed by the softer bearing material. This property, known as *embeddability* (**Figure 12.47a**), helps prevent crankshaft wear. When the particle is too large to be completely absorbed, it creates a high spot on the bearing.

If the crankshaft journal surface is damaged, the bearing metal "flows" to conform to it. This property is called *conformability* (**Figure 12.47b**).

The third primary bearing property is *fatigue* intermittent loads without deteriorating (**Figure 12.48**).

Different bearing materials are best for specific uses (**Figure 12.49**). Babbitt bearings, which have the best embeddability, were once widely used, but the loads of today's engines call for more load carrying capacity.

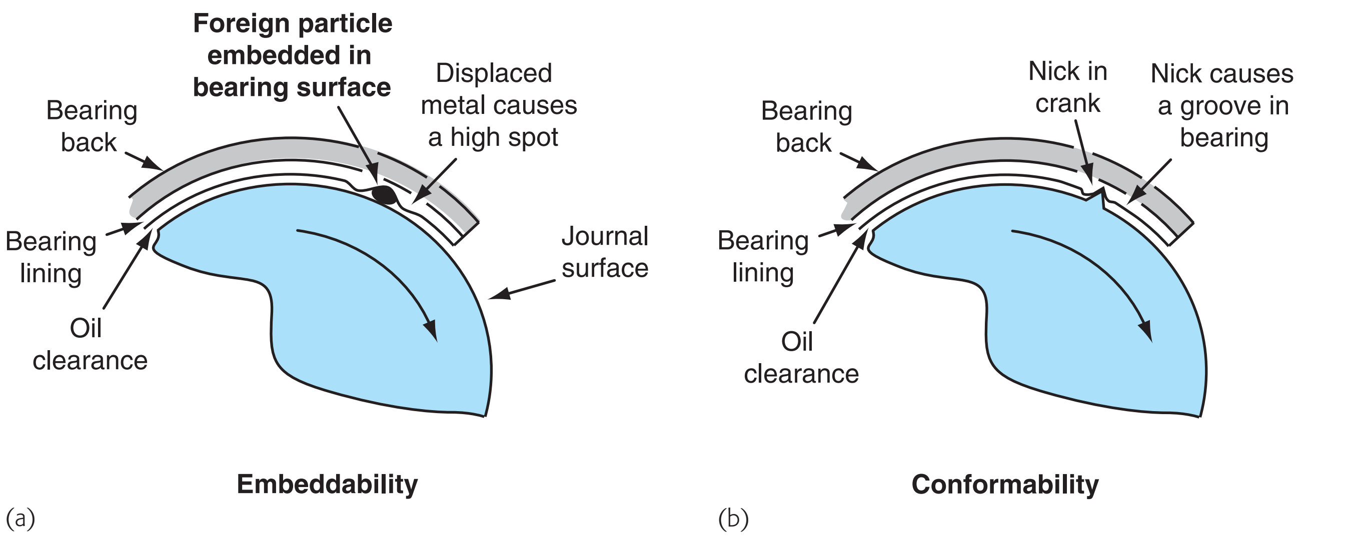


FIGURE 12.47 Bearing properties. (a) Embeddability. (b) Conformability.

VINTAGE ENGINES

In 1839, Isaac Babbitt was granted a patent for a white metal alloy, useful as a bearing material, and the Babbitt name has become synonymous with bearing metals of this type. Early engine bearings were not inserts like bearings of today. The bearing material was poured in place on the main bearing and rod bearing surfaces using special jigs. Then the bores were machined to their finished size. Poured *babbitt* connecting rods had bearing surfaces on the sides, called cheeks, and some had an oil dipper (see Figure 12.46). Until the early 1950s, some engines still used poured babbitt bearing surfaces. A common procedure in later years was to retrofit these engines to accept a new bearing insert. The insides of the connecting rods were bored or ground and new slots for the bearing insert locating lugs were milled.

There are many different babbitt types, categorized by number, with #2 and #7 being the predominant types. Babbitt is either tin based or lead based. Tin-based babbitt, called #2, is the “white metal.” Nearly 90% tin, it is alloyed with antimony and copper and is hard with higher load carrying capability. Lead-based babbitt, called #7, is made of at least 75% lead with antimony and tin. It has a lower load carrying capacity with better conformability and embeddability characteristics than tin-based babbitt. Tin-based babbitt is more expensive than lead-based babbitt.

Babbitt melts between 350°F (177°C) and 475°F (246°C). Babbitt and lead are similar in appearance but lead is soft and folds when bent. Babbitt is more brittle and breaks when folded, exposing porous material.

FIGURE 12.48 Bearing surface fatigue.

Multilayered Bearings

Most bearing manufacturers prefer trimetal bearings, which can carry at least three times the load as babbitt and are acceptable in the other categories. Aluminum bearings have the best load carrying capacity but are poor in embeddability.

A typical multilayered bearing has a steel back covered with a layer of copper/lead covered by a very thin (0.0005"–0.0008") electroplated overlay of babbitt. Babbitt provides protection against dirt, which is by far the number one reason for premature bearing failure. The babbitt layer is kept very thin to minimize its effect on the bearing's capacity to carry a load. High-performance bearings have an even thinner (0.0005") layer of babbitt. For mostly cosmetic reasons, some bearings also have an additional shiny layer of tin. Performance bearings do not have a tin flash because the tin can move under heavy loads.

The copper-lead alloy, which is stronger than babbitt, combines copper, a harder metal with a small amount of lead, which is a softer metal. A copper-lead alloy has good fatigue strength as well as high load capacity and decent performance at high temperatures. Sometimes a very thin layer of lead is electroplated to a finished bearing. This is known as an overlay.

Multilayered bearings are popular in the aftermarket because they are more forgiving of tolerance

Bearing Materials and Design Considerations					
Material	**Conformability**	**Surface Action**	**Embeddability**	**Corrosion Resistance**	**Fatigue Strength**
Babbitt	Excellent	Excellent	Excellent	Excellent	Poor
Aluminum	Poor	Poor	Poor/Fair	Excellent	Excellent
Trimetal Copper-Lead-Tin	Fair	Fair	Fair/Good	Poor/Fair	Excellent

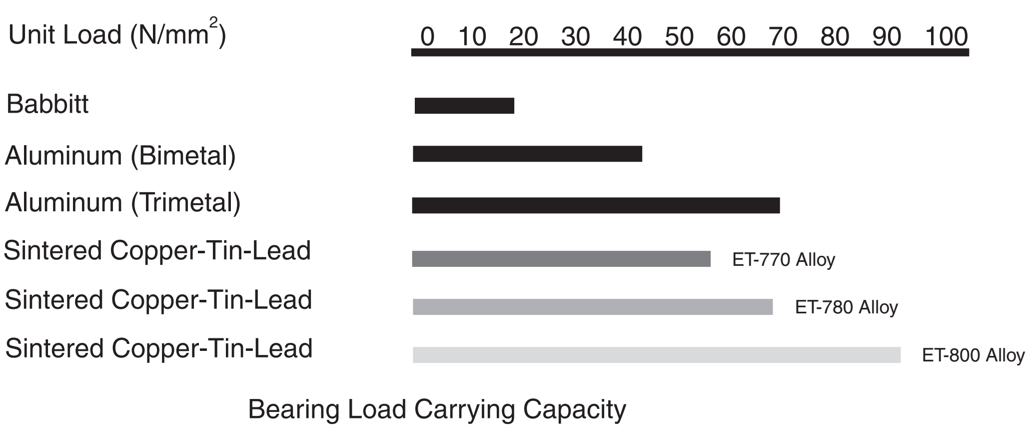


FIGURE 12.49 Bearing properties.

errors and, therefore, more dependable. These are the bearings of choice for high-performance applications. The load on a bearing is approximately 6500 pounds per square inch every time a cylinder fires and a bearing with a high load will have a lower life expectancy. Top fuel dragsters have such tremendous bearing loads that their lifetime might only be one or two runs down the dragstrip.

Aluminum Bearings

Bimetal aluminum/silicon bearings are used in many late-model engines because they are less expensive. They are also desirable for environmental reasons, because they do not contain lead. Another positive aspect of an aluminum bearing is that it has a melting temperature that is over three times that of copper-lead multilayered bearings. The silicon alloy significantly hardens the bearing surface, which polishes the crankshaft as it wears. Aluminum bearings are more resistant to crankshaft seizure as well. Bearing manufacturers claim that bearing clearance can be reduced by as much as 40% with aluminum bearings.

On the downside, aluminum bearings are not as forgiving of a rough crankshaft finish and do not have the embeddability of multilayered bearings, but embeddability is not usually an important consideration unless the engine is used off-road or was assembled in less than clean conditions. Another shortcoming of aluminum bearings is that they are not as resistant to cavitation erosion as multilayer bearings. Cavitation erosion happens at high rpm when the speed and load cause bubbles to form in the lubricant film. When the bubbles break, the resulting shock waves create craters and pits in the bearing.

Trimetal bearings can carry loads of as much as 35% higher than aluminum bearings. A copper-lead bearing can carry 12,000 psi of load, whereas aluminum bearings can carry only 7000–8000 psi. The copper-lead bearing's softer lead layer protects against seizure during heavy acceleration. This is when the crankshaft deflects against the bearing.

Bearing Undersizes. Bearings come in standard sizes, and in 0.010", 0.020", and 0.030" undersizes. The size is usually marked on the back of the bearing. *Undersize bearings* are used when a crankshaft is reground or on some new engines to compensate for errors in production. Undersize bearings have a thicker bearing back to compensate for the smaller, reground crankshaft (**Figure 12.50a**).

NOTE

A crankshaft that is ground to a 0.030" undersize has had 0.015" of metal removed from its surface so both of its new bearing inserts will be 0.015" thicker (**Figure 12.50b**).

Some engines also have bearings available in 0.001" and 0.002" undersizes but not 0.011" and 0.012". Some rod bearings may be 0.009" undersize to correct for factory mistakes. Watch for these; replacements are available from the dealer only. Mains are sometimes 0.009" under also, but some of the other mains in the same engine might be of standard size. These crankshafts are usually identified only with a splash of paint next to the undersize journal.

Many newer engines use *select-fit* bearings for both main and rod locations. These bearings are

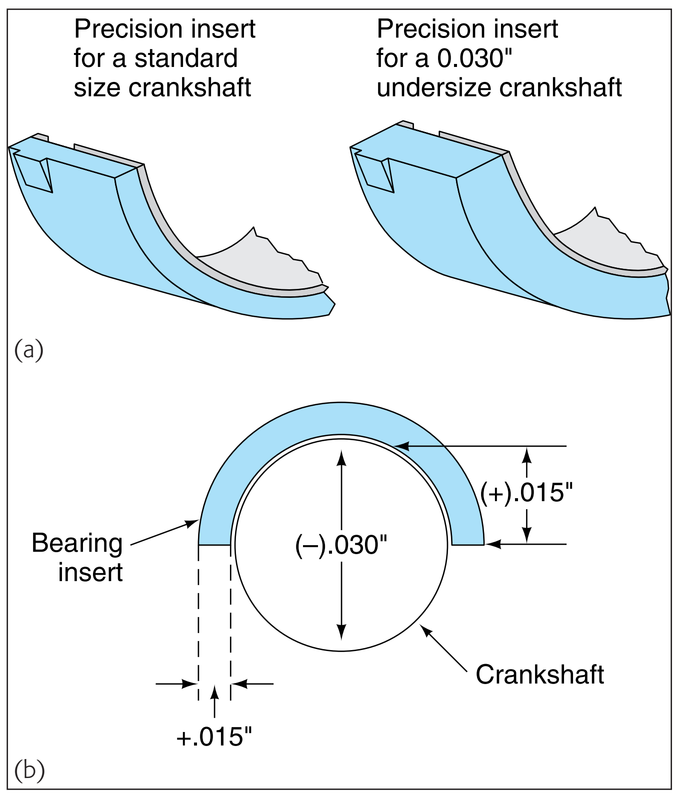


FIGURE 12.50 (a) An undersize bearing insert is thicker. (b) A 0.030" undersized crankshaft will require bearing inserts that are 0.015" thicker on the bearing back.

used in many combinations to achieve the desired minimal clearance.

Main bearings often come with an oil hole and groove in only one half; install these bearings in the upper bearing position (see Figure 12.11). Lower main bearings (especially for heavy-duty use) are sometimes solid with no oil holes or grooves. Other times the same bearing style with a hole and groove is used in both the upper and lower positions.

Heavy-Duty Bearings. Heavy-duty main bearing sets usually have a grooved upper bearing accompanied by a lower bearing without a groove. This is because the load carrying ability of the bearing is substantially reduced by a bearing oil groove.

Locating Lug and Oil Groove. Bearing inserts are positioned in the bearing bore by a **locating lug (tang)** or by a *dowel* (**Figure 12.51**). The lug is located on the parting face. It fits into a recess in the bearing bore. Except for a few vintage, industrial, and truck engines, the bearing locating lugs for the top and bottom bearings face toward each other at the parting faces. When a dowel is used, it fits into a hole in the bearing back. The other end of the dowel fits snugly in a hole in the block or bearing cap. Be certain it is not loose.

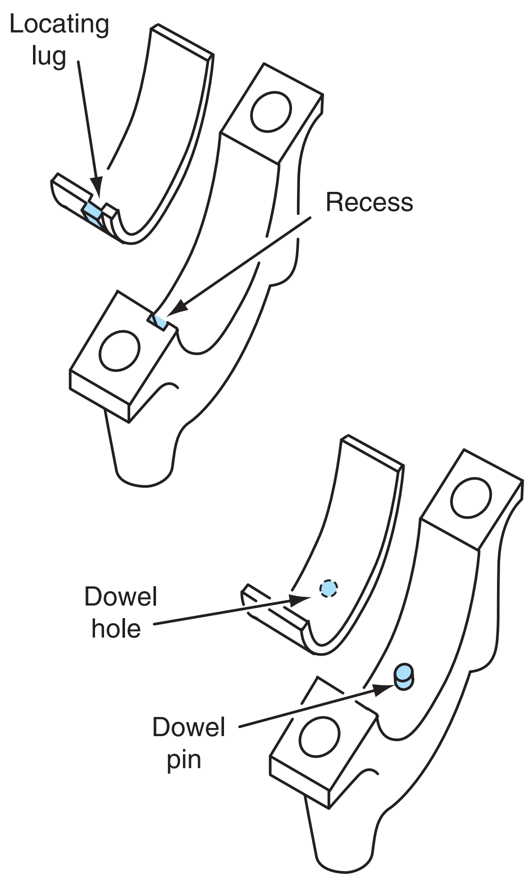


FIGURE 12.51 Bearings are located in the bearing bore by a locating lug or a dowel.

NOTE

Locating lugs are used to locate or position the bearing laterally, not to keep it from spinning. This is the job of bearing crush.

Bearing Spread and Crush. **Bearing spread** (**Figure 12.52**) is where the measurement across the parting face is slightly larger than the diameter of the bearing bore. Spread allows the bearing to snap into place and remain in place during assembly of the engine.

A good bearing that is going to be reused might have lost its spread. According to Federal-Mogul Corporation, a bearing can be respread by placing it on a hardwood surface with the parting face down and gently tapping the back with a soft-faced mallet.

NOTE

When a bearing has lost its spread, inspect the top of the piston for evidence of abnormal combustion. Spark knock can leave small indentations in the tops of pistons.

Bearing crush is when the bearing extends slightly above the parting line of the bearing bore half by about 0.0005"–0.0015" (**Figure 12.53**). Crush helps to seat the bearing in the bore, promoting

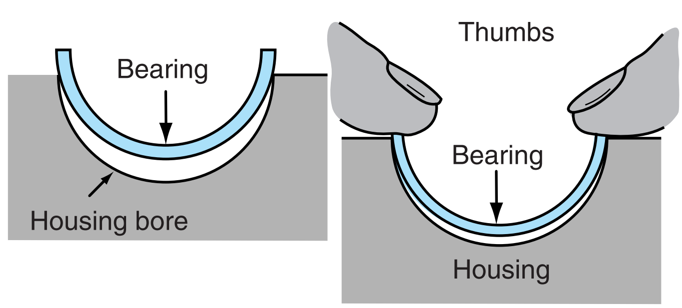


FIGURE 12.52 Bearing spread permits the bearing to be snapped into place.

better heat transfer and helping to keep the bearing from spinning in the bore.

Excessive crush will distort the bearing at its parting lines (**Figure 12.54**). The bearing is often relieved or tapered at the parting lines to minimize its distortion into the oil clearance space (**Figure 12.55**). New cast iron rods cure, settling into a more consistent shape. Rods that are not fully cured sometimes stretch in an up-and-down direction. When a rod stretches, bearing clearance is pulled closer at the connecting rod parting lines, resulting in bearing wear. **Figure 12.56** shows the lack of wear at the parting line of a typical rod bearing.

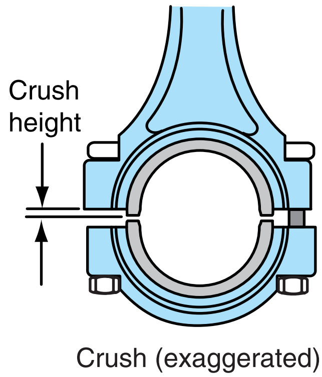


FIGURE 12.53 Bearing crush.

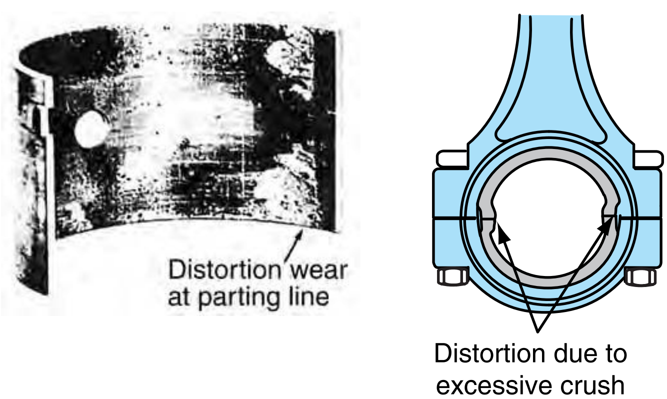


FIGURE 12.54 Excessive crush distorts the parting faces of the bearing. (*Courtesy of Clevite 77 Engine Bearings, Clevite Engine Parts*)

FIGURE 12.55 Crush relief helps maintain the oil film between the bearing and the journal.

FIGURE 12.56 This unworn area nest to the parting line of the bearing shell shows the effect of crush relief. (*Courtesy of Tim Gilles*)

Insufficient crush, on the other hand, will allow the bearing to move back and forth in the housing, because there will not be enough radial pressure on the bearing (**Figure 12.57**). Dirt, or a burr on the connecting rod parting surface, can result in insufficient crush.

Bearing Eccentricity

Bearing *eccentricity* describes the taper or drop in wall thickness of a bearing shell above its parting line. Normal bearing wear will only show a pattern on about three-quarters of the bearing surface. At

FIGURE 12.57 Insufficient crush allows the bearing to move. (*Courtesy of Federal-Mogul Corporation*)

VINTAGE ENGINES

Incorrect crush can result when feathered or tapered shims are used to adjust bearing oil clearance. In vintage engines, shimstock was placed under the lower bearing insert, a practice that is no longer followed. Excessive upper front crankshaft bearing clearance was a common result of too much tension on manually adjusted drive belts, but today's spring-loaded serpentine drive belts have minimized this problem. On older engines, feathered shimstock can be used to correct an engine knock from excessive front bearing clearance when an engine is still in the vehicle. The shimstock is tapered so that it takes up clearance accurately at the top bearing, too. The disadvantage to this method is that the bearing must be filed at the parting line to maintain the correct bearing crush. Filing is not very precise; the end result can be insufficient crush.

higher rpm the rod can stretch, pulling the rod bore tighter at the parting line. The bearing taper provides extra clearance to compensate and also helps build an oil film under the bearing. Bearings have different amounts of taper, ranging from 0.0005" to 0.0015", depending on the application. For instance, aluminum racing rods require more eccentricity than ferrous metal rods.

Inspecting Worn Engine Bearings

It is a good idea to keep all bearings in order for inspection. Reading the bearings will give you valuable information that can be used to repair a problem and prevent it from happening again. A good parallel is looking at tire wear before doing a wheel alignment. If the tire is worn on one side, an adjustment can be made to correct this. But it took many miles of driving to produce this wear. The alignment technician would be disappointed if the vehicle came into the shop with new tires and he or she did not get to inspect previous tire wear. Looking at engine bearings presents a similar situation. It often takes many years of engine operation to develop an unusual wear pattern on a bearing.

According to engine bearing manufacturers, dirt is the cause of nearly half of all engine bearing failures. Dirt includes grit, metallic particles, and other abrasives. Sometimes sandy dirt enters the engine through the air cleaner or the dipstick opening. Fine scoring on the bearing surface can be caused by dirt that has accumulated in engine oil or by failing to clean an engine properly during a rebuild. Metallic chips cause wider grooves. Pieces of grit and iron from cylinder refinishing operations can become embedded in the bearing surfaces. Another cause of bearing wear is engine part failure.

NOTE

When engine parts fail, the oil pump can also be damaged because oil drawn through the oil pump is unfiltered. A thorough cleaning of the oil galleries as described in Chapter 11 is mandatory. Some engines have oil coolers as well (**Figure 12.58**). These have very small passageways and the recommended procedure when engine parts have failed is to replace the oil cooler. This is the only certain way to ensure that debris will not enter the oiling system on the newly rebuilt engine.

A magnifying glass can be helpful in inspecting a bearing for wear.

Federal-Mogul suggests the following procedure for checking for metallic particles:

- Scrape the bearing surface with a sharp tool.
- Place the scrapings on a clean paper.
- Then rub a permanent magnet on the underside of the paper. If the particles are iron or steel, they will follow the magnet as it is moved around.

Excessive Loads on Bearings. Bearings will have the longest service life if they operate at an engine speed that is between a few hundred rpm above

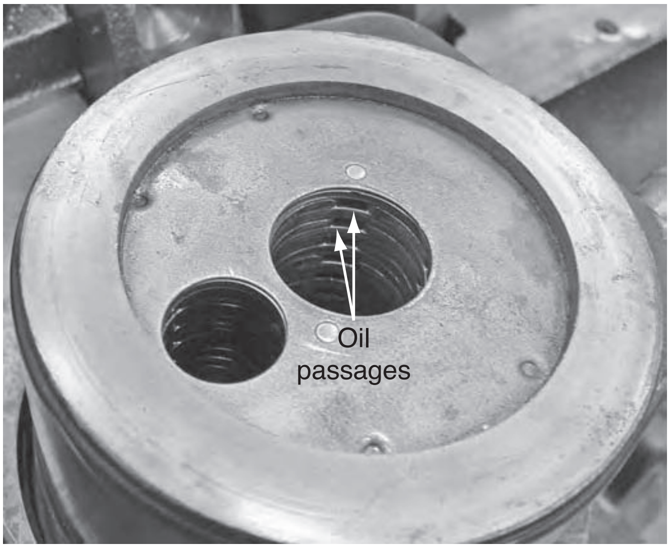


FIGURE 12.58 The inside passageways in an engine oil cooler are very small and can trap debris. When an engine has suffered bearing failure, oil cooler replacement is recommended. *(Courtesy of Tim Gilles)*

lugging (maximum torque) and a few hundred rpm below the highest horsepower.

Bearings are subjected to normal loads from three sources:

- Pressure from the flame front against the piston
- Centrifugal force from the rotating weight of the rod and crankpin
- Inertia from the up-and-down motion of the piston and rod assembly

These sources of load are combined into a continuous series of loadings. The dynamic loads (inertia and centrifugal force without ignition) differ with engine rpm and increase with engine speed.

Normal Bearing Wear. Bearings have loaded and unloaded bearing halves. The upper rod bearing and the lower main bearing are the loaded halves. Upper rod bearing wear is often found in combination with lower main bearing wear (**Figure 12.59**). On vehicles with standard transmissions, moderate wear of this type often indicates poor driving habits. The engine may have been lugged (not shifted into a gear low enough for the load). This wear can also result from excessive idling, too low an idle speed, or excessive spark knock. A *little* of this kind of wear is considered normal. When the wear is severe, bearing material will flake off the upper rod bearing halves and be deposited on the lower bearing halves.

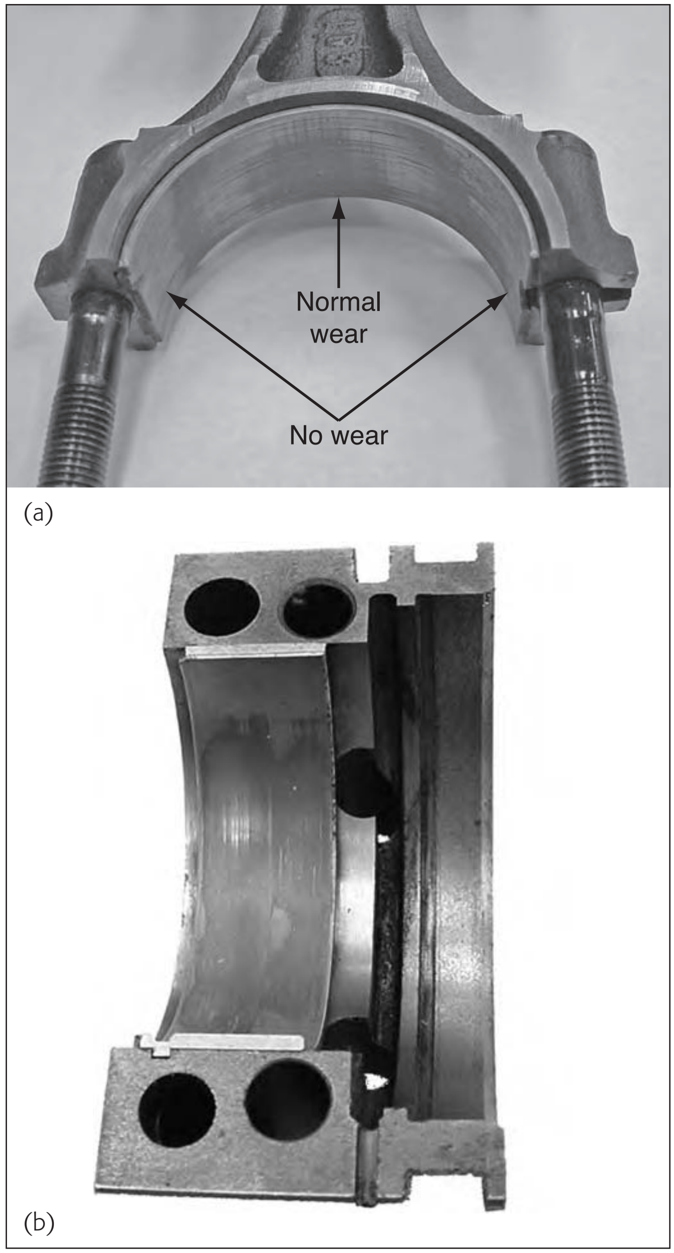


FIGURE 12.59 (a) It is normal for the upper rod bearing to have this type of wear. The sides of the bearing do not wear because they are tapered for crush relief and carry little, if any, load. (b) A worn lower main bearing. *(Courtesy of Tim Gilles)*

Bearing Fatigue. The basic cause of bearing fatigue is overloading. When both upper and lower main and rod bearings show fatigue breakdown, excessive engine speed is a probable cause. Fatigue breakdown can also be caused by over-revving when going downhill; over-revving can sometimes occur when engine compression is used to slow the vehicle.

Maintaining proper oil clearance and using a higher oil viscosity increases the fatigue life of a bearing. Racers closely control bearing clearances and use higher viscosity oil.

Dry Start. When the main bearing furthest from the oil pump shows more wear than the other main bearings, a dry start condition is indicated. This means that the engine was probably revved before oil had filled the system. This problem occurs most often in cold weather. This condition can also be caused by using an oil filter with a missing or defective anti-drain back valve (see Chapter 14).

Streaked or Smeared Bearings. When bearings are smeared or streaked, this can be due to oil starvation, too little bearing clearance, too low an oil viscosity, diluted oil, or an oil pump drawing in air under hard acceleration or from a leaking sump screen gasket.

Belt Tension. Sometimes all the lower main bearings will be worn except for the front bearing. This bearing usually wears less on the bottom because of the upward tension of the accessory drive belt. Excessive belt tension can cause wear on the *upper* front main bearing and, possibly, a bearing knock.

Thrust Bearing Wear

Thrust bearing wear can result from multiple causes. Crankshaft thrust bearing failure has been a costly problem for both engine and transmission rebuilders. Some causes of failure can be traced to the engine and others can be traced to the transmission. There was a history of controversy so several parties (AERA, ATRA, PERA , ASA, and AE Clevite) collaborated to come up with realistic diagnoses and recommendations for dealing with thrust bearing failures.

Normal crankshaft bearings can handle thousands of pounds of load because of the hydrodynamic wedge of oil that lifts the crankshaft journal away from the bearing surface (**Figure 12.60**). Thrust bearings do not share this advantage because the two flat thrust surfaces contact each other without the benefit of an oil wedge. Forming a protective oil film in this environment is difficult. Imagine two pieces of glass with an oil film between them. Pressing the two pieces of glass together causes them to stick to one another; the oil film does not work. To allow oil to

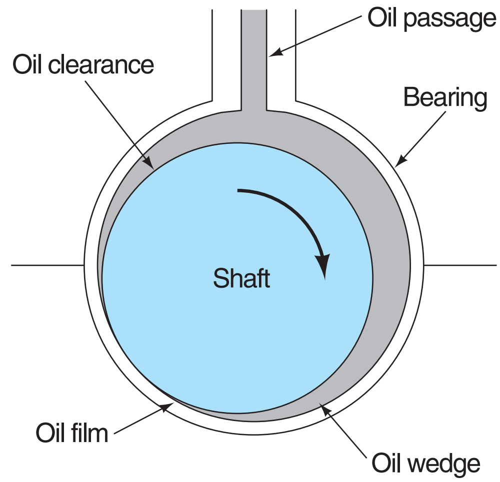


FIGURE 12.60 A hydrodynamic wedge of oil forms under the bearing journal.

lubricate the thrust contact surfaces, single-piece thrust bearings have machined grooves or wedge-shaped ramps at the bearing parting lines.

The thrust bearing surface facing the rear of the engine is most likely to experience wear. Most thrust bearings are machined with concave reliefs to provide lubrication (**Figure 12.61**). But thrust surfaces can only handle intermittent loads and wear and failure can occur if a continuous load causes more heat than can be carried away by the oil.

Several things can cause a thrust bearing to fail:

- A thrust surface that is too rough
- Misalignment
- Pressure from a standard or automatic transmission pushing forward on the rear of the crankshaft
- A rope seal installed too tight, resulting in heat
- A bent connecting rod that can wear both sides of the thrust bearing as it knocks the crankshaft back and forth
- A missing or broken electrical ground strap that causes arcing on the thrust bearing wear when electrons take an easier path to ground

End thrust tolerance specifications varied on vintage engines between 0.002" and 0.012". Typical end thrust on newer engines is 0.002–0.004". Substantial clearance exists between the main cap screws and the main bearing cap holes (**Figure 12.62**). Although there is a raised shoulder at the top of the bolt, there is still enough clearance to make a critical difference in the thrust bearing clearance. A procedure for

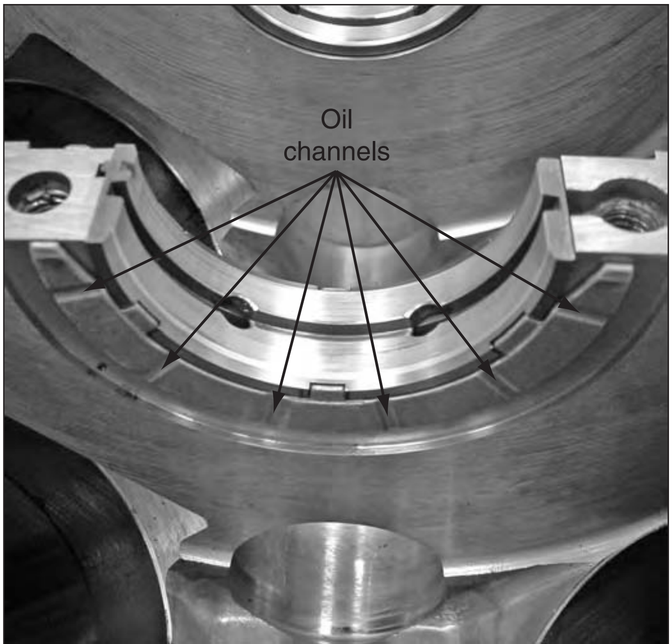


FIGURE 12.61 (a) These oil channels provide the thrust surfaces with the necessary lubrication to prevent failure. (b) When an engine has thrust bearing inserts, install them with the oil grooves facing the crankshaft thrust surfaces. (*Courtesy of Tim Gilles*)

aligning the thrust bearing halves during engine assembly is covered in Chapter 17.

The most common cause of thrust bearing failure is too little clearance.

FIGURE 12.62 Clearance between the holes in the thrust main cap and the cap screws allow the cap to be positioned a few thousandths of an inch fore or aft. An incorrectly positioned main cap can result in little or no thrust bearing clearance. (*Courtesy of Tim Gilles*)

Most vehicles today use lockup torque converters that increase the front loading on the crankshaft. Newer engines also have smaller crankshaft thrust bearing surfaces, which carry greater thrust loads. These increased loads have magnified the importance of correctly polishing the thrust surfaces during a crankshaft regrind. A poor surface finish can occur because thrust surfaces are difficult to grind. The side of a crankshaft grinding wheel is not designed for grinding the thrust surface; when it is used for this, a swirled crisscross pattern similar to a cylinder wall crosshatch can result. This is not an acceptable finish, and if not polished completely away, it will wipe and remove the oil film. A correctly finished crankshaft should show only fine polishing marks in a circular pattern, not in a swirl pattern.

When grinding the thrust surface, the grinding wheel must be fed very slowly into the thrust surface and be allowed to spark out. The area must be flooded with sufficient coolant to avoid overheating and warping the surface.

If there is a thrust bearing failure, it will probably be on the rear side. Check the surface on the front side to see if a rough surface finish might have

VINTAGE ENGINES

Some older import engines used thicker aftermarket thrust bearings, requiring the thrust surfaces of the crankshaft to be ground to fit. Air-cooled Volkswagen and Porsche engines had bearings with unfinished thrust surfaces that required machining on a lathe.

been the cause of the problem. A very fine surface finish is extremely important for thrust surfaces. In the past, minimum surface finish requirements were listed at less than 12 Ra. But thrust bearing failures have been prevalent, and, according to AERA, shops that produce a thrust surface finish of 6–8 Ra claim to have no thrust bearing failures on recently rebuilt engines.

When a transmission-related cause is suspected, a good question to ask is, "Did the vehicle have a previous engine that had a thrust bearing failure?" Excessive thrust wear is often caused by too little clutch free play or by a driver who habitually rests his or her foot on the clutch pedal while driving (called "riding the clutch"). This is often indicated by a worn throw-out bearing. Thrust bearing failure can also be traced to excessive oil pressure in an automatic transmission's torque converter. Any of these conditions force the crankshaft thrust flange forward against the rear-facing surface of the crankshaft thrust main bearing. Because normal oil clearance is eliminated, the oil film that lubricates the thrust surface cannot be maintained and the result is a worn or burned thrust bearing (**Figure 12.63**).

FIGURE 12.63 This thrust bearing has melted on one side. (*Courtesy of Tim Gilles*)

Thrust bearing failure can be caused by an automatic transmission torque converter that is pushed forward in reaction to excessive hydraulic fluid pressure. The torque converter expands more in the front because it has more surface area than the rear. The rear of the converter where the transmission input shaft and stator support are inserted is what causes the difference. Fluid cannot act against this area, but it *can* act against the entire flat area of the front of the converter. If pressure in the converter circuit is above normal, thrust bearing failure might result. Normal pressure is usually 50–80 psi under load, although some late-model transmissions have normal pressures in excess of 100 psi.

An AERA technical service bulletin (TSB) states that a kink in the metal line from an automatic transmission to its heat exchanger in the radiator can cause such a rise in converter pressure. The higher pressure that builds between the pump and the converter hub creates excessive forward pressure on the crankshaft. This pressure is isolated from the pressure relief valve and cannot be vented.

CASE HISTORY

A rebuilt engine was installed in a vehicle and returned to the customer before developing a serious engine knock. When the engine was removed and disassembled, a badly worn thrust bearing was discovered. A new engine was installed and the vehicle was returned to the customer. Once again the thrust bearing wore excessively. The owner of the business called several machine shops and discovered the information in the previously mentioned technical

service bulletin. Further inspection revealed a kinked line to the transmission cooler.

In a case like this, an engine rebuilding company could be blamed for a problem that was caused during a careless engine R&R job. If the rebuilder provides a replacement engine under this circumstance and the thrust bearing in the new engine then fails, the installer will also be liable for the cost of the first engine.

SHOP TIP

When a crankshaft thrust bearing has failed, look for the possibility of an automatic transmission failure. A defective automatic transmission can result in a plugged transmission oil cooler, which can increase pressure on the rear of the crankshaft thrust bearing. Use compressed air and a rubber-tipped blowgun to determine that the transmission oil cooler is not restricted.

The *flexplate* is so named because it flexes toward the engine, allowing movement of up to 0.080"–0.100". When the engine is under load, the converter is driving its turbine and there is no forward load on the crankshaft. It is normal for the converter to slide forward during deceleration, however. As the rear wheels drive the converter, the direction of thrust is reversed. As the converter moves forward, the converter (see Figure 4.33b) moves into the bore in the rear of the crankshaft. Rust, paint, or damage to the crankshaft pilot bore can result in damaging loads to the crankshaft. Crankshaft thrust bearing wear can also be caused by converter splines with excessive wear, grit, or misalignment.

CASE HISTORY

A machinist rebuilt an engine using a master engine kit that included an exchange crankshaft. The engine was installed in the vehicle and returned to the customer. After a few hundred miles it returned with a failed rear thrust bearing. Further disassembly and examination showed that a pilot bearing from a standard transmission vehicle was installed in the rear of the crankshaft, even though this vehicle had an automatic transmission. The converter did not have room to move forward, so it forced the crankshaft forward into the thrust bearing.

NOTE

The pilot bushing extends out of the crankshaft on some Jeeps. Its outside diameter is used to center the flywheel. Automatic transmissions supplied with some of these engines use a pilot bushing because it centers the flexplate.

A modification can be done to the upper thrust bearing rear surface to provide a path for pressurized oil to the thrust bearing area from the oil groove. Use a file to increase the chamfer on the inside edge of the bearing parting line to about 0.040″. Do this only from the oil groove to the rear of the bearing. File outward toward the parting line to avoid damaging the bearing metal.

Some newer engines use heavy-duty thrust washers that have a contoured face. Contoured thrust faces can handle more load but are not designed into single-piece thrust bearings. They are part of a six-piece bearing assembly (see Figure 12.10).

Electrical Grounds and Thrust Bearing Problems

Thrust bearing failure can result from a missing or broken electrical ground strap that causes arcing on the thrust bearing wear when electrons take an easier path to ground. When checking for electrical ground problems, use a digital voltmeter to perform a voltage drop test between the negative post on the battery and the transmission housing. During engine cranking, there should be less than 0.1 V (0.3 V momentarily). The test should last at least 4 seconds, so disable the ignition system if necessary.

CRANKSHAFT DESIGN AND ENGINE BALANCE

All moving parts should be in balance. An imbalance of rotating parts can be compared to a washing machine with all the clothes on one side of the tub. The result is vibration and worn parts.

When the piston slows down as it approaches TDC, its force pulls the engine up. When it approaches BDC, it pulls the engine down. This is known as *primary vibration.* To counteract the up-or-down vibration force, *counterweights* added to the crankshaft are positioned so they arrive at exactly TDC when the piston is arriving at BDC, and vice versa. To absorb all vibration force, a counterweight would equal the weight of the piston reciprocating weight. However, when it is halfway through a stroke, the rod is nearly at a right angle to the crankshaft, causing the engine to vibrate horizontally. Therefore, counterweights are only half of the total piston reciprocating weight. In this way, although the engine is not perfectly balanced at TDC/BDC, it is not as badly out of balance at half stroke.

Crankshafts with two rod throws 180° apart counterbalance each other to give perfect primary balance. But if there are only two cylinders and they are 180° apart instead of 360° apart, another form of vibration called a rocking couple causes the engine to rock from end to end. A four cylinder engine eliminates the rocking couple problem because one pair of couples cancels out the other pair. Cylinders numbers 1 and 4 move in the opposite direction of the inner two cylinders, numbers 2 and 3 (**Figure 12.64**). The dotted line represents the force generated by cylinders 1 and 4, and the fine line represents cylinders 2 and 3. The two cancel each other out.

Another form of vibration, called secondary vibration, occurs in in-line four cylinder engines. Because the connecting rod is longer than the crankshaft stroke, the piston has to slow down more quickly before changing directions at TDC than at BDC. More upward force is created by the piston than downward force, so secondary vibration results. They are only about one-quarter of the strength of primary vibrations but can become much stronger at the higher engine speeds at which four cylinder engines often operate. Secondary vibrations occur at twice the frequency because the inertia change in direction happens twice per revolution of the crankshaft. Secondary imbalance is represented by the bold black solid line in Figure 12.54.

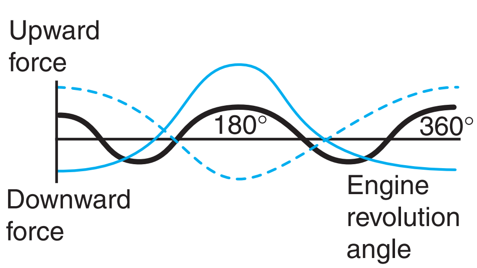


FIGURE 12.64 The dotted line represents the force generated by cylinders 1 and 4. The fine line represents cylinders 2 and 3. Secondary imbalance is represented by the bold line.

V8 Crankshaft Design

Production V8 engines have four rod throws spaced 90° from each other; 90° crankshafts are used in factory V8 engines because four cylinder engines inherently vibrate. The crankshafts in these engines are heavier because of the counterweights.

Racing engines often use crankshafts called *flat cranks*, with throws spaced 180° apart located in one plane at the top (0°) and bottom (180°) of the crankshaft. An engine with a flat crank is like four, two cylinder engines in one block. There are two pistons at TDC on the same bank at the same time. When the crankshaft turns ¼ turn, two are up on the other bank. In another 90°, two more pistons will be up on the first bank, and so on. Because pistons are moving in opposite directions at the same time, counterweights are not needed. With no counterweights, the crankshaft is much lighter in weight. Horizontal engine vibration is produced at twice engine rpm, but flat cranks are popular in racing because the crankshaft is lighter and the engine is always at high speed. There is no drag from heavy counterweights when they stand on the throttle, and racers do not care if the engine vibrates.

The last production engine with a 180° crankshaft was the General Motors Oakland in 1932.

There is also a 360° crankshaft design, where multiple pistons travel in the same direction at once.

Balance Shafts

Secondary imbalance can be corrected using two counterweighted balance shafts driven by the crankshaft in opposite directions at twice crankshaft speed. These shafts, also called silent shafts, have counterweights timed to cancel out the engine's imbalance by generating a vibration of the same magnitude and in the opposite direction of rotation as the engine's existing vibration (**Figure 12.65**).

There are two types of secondary vibration: vertical and rolling. When the connecting rods are not at TDC or BDC, secondary vertical vibration also causes rolling vibration in the direction of crankshaft

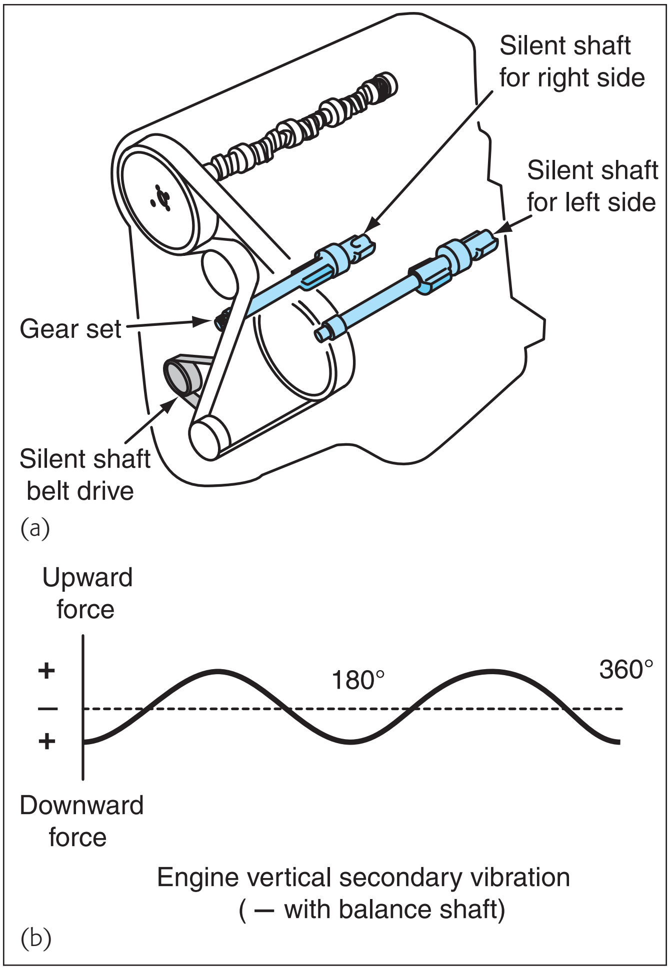


FIGURE 12.65 (a) An engine with balance shafts, also called silent shafts. (b) Engine vertical secondary vibration is eliminated by the balance shafts.

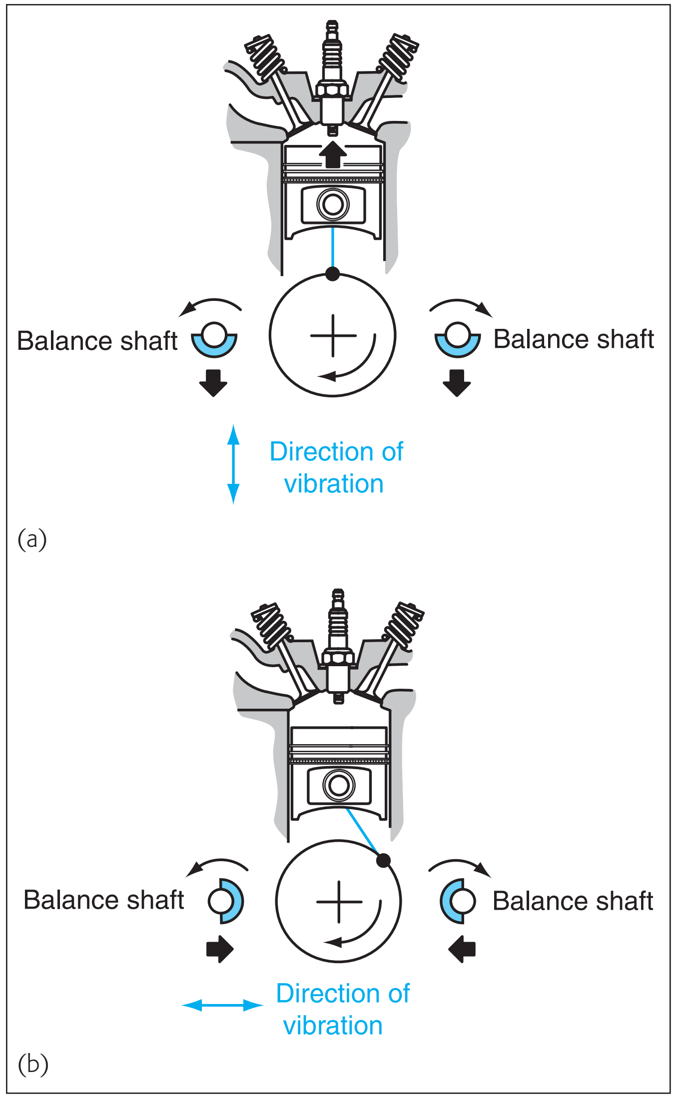


FIGURE 12.66 Reducing vibration in an in-line engine with two balance shafts. (a) Reducing secondary vertical vibration. (b) Reducing rotational vibration.

rotation. Whenever the fuel in the cylinder ignites, secondary rolling vibration is another result as the crankshaft is accelerated by the force. **Figure 12.66a** and **Figure 12.66b** show how vertical and rotational vibrations are canceled by balance shafts. Engines with balance shafts run very smoothly but the timing of the shafts is critical and they must be replaced correctly to maintain balance.

Ninety-degree V6 engines have unusually strong primary (up and down) imbalance. The vibration can be felt through the steering wheel. **Figure 12.67** shows the splayed crankshaft pin design used with these engines. Manufacturers modify the crankshaft counterweights by underbalancing the engines. Other engines use half of the reciprocating weight on the *bob weights* installed on the connecting rod throws during engine balancing, but 90° V6 engines use lesser amounts of weight. These are discussed later in this chapter under the bob weight heading.

By underbalancing, the vibration from vertical imbalance is reduced to almost nothing, providing a smooth idle and no steering wheel vibration. But these engines still have a rocking couple that causes the engine to shake worse from side to side. To isolate this vibration, soft engine mounts are used that allow the engine to move from side to side. This causes increased wear and failure of engine mounts and exhaust connections but it is an effective way of smoothing out engine vibrations for rear-wheel-drive vehicles.

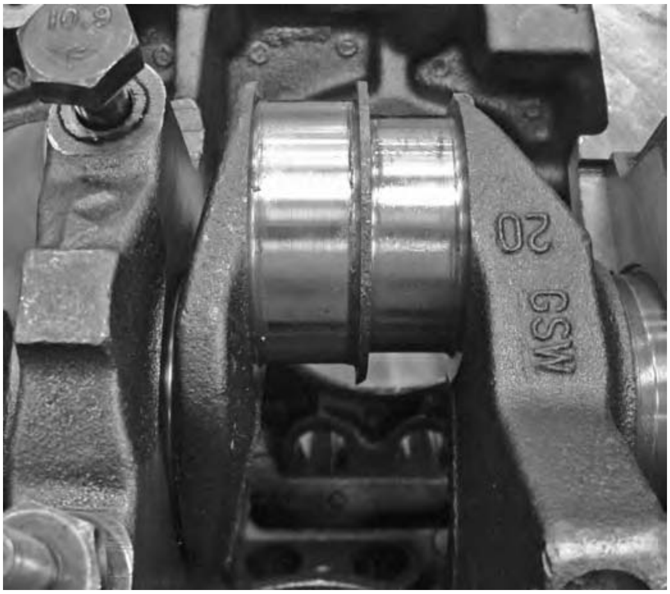


FIGURE 12.67 The crankshaft journals on a 90° V6 minimize engine imbalance. (*Courtesy of Tim Gilles*)

CASE HISTORY

After a timing belt was replaced on a Mitsubishi 1.8 L four cylinder with dual balance shafts, the engine had a serious vibration problem. The timing marks on the front balance shaft and oil pump drive were inspected and found to be aligned properly. After investigation in the repair manual, the technician discovered that the oil pump drives a rear balance shaft that was actually installed 180° out of position even though the timing marks were correct. When putting on the timing belt, installation instructions call for installing a shaft through a hole in the rear of the block to correctly align the rear balance shaft to the oil pump. This corrected the problem.

SHOP TIP

When the customer concern is engine vibration, start with the engine mounts. They could be worn out, or stiff ones could have been installed by mistake. Most original equipment mounts are softer than aftermarket mounts.

When these engines are installed transversely in front-wheel-drive vehicles, the driver feels the rocking motion inside the car. General Motors and Ford both use a single balance shaft on late-model 90° V6s used in front-wheel drives. It is located below the intake manifold in the lifter valley (**Figure 12.68**). The balance shaft is driven by a gear that turns it opposite normal crankshaft rotation at crankshaft speed to cancel out the rocking couple. Engines with balance shafts run very smoothly, but the timing of the shafts is critical and they must be replaced correctly to retain balance. An incorrectly timed balance shaft will amplify engine vibrations instead of minimizing them.

Balance shafts are usually supported by needle bearings (**Figure 12.69**) or ball bearings because those supported by ordinary cam bushings sometimes fail. The balance shaft on the engine shown in **Figure 12.70** seized, but because the balance shaft drive belt was independent of the timing belt, the engine continued to run. Aftermarket kits are

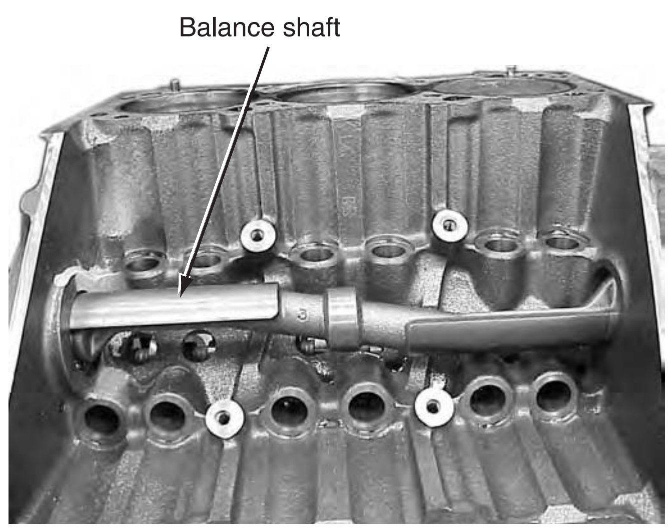


FIGURE 12.68 Reducing vibration in a V6 with a single balance shaft. (*Courtesy of Tim Gilles*)

FIGURE 12.69 This balance shaft rides on needle bearings to lessen the possibility of seizure. (*Courtesy of Tim Gilles*)

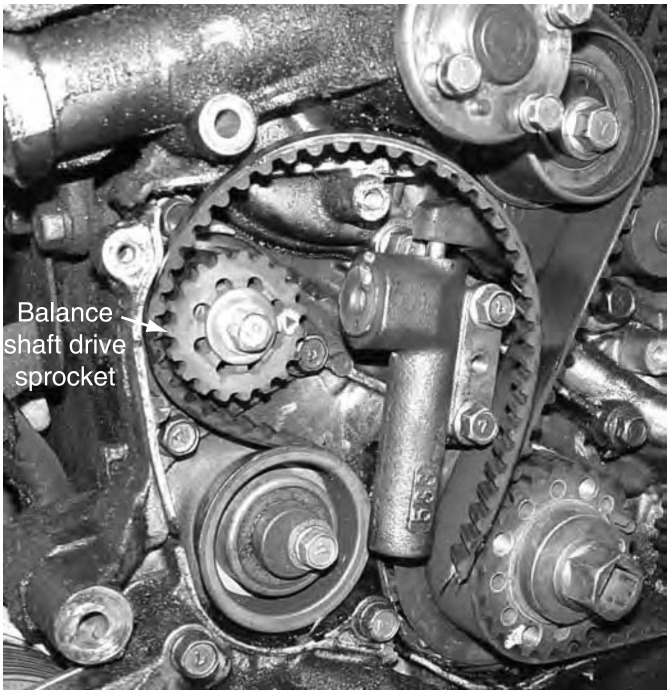


FIGURE 12.70 The balance shaft on this vintage engine seized, breaking its auxiliary drive belt. (*Courtesy of Tim Gilles*)

available for eliminating some older troublesome Chrysler/Mitsubishi balance shafts.

ENGINE BALANCING

As we explore the theory of engine balancing, the intent is to provide you with a basic understanding of the process. A good background in engine balancing theory will lower your learning curve as you learn to use new equipment.

Every time engine speed doubles, the force that results from the imbalance is multiplied by 4. An imbalance of ¼ ounce (7 grams or about one sheet of paper) at a 4" radius on a rotating part creates forces of:

- 7 lb at 2000 rpm
- 28 lb at 4000 rpm
- 63 lb at 6000 rpm
- 112 lb at 8000 rpm

Reciprocating parts (the piston assembly, including rings, wrist pins, and the pin end of the rod) are balanced to approximately the same weight. Rotating parts are balanced by spinning the crankshaft on an engine balancer to find heavy spots (**Figure 12.71**). Bob weights are installed on the crankshaft throws to simulate the weight of rotating parts. Bob weights are discussed later in the chapter.

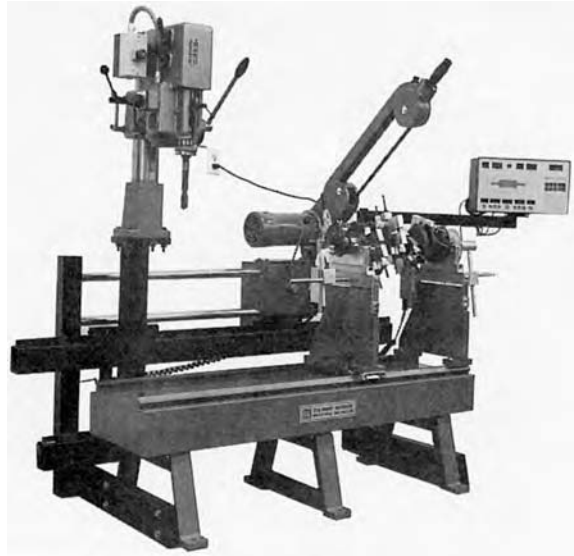


FIGURE 12.71 A crankshaft balancer. (*Courtesy of Pro-Bal Industrial Balancers*)

Heavy counterweights can be lightened by drilling (**Figure 12.72**) or by machining to make them smaller (see Figure 12.37). Sometimes counterweights are too light (the crankshaft journal is too heavy). This is typical with crankshafts being converted from external to internal balance or with stroker crankshafts. Weight can be added to the counterweights. Tungsten is expensive, but it is about twice as heavy as steel and can be added to

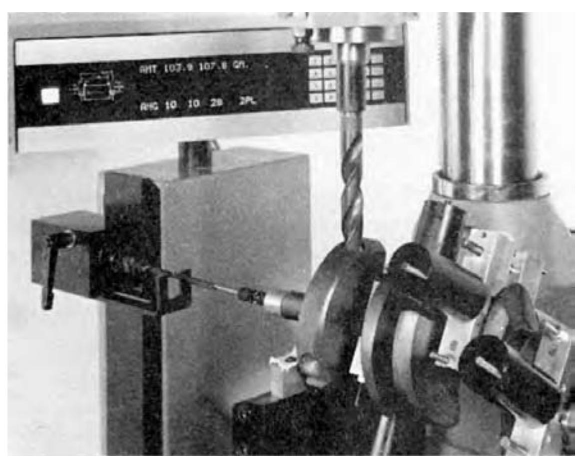


FIGURE 12.72 Drilling a hole in a crankshaft counterweight. (*Courtesy of Pro-Bal Industrial Balancers*)

the counterweights by drilling them horizontally to prevent the tungsten from being tossed out by centrifugal force at high rpm. The tungsten is either welded to the counterweight or a hole is tapped and the weight is threaded into it.

Piston Weight

When an engine is produced at the factory, the reciprocating weights of the pistons and rods are used to determine the correct weight of the crankshaft counterweights. When an engine is rebuilt, its new pistons might not be the same weight as the OEM pistons. Aftermarket pistons are usually balanced to the average weight of the original equipment pistons, but some piston manufacturers do not match their oversized pistons to the average OEM weights of standard pistons. Also, high-performance pistons are usually lighter than original equipment pistons, their lighter mass allowing for quicker acceleration. Weight can be added to a wrist pin if a piston is too light.

Balance is not as important with in-line engines, but it is critical in V-type engines because of the difference in rotating weight. When replacing a piston on a V-type engine, match the weight of the new piston to the stock piston to maintain correct balance. Pistons in a new set should not have a spread of more than 5 grams from the heaviest to the lightest. Some balance shops narrow this range to ±1 gram or even ±0.5 gram. Regrinding a crankshaft on an engine that was balanced as an assembly will change the balance because the rod throws will weigh less.

Some steel crankshafts must not be replaced with a cast crankshaft or balance problems can result. Also, some crankshafts are balanced with part of the counterweight on the flywheel or damper. These engines are called **externally balanced**. When balancing an externally balanced engine, the flywheel and damper must be installed. On internally balanced engines, the parts can be balanced separately or they can be installed on the crankshaft and balanced after the crankshaft is balanced.

Some cast crankshafts must be balanced with the torque converter in place. The correct converter must be used with these crankshafts. Be sure to check that the damper (**Figure 12.73**), flywheel, flexplate

FIGURE 12.73 A vibration damper used with an externally balanced crankshaft. (*Courtesy of Tim Gilles*)

(**Figure 12.74**), or torque converter is counterweighted. If so, it will need to be balanced with the crankshaft.

When balancing an engine used with a standard transmission, the clutch cover (pressure plate) should be balanced, too. It is usually balanced with the flywheel. Balancing a torque converter is tougher because the stator moves around unless it is supported.

Vibration dampers are balanced with the belt pulley installed. The relationship of the damper to the pulley should be marked before disassembly.

FIGURE 12.74 A flexplate used with an externally balanced crankshaft. (*Courtesy of Tim Gilles*)

Types of Imbalance

The forces of imbalance are measured in two directions and can be in multiple locations on a crankshaft.

- Centrifugal force is a force like a slingshot that causes an object to continue traveling in the same direction as it rotates.
- Centripetal force, which is the opposite of centrifugal force, is a perpendicular load to the direction of rotation.

Centrifugal force imbalance is called force imbalance, static, or kinetic imbalance. It can be compared to the type of imbalance that is corrected when balancing tires with a bubble balancer. When the crankshaft is spun, the balancer picks up the vibration and "notices" whenever a heavy area is forcing down. Removing this heavy spot, or counterbalancing it by adding equal weight to the light side, would correct the force imbalance. Force imbalance is smallest at 90° of rod angle and most at TDC or BDC.

Centripetal imbalance causes the force to take a circular path. If you have a ball attached to the end of a string and spin it in a circle, the weight of the ball will pull it further up in its path of travel the faster it goes. Centripetal imbalance bends the crankshaft from front to rear as it rotates.

When static imbalance is in two different planes, this is called couple imbalance. Dynamic imbalance is a combination of couple imbalance and force imbalance. Correcting it requires adding or removing metal at two different places on the crankshaft. Correcting dynamic imbalance can result in the correction of force imbalance at the same time. Computer balancers compute the combined dynamic and force imbalance and identify where to remove metal.

Balancers operate at low speed (less than 400 rpm) for safety. This rpm is sufficient to calculate what the imbalance will be at higher speeds.

Some older engine balancers use a triggered strobe light to determine when a heavy spot is at the bottom. When using these balancers, clay is attached to the crankshaft opposite the heavy spot to simulate correct balance. When spinning balance has been achieved, the clay is weighed and metal of an equal amount is removed from the counterweight.

Scales

The tolerance used for comparison of the weight of various parts is ±⅛ gram.

NOTE

A dollar bill weighs about 1 gram.

There are three types of scales. The common *balance beam-type scale* is the least expensive. An older-type scale is the shadow graph scale. The newest balancers use digital scales, which measure to 0.1 gram.

Equalizing Part Weight

Pistons should be balanced with their respective pins installed. Piston pins are fit to their pistons and should not be interchanged.

First, determine the lightest piston-and-rod assembly. Then lighten the others to match. The most popular way of lightening a piston is to remove metal from the piston balance pads using a mill, a lathe, a belt sander, or a die grinder (**Figure 12.75**). Sometimes metal is removed from the pin boss pads on the inside of the piston. When grinding or sanding a connecting rod, remove metal in a direction perpendicular to the crankshaft and wrist pin. Grinding scratches in a direction across from the direction of crankshaft rotation will raise stresses that could result in the formation of hairline cracks.

FIGURE 12.75 One method of removing weight from piston balance pads. (*Courtesy of Tim Gilles*)

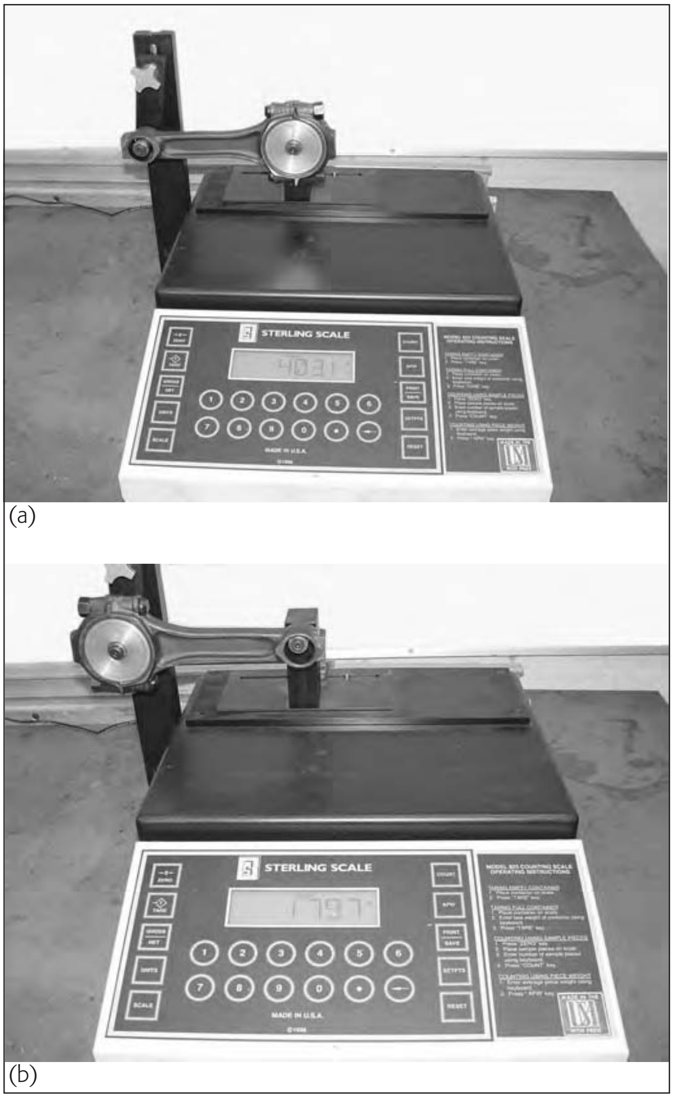


FIGURE 12.76 (a) Weighing the big end of the connecting rod. (b) Weighing the small end of the connecting rod. (*Courtesy of Tim Gilles*)

FIGURE 12.77 Connecting rod balance pads. (Courtesy of Tim Gilles)

FIGURE 12.78 Removing weight from the crankshaft end of the connecting rod. Quench often to avoid overheating. (*Courtesy of Tim Gilles*)

Before lightening a connecting rod, the rotating (big end) and reciprocating (small end) ends of the rod are weighed independently using a "trapeze" setup (**Figure 12.76**). The rod must be level when weighing the ends. If the big ends of the connecting rods need to be resized and honed, this should be completed first (see Chapter 13). The big ends are balanced first to make them all weigh the same. The small ends can be weighed separately on the trapeze scale, or the entire rod can be weighed on the scale and lightened from the small end to match the weight of the lightest rod. Metal is ground or belt sanded from the balance pad at the end of the rod (**Figure 12.77**). When grinding, quench often to avoid overheating and weakening the rod (**Figure 12.78**).

Bob Weights

When balancing an engine, the weights of all of the rotating and reciprocating parts must be simulated because pistons and rods would not be able to be spun with the crankshaft unless the parts were assembled in the block. Spinning the crankshaft is done using *bob weights* (**Figure 12.79**) that simulate 50% of the reciprocating weight and 100% of the rotating weight. The 50% factor is because the weight of the big end of the rod makes it weightless when it is at half travel in the stroke. One hundred percent weight is reached at both TDC and BDC. In-line engines use no bob weights and not all use 50% of the reciprocating weight. Some of

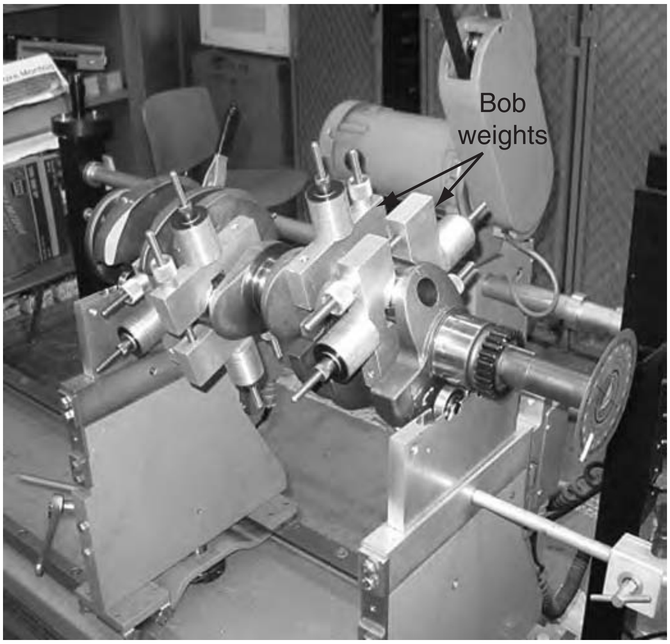


FIGURE 12.79 Bob weights are positioned on the rod journal centered at 90° to the stroke. (*Courtesy of Butch Reilly, Spokane Community College*)

V-8 Bob Weight Calculation

Piston (ea) ______	x 1 =	______
Piston pin (ea) ______	x 1 =	______
Pin locks (set) ______	x 1 =	______
P. rings (set) ______	x 1 =	______
Recip rod (ea) ______	x 1 =	______
Rot. rod (ea) ______	x 2 =	______
Rod brgs. (set) ______	x 2 =	______
Lock nuts (pr) ______	x 2 =	______
Oil allowance ______	x 1 =	______
Total Bob Weight Grams		

FIGURE 12.80 A bob weight chart for a V8. Note that the bearings and rotating end of the rod are measured twice because two rods fit on one rod journal. (*Courtesy of Butch Reilly, Spokane Community College*)

the different bob weight percentages for balancing 90° V6 engines are:

- Buick 181, 196, 231, 252—36%
- Ford 232—39%
- Chevrolet 200, 229—46%

Reciprocating Weight. Reciprocating weight is the weight of one piston and ring set plus the smaller end of the rod, determined by subtracting the rotating weight from the total weight. V-type engines use two rods per crank pin, so the weight of one rod and its bearings equals 50% of the rotating weight needed.

Oil Weight. A bob weight also includes 3 to 6 grams to simulate the weight of oil in the crankshaft oil passages. Cross-drilled crankshafts carry more oil, so even more weight must be added.

When assembling a bob weight, make the gaps equal on each side. Attach the bob weight with its weights positioned at a 90° angle to the crank throw. The assembly should be snug to the crankshaft journal, but be careful not to tighten it so tight that it damages the journal's bearing surface.

Figure 12.80 is a chart showing bob weight calculation. Check to see if the damper and the flywheel have counterweights. If they do, these parts must to the crankshaft during balancing.

Time Required for Balancing

An experienced operator can balance a typical V8 in 45 minutes to 1½ hours. The most time-consuming part of the job is altering the weights of the pistons and rods to match the lightest ones. Making up the bob weights takes a bit of time as well but bob weights are not necessary when balancing in-line four or six cylinder engines. Setting up the balancer and taking the readings only takes a few minutes.

Quicker setup is possible with newer crankshaft balancers. An indexing wheel is attached to the crankshaft for determining the position where weight will need to be added or subtracted. After the crankshaft has been spun, the computer calculates and displays the results on a screen that shows where to make the corrections. Some crankshaft balancers have a time-saving feature that allows drilling or sanding the counterweights while the crankshaft remains on the balancer.

Key Terms

bearing crush
bearing spread
end thrust
externally balanced
fillet radius
locating lug or tang
Rockwell "C" scale
torsional vibration

Study Questions

1. What is another name for the rod journal?
2. What is the name of the rounded area at the edge of each bearing journal?
3. What is the difference in appearance between an in-line engine rod journal and a V8 rod journal?
4. Which crankshaft is stronger, cast or forged?
5. What is the term that describes the crankshaft being pushed forward by the clutch or torque converter?
6. When a rod journal is tapered, what should be checked as a possible cause?
7. List (in inches) the different undersizes to which a crankshaft can be reground.
8. What are the names of two types of hardening?
   a.
   b.
9. The hardness specification is usually given on the _____ "C" scale.
10. What part of the crankshaft can be rolled with a hydraulic roller to increase crankshaft strength?
11. How much thicker than standard would a 0.020" undersized bearing insert be?
12. When there is less clearance, will a Plastigage reading be wider or narrower?
13. What are three properties of a bearing?
    a.
    b.
    c.
14. Normal main bearing wear is on the _____.
    a. top
    b. bottom
15. Name three types of scales used in engine balancing.
    a.
    b.
    c.

ASE-Style Review Questions

1. An engine has a burned thrust main bearing. Technician A says that this can be caused by a driver who "rides" the clutch. Technician B says that this can be caused by insufficient clutch pedal-free travel. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. Technician A says that normal main bearing wear is on the top. Technician B says that worn lower main bearings can be caused by lugging the engine. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. Technician A says that bearings have a soft surface that flows away from high spots in case of a nick in the crankshaft. Technician B says that dirt can be absorbed into the crankshaft journal surface. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

4. Technician A says that stretched connecting rods often need resizing when the bearing clearance at the bearing parting line becomes excessive. Technician B says that normal connecting bearing wear is on the cap end. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. A crankshaft has been ground to 0.010"–0.020". Technician A says that 0.010" traditionally represents the rod journal undersize. Technician B says that 0.020" represents the main bearing undersize. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. Technician A says that cast crankshafts have larger counterweights than forged crankshafts. Technician B says that forged crankshafts are usually externally balanced with weights on the damper and torque converter. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that many four cylinder engines do not use a damper. Technician B says that a loose or damaged damper can break the crankshaft. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Metal is being ground from the surface of a crankshaft. Technician A says that 0.010" of metal is removed from the surface of a 0.010" crankshaft. Technician B says that 0.015" of metal is removed from the surface of a 0.030" crankshaft. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that engine vibration problems can sometimes be resolved by installing the correct engine mounts. Technician B says that counterweights that are too light are drilled and filled with heavier metal. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Technician A says that spread is when the bearing insert extends above the parting surface. Technician B says that crush is what keeps the bearing from spinning in the bearing bore. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 13

Pistons, Rings, and Connecting Rods

Contents

- Pistons
- Piston Rings
- Piston Pins
- Connecting Rods

Objectives

Upon completion of this chapter, you should be able to:

- Analyze wear and damage to the pistons, rings, pins, and rods.
- Select the most appropriate repairs to perform.
- Describe the theory of pistons, rings, piston pins, connecting rods, and related parts.

Introduction

The piston and rod assembly is part of the engine's *lower* end. Other lower end parts include the crankshaft and bearings, which are covered in Chapter 12. This chapter deals with the pistons, rings, and connecting rods and various service procedures performed on them as well as diagnosis of part failures.

PISTONS

The piston (**Figure 13.1**) undergoes remarkable stress as it starts and stops momentarily, twice in every crankshaft revolution. At highway speeds, 3000 rpm is not unusual. The piston must start and stop 6000 times per minute or 100 times per second when the crankshaft turns at 3000 rpm. Obviously, it must be as light as possible. Older automotive and light truck pistons were made of cast iron, but pistons today are cast or forged aluminum.

Cast and Forged Pistons

Most pistons are cast (**Figure 13.2**), although forged pistons are available for heavy-duty or high-performance use. A cast piston has a porous grain structure (**Figure 13.3**), whereas a forged piston is dense (**Figure 13.4**). A forged piston is more efficient at dissipating heat (**Figure 13.5**), although some types of forged aluminum expand more than others. This topic is covered later in the chapter during the

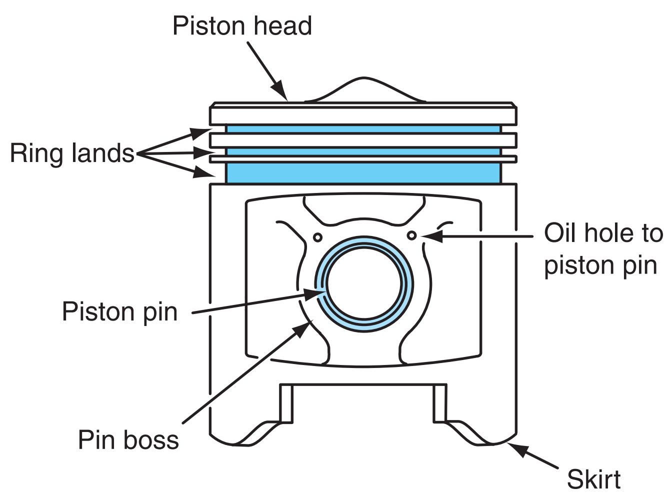


FIGURE 13.1 Piston nomenclature.

FIGURE 13.2 This is what a cast piston looks like after the foundry before machining. *(Courtesy of Tim Gilles)*

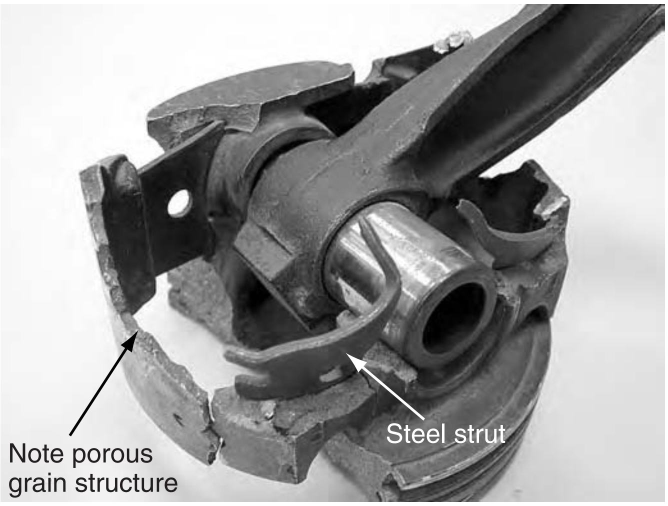


FIGURE 13.3 This cast piston was destroyed when an overtightened connecting rod bolt failed, breaking the rod cap. Notice the porous grain structure of the piston casting. *(Courtesy of Tim Gilles)*

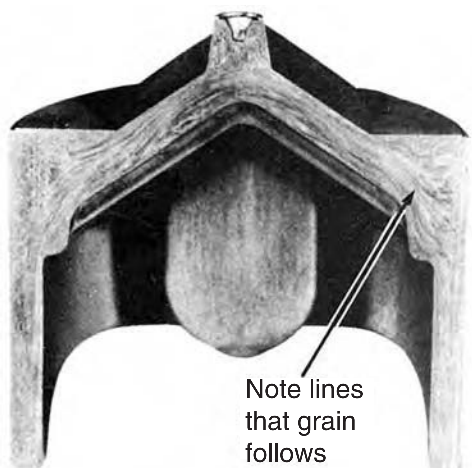


FIGURE 13.4 This cutaway of a forged piston shows its dense and uniform grain structure. *(Courtesy of Federal-Mogul Corporation)*

discussion on piston clearance. A forged piston is about 70% stronger than a cast piston. Unlike new aluminum formulations, ordinary cast pistons are not strong enough for repeated use above 5000 rpm.

Hypereutectic is the description of a popular cast aluminum alloy referring to the percentage of silicon in the aluminum in a piston. When the silicon content of an aluminum alloy exceeds 12%, hard primary silicon particles form. Although the primary silicon particles make up only 4-6% of the entire hypereutectic piston, the particles are so hard that pistons must be machined using diamond tools. The largest primary silicon particles are limited to less than 0.0004" in size by foundry practices, which also keep the particles evenly distributed throughout the base aluminum.

A hypereutectic cast piston cannot withstand the tensile loads of a forged piston but it weighs less and the ring groove and pin bore areas suffer less wear. A hypereutectic piston expands about 15% less than an ordinary aluminum piston so it can be used with tighter piston-to-cylinder wall clearance. Silicon, being ceramic, is resistant to heat expansion. So the percentage of the aluminum displaced by silicon does not expand.

Because hypereutectic pistons are more brittle than ordinary aluminum pistons, a heat furnace is recommended for installing the piston pins rather than using a press.

Piston Head and Ring Grooves

The diameter of the ring belt area of the piston is 0.019" to 0.027" less than the largest diameter of the skirt (most are about 0.022" less) (**Figure 13.6**). The ring belt area is round, whereas the skirt is oval.

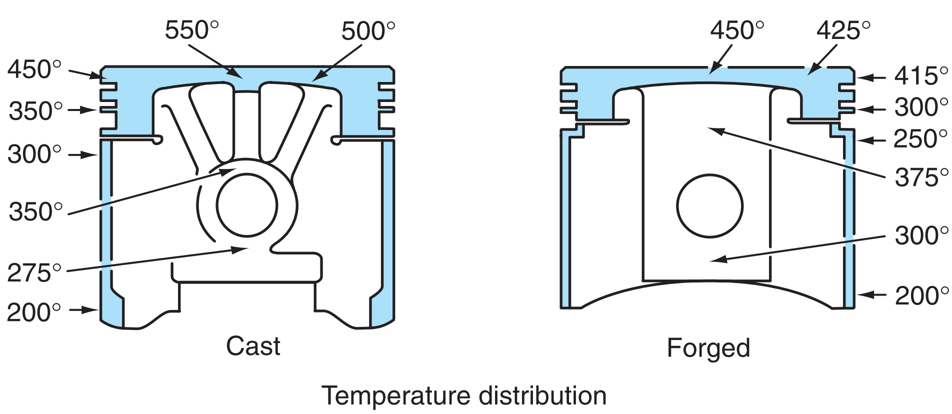


FIGURE 13.5 A comparison of the temperature differences between cast and forged pistons.

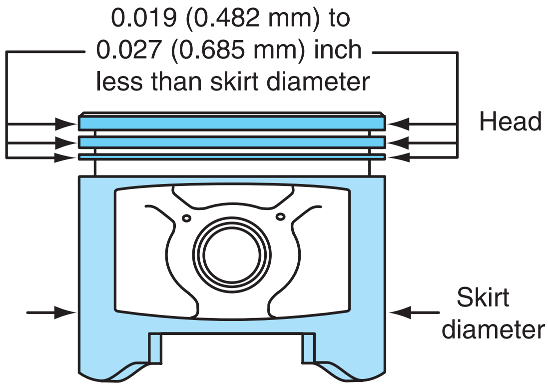


FIGURE 13.6 The piston head is smaller than its skirt.

The fit of the ring groove to the ring is as important when sealing combustion gases as the fit between the ring and cylinder wall.

Engineers design the placement of the top piston ring to be as high as possible on the piston. This lessens piston slap, helps ring durability, and lowers emissions. The piston rings also stabilize the piston, helping to resist piston slap. When an engine has stuck piston rings, it can be really noisy due to piston slap.

The top ring groove suffers the most abuse, so some heavy-duty truck top grooves are "fortified" with a cast steel or iron insert. The top ring groove of a performance piston is often anodized or coated to protect it against groove pounding or ring welding. The trend in newer passenger car and light truck engines is to use hypereutectic pistons whose higher silicon content provides resistance to groove wear.

Holes or slots in the back of the oil ring groove allow excess oil on the cylinder wall to return to the crankcase by way of the inside of the piston (see Chapter 3).

Some oil return holes are long slots that also help to prevent the transfer of heat from the piston crown to the skirt; it is better to have the crown heat transferred through the piston rings to the coolant jackets behind the cylinder walls. Some pistons have a slot below the oil groove and some have a heat dam above the top groove to keep crown heat from traveling down to the top ring groove.

Piston Head Shapes

In order to allow engineers to vary compression ratios and exhaust emissions, many different piston head shapes can be used for the same engine family (**Figure 13.7**). The **piston compression height** is the distance from the center of the pin bore to the flat area of the top of the piston. Pistons of the same size can have different compression heights.

NOTE

If two engines with equal bore diameters have different displacements because they have different length strokes, do *not* interchange pistons between them without checking the critical compression height dimension.

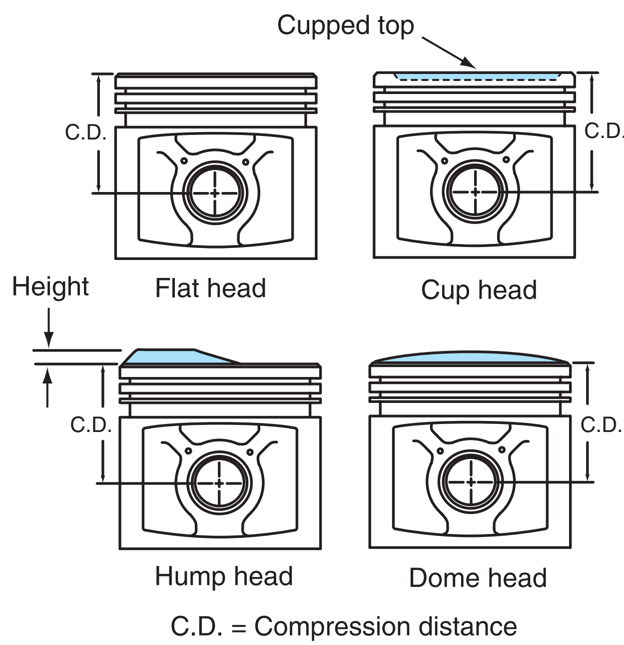


FIGURE 13.7 Common piston head shapes.

VINTAGE ENGINES

Some replacement pistons for passenger cars and light trucks (especially older ones) are de-stroked 0.020" to compensate for block and head resurfacing. If 0.020" of resurfacing is not done, the compression ratio will be diminished by about ¼ of a ratio (for instance, 9:1 would be reduced to 8.75:1).

Calculating Compression Height. To calculate a piston's compression height, measure the distance to the top of the piston from the top of the pin hole and add half of the pin diameter to your measurement.

High-compression pistons can only be installed in one direction in the cylinder (**Figure 13.8**). If they are installed backward, the piston crown will interfere with the combustion chamber or valves.

Piston Skirt Surface Finish

The surface of the piston skirt is purposely left slightly rough with small machine marks less than 0.001" deep. This somewhat rough surface is superior for retaining lubrication. The skirt is finished either by grinding or diamond turning. Diamond turning, which is done on more expensive machinery, produces more finely defined lines on the skirt. Glass beading piston skirts during service also leaves a rough surface that is said to be desirable for lubricant retention; however, the pistons must be removed from the connecting rods first.

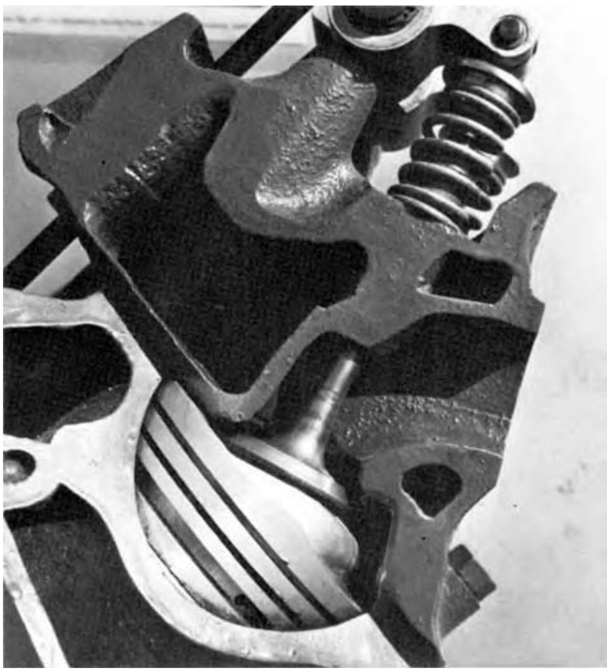


FIGURE 13.8 A cutaway of a combustion chamber and cylinder showing the relationship between a high-compression piston and the valve and cylinder head. *(Courtesy of Iskenderian Cams)*

Piston Coatings

Piston skirt coating is popular on many new engines and on aftermarket pistons (**Figure 13.9**). Some manufacturers apply friction-reducing piston coatings to the top, the skirts, or the entire piston. Skirt coatings include moly, graphite, and Teflon®. Although these coatings can add about 0.001" to the diameter of the piston, the measured size of the piston is not used in figuring the finished bore size and the piston will run with less clearance.

FIGURE 13.9 This piston has a moly skirt coating. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Tin plating was done on vintage piston skirts since the days of cast iron pistons because having a different metal between the piston and cylinder wall can reduce the possibility of scuffing. The tin coating is only about 0.0001" thick. It provides lubricity protection during engine startup and prevents scuffing during initial engine break-in or dry starts. Another reason for tin-plated pistons was cosmetic; they have a nice appearance. Today's pistons are less likely to scuff, so most manufacturers do not tin plate any longer.

Piston skirt coating offers several possible advantages. It reduces friction between the cylinder wall and piston skirt and prevents piston scuffing, especially in cold weather. Lower friction allows easier engine starting and improved fuel economy and efficiency. Some claim a 5% increase in fuel economy. Blowby is reduced because the piston-to-cylinder seal is improved. An engine with skirt-coated pistons can run quieter because it has less piston noise. An uncoated piston can sometimes ring like a bell when it slaps as it changes direction at TDC.

Some supercharged and drag racing engines have a thermal barrier coating applied only to the top. This prevents heat dissipation from the crown to the skirt, so these coatings are not recommended for many applications.

Some high-performance manufacturers coat the entire piston by dipping it, using a dry film phosphate process similar to anodizing. This provides extra protection to the ring grooves and pin bores.

Some engines use spray jets to cool the center of the inside of the piston. This topic is covered in depth in Chapter 11.

Piston Clearance

Typical clearance on a new cast 4" piston is 0.0015–0.002". Used pistons should have less than 0.0035" clearance. Pistons with more silicon content expand less and can be fit tighter to the cylinder walls.

Most forged pistons used in street engines are made of 4032 alloy, which is very stable and does not require additional piston skirt clearance. Typical clearance with these pistons is 0.0025–0.0035". Another forged alloy, 2618, used under severe racing conditions, is much stronger so it can withstand detonation and heavy loads. The alloy contains less silicon so it expands more when warm and must be fitted with more clearance—up to 0.011" for a supercharged monster truck! Racing engines often have audible piston slap when cold, but the noise lessens as the pistons warm to their running clearance.

Selective Fitting of Pistons to Bores

At the factory, pistons are fitted selectively to their blocks. During production, some pistons come out slightly smaller or larger than others. Bores have honing tolerances also. Large bores are matched with larger pistons. Pistons are matched in what are called *tolerance groups.* There are usually three groups of piston sizes. The allowance for size differences within each group is 0.001" or less.

Piston Expansion Control

An aluminum piston expands at about twice the rate of the cast iron block. Three things can be done to control this expansion:

- First, most piston skirts are tapered (**Figure 13.10a**). They are larger in diameter at the bottom because the bottom of the piston runs cooler than the top. At operating temperature, the piston-to-cylinder wall clearance is correct. Many newer pistons are barrel-shaped (**Figure 13.10b**) , meaning they are smaller at both the top and bottom. The place to measure a piston varies among manufacturers, so check the service information. **Figure 13.11** shows where most manufacturers recommend that a piston skirt be measured.

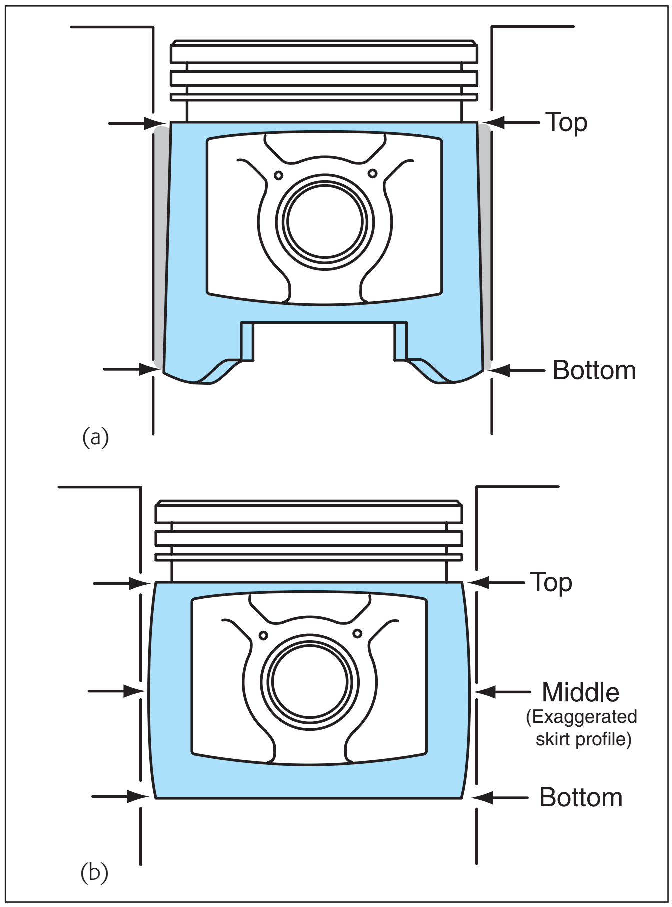


FIGURE 13.10 Piston skirt. (a) Piston skirt taper. (b) Barrel-shaped piston skirt.

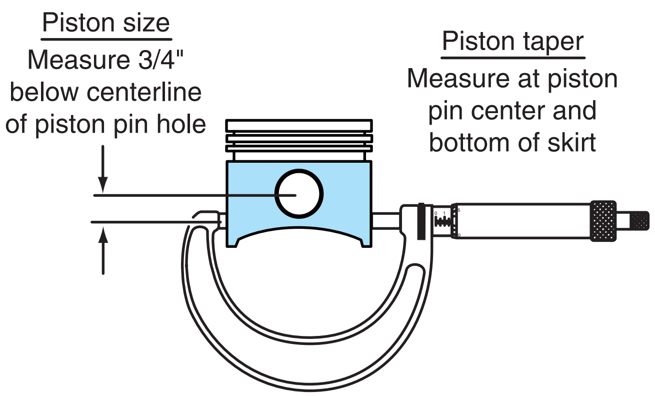


FIGURE 13.11 Measuring maximum piston skirt diameter.

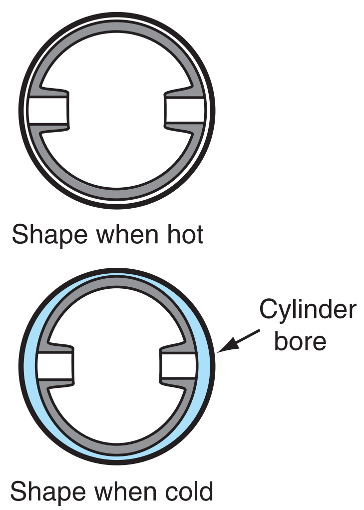


FIGURE 13.12 Cam ground piston skirt.

- Second, the piston skirt is **cam ground** (**Figure 13.12**). This allows it to fit the cylinder with only 0.0005" to 0.0025" of clearance. The smaller the clearance, the less chance of piston "slap" and the oval cylinder wear that it causes. Expansion takes place perpendicular (at a 90° angle) to the piston skirt.
- Finally, cast pistons have spring-loaded steel struts cast into them (**Figure 13.13**). The struts push on the pin bosses to help the piston to expand along the piston pin axis as it warms up.

When replacing an original piston with another standard size piston, *carefully* measure the replacement. Remember, pistons and bores are matched at the factory and assembly line bore tolerances are wide. An aftermarket replacement piston might be too tight or too loose, simply because it was made to fit *specifications* for a standard bore.

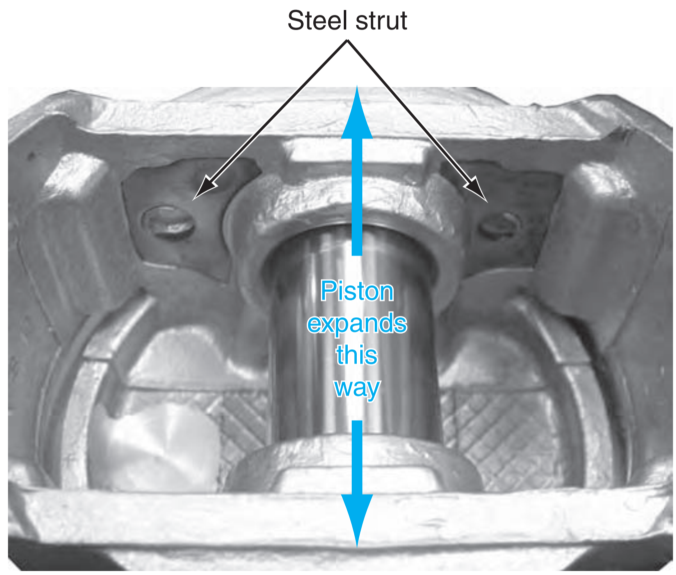


FIGURE 13.13 This steel strut controls the expansion of a cast aluminum piston. The piston expands in the direction shown by the arrows. (*Courtesy of Tim Gilles*)

Standard sized pistons are sometimes slightly oversize, which could require rigid honing of the standard bore for proper fit of the replacement. An alternative would be to buy the correct select fit piston from the OEM.

Skirt Types

Most of today's automotive pistons are slipper skirt pistons. A slipper skirt is designed to clear the crankshaft counterweights on engines with shorter rods. A full skirt piston used on longer stroke engines is known as a trunk piston. **Figure 13.14** shows slipper skirt and trunk skirt pistons. The surfaces of the piston skirts that are 90° to the piston pin are called thrust surfaces.

Piston Pin Offset

Piston pins are often offset approximately $^{1}/_{16}$" (0.062) from the piston centerline (**Figure 13.15**). The piston stops at TDC between the compression and power strokes as the connecting rod pivots to the other side. This causes the piston to rock from one skirt to the other, "thrusting" the side of the piston against the opposite cylinder wall.

More force is exerted on the piston skirt during the power stroke than the compression stroke. Therefore, the side of the piston that pushes on the cylinder wall during the power stroke is called the

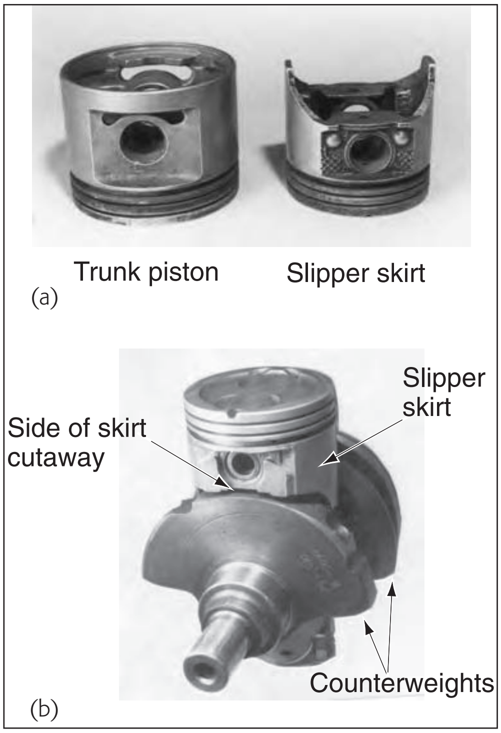


FIGURE 13.14 Trunk and slipper pistons. The slipper piston skirt is cut away to clear the crankshaft counterweights. (*Courtesy of Tim Gilles*)

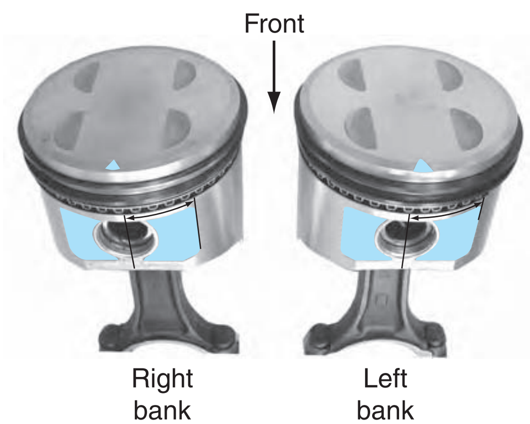


FIGURE 13.15 Piston pin offset. Notice that pistons from both banks are offset toward the right bank. (*Courtesy of Tim Gilles*)

major thrust surface. The piston pin is offset toward the major thrust side to reduce the tendency of the piston to "slap" as it rocks between the minor and major thrust surfaces at TDC.

The connecting rod pushes the minor thrust surface against the cylinder wall on the compression stroke (**Figure 13.16a**). Pin offset causes more of the combustion pressure to be exerted on the "larger" half of the piston head (**Figure 13.16b**). This results in the piston contacting the cylinder

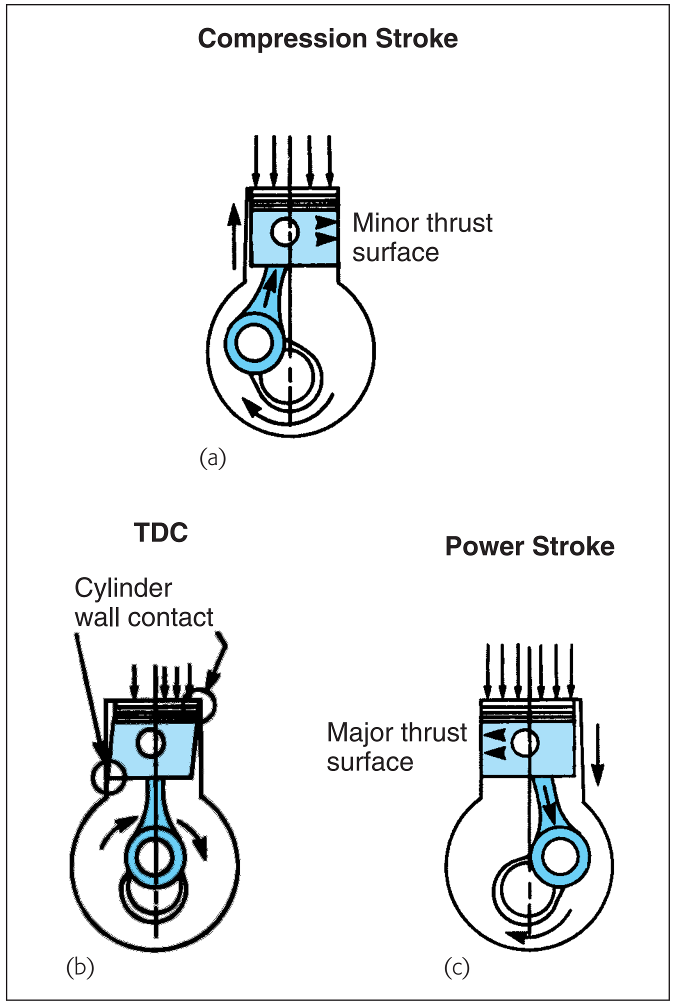


FIGURE 13.16 Piston pin offset reduces piston slap. (a) The minor thrust surface pushes against the cylinder wall. (b) More pressure is exerted against the "large" half of the piston head. (c) The piston slides into contact with the major thrust surface.

wall at the bottom of the major thrust surface. As the piston starts down, the upper half slides smoothly into contact with the major thrust surface (**Figure 13.16c**).

A piston usually has a direction-identifying notch that faces the front of the engine. On V-type engines, the pins on one bank of pistons will be offset to the intake manifold side of the cylinder, and the pins in the opposite bank will be offset toward the lower side of the cylinder. This is because the major thrust surface is determined by the direction of crank rotation.

Some crowned head (pop-up) pistons used in high-compression engines are not offset, so all of the pistons for a V-type engine can be identical. The engine may not turn over if these pistons are accidentally installed backward.

Piston Weight

Pistons are precisely balanced. It is important to match the new pistons' weight to the originals to maintain balance. Replacement pistons are supposed to weigh the same as originals, even if they are oversize. This is not always the case and should be double-checked. Engine balance was covered previously.

Sometimes a replacement piston is not the same weight as the other pistons. If the piston is only slightly heavier than the rest of the pistons, it can be lightened at the balance pads (see Chapter 12). Balance pads are usually located on the edge of the skirt under the piston pin. If the piston is lighter than the originals, a machine shop can add weight by installing plugs in the piston pins.

Piston Wear Problems

There are several kinds of piston wear (**Figure 13.17**). Scuffing results from excessive heat and occurs when the cylinder wall and piston are momentarily welded to each other as the piston stops at TDC. These welds are constantly made and broken. Scuffing on both skirts is usually a problem caused by insufficient clearance between new pistons and cylinder walls.

- Scuffing on one skirt only can be caused by excessive idling at too low an rpm, or by lugging the engine. In either case, there is not enough oil thrown from the rods to provide adequate cylinder wall lubrication (**Figure 13.17a**).
- Scuffing can also be caused by cylinder wall hot spots resulting from poor cooling system maintenance.
- Tight piston pins cause what is commonly called "four corner" scuffing. Both skirts are scuffed on the edges next to the piston pin.

NOTE

Piston manufacturers attribute most cases of four corner scuffing to excessive combustion chamber temperatures. The problem usually shows up within 1 week of installing a rebuilt engine. When the piston pin seizes, it is usually on the top part of the pin bore. This is due to heat transfer down from the ring belt area of the piston. High combustion chamber temperatures are caused by a problem unrelated to the engine rebuild.

- A piston that overheats because of cooling system problems, or abnormal combustion, will expand excessively near the piston pin. This can cause scuffing of the piston skirt near the pin (**Figure 13.17b**).
- Piston head wear above the top ring land can result if piston skirt-to-cylinder wall clearance is excessive.
- If the area of wear is located above the piston pin, a bent connecting rod could be the cause.

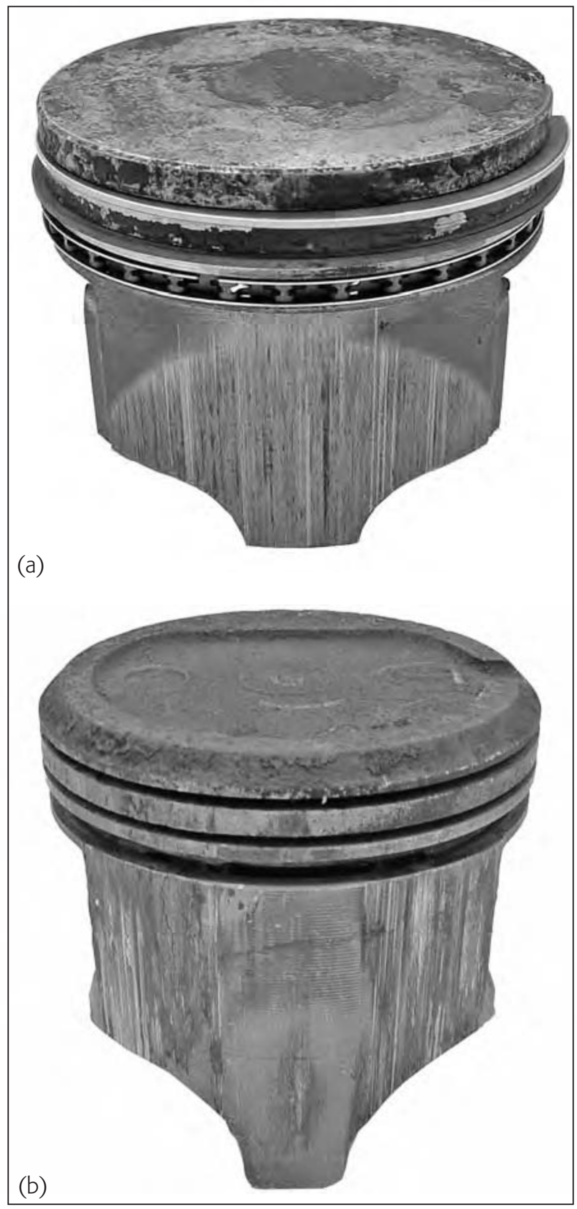


FIGURE 13.17 Piston wear. (a) A scuffed thrust surface. (b) Scuffing near the wrist pin. (*Courtesy of Tim Gilles*)

Ring Groove Wear/Side Clearance Check

The top ring groove wears the most. The ring is forced against the bottom of the ring groove during combustion. This can cause wear to the piston. At first glance, you would think that an aluminum piston would be worn away by the harder iron or steel piston ring. But aluminum pistons have a high silicon content, which makes them hard and causes them to wear the piston ring (**Figure 13.18**). The ring wears on the surface that rides against the ring groove, leaving a lip on the lower edge of the piston ring (**Figure 13.19**). Rings with excessive side clearance can break. Also, the old ring wears into the groove. New rings cannot seal against a worn ring groove. Before cleaning the piston, check the top ring groove for excessive wear (**Figure 13.20**). Normal ring-to-groove side clearance is from 0.002" to 0.004". A new ring is placed in the groove. If a 0.006" feeler gauge can be inserted under it, the groove is worn excessively. This check also ensures that a ring of the proper width and depth is used.

Notice how the ring in Figure 13.20 is installed backward in the groove. This allows the use of the old ring in assessing the wear in the groove before purchasing new pistons or rings. The feeler gauge can measure the clearance between the unworn surface of a worn piston ring and the ring groove (**Figure 13. 21**).

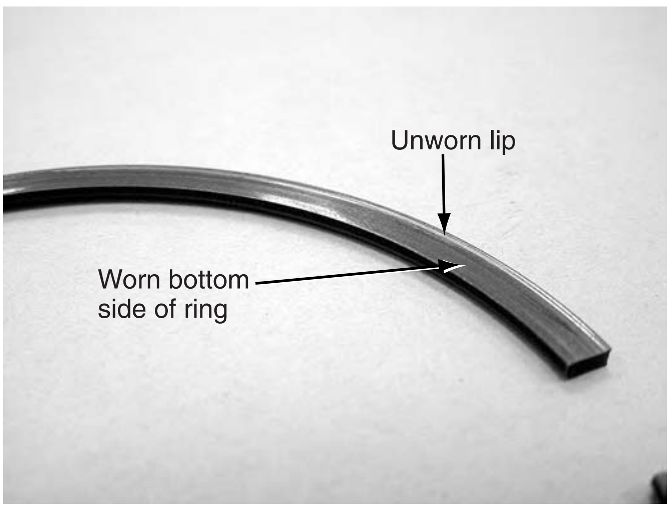


FIGURE 13.18 The top ring wears against the bottom of the ring groove.

FIGURE 13.20 Checking a ring groove for wear. (*Courtesy of Tim Gilles*)

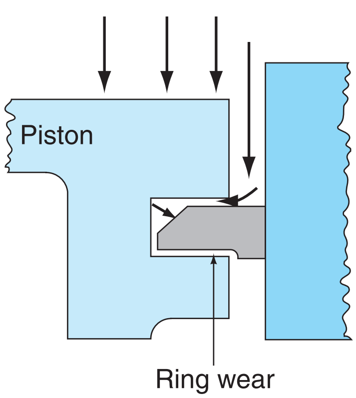


FIGURE 13.19 The bottom side of the top ring wears against the ring groove. (*Courtesy of Tim Gilles*)

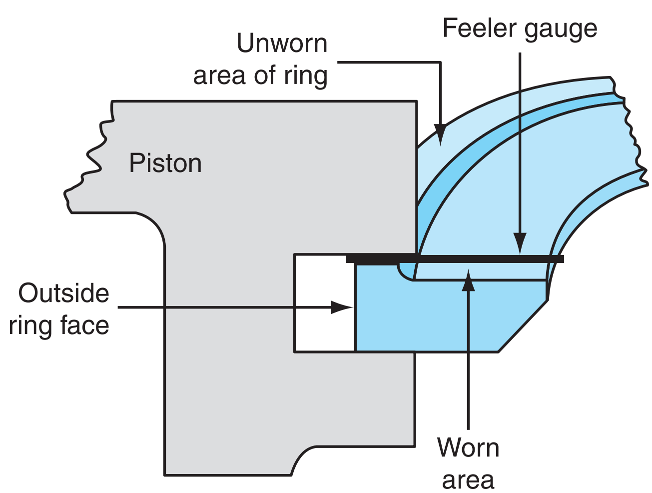


FIGURE 13.21 A used ring can be used to measure ring groove wear against its unworn area.

VINTAGE ENGINES

Excessively worn ring grooves can be remachined 0.025" wider with a special groove lathe. A groove insert (GI) spacer, which is similar to the rails used with a three-piece oil ring, is installed *above* the new ring. This is because the ring seals against the bottom of the ring groove. In most cases, this is not an economical service procedure because new pistons for most of the more popular engines are so inexpensive. This service is uncommon today, but if a piston is especially expensive, this procedure might be used.

Piston Service

When pistons are to be reused, they must be thoroughly cleaned and measured. If pistons are cleaned with a media blaster, be sure to blast for as short a period as possible to avoid damaging the piston (see Figure 5.20).

- The pistons must be off the rods with the pins removed.
- The piston pin bores must be protected.
- Excessive blasting can distort the ring grooves and cause combustion leaks.

The top of the piston can be cleaned with a scraper. The top of the piston can also be cleaned on a wire wheel, but be especially careful not to round off the edges of the piston head (**Figure 13.22**).

CAUTION

When cleaning the top of a piston with a wire brush, do *not* clean the ring groove area or the piston skirts. The ring grooves and skirts can be easily damaged. Leave the rings on for extra assurance against damaging the ring grooves.

Right

Wrong

FIGURE 13.22 Cleaning the top of a piston using a wire brush. Do not clean the ring groove area. Leave the rings on for extra assurance against damaging the ring grooves. (*Courtesy of Tim Gilles*)

Some shop owners advise against cleaning any part of the piston with a wire wheel because it requires skill and care. Many beginning technicians accidentally ruin otherwise good pistons by trying to clean the skirt and ring grooves using the wire wheel. Pistons are never to be chemically cleaned while assembled to the piston pin and connecting rod.

CASE HISTORY

An apprentice cleaned a set of pistons in carburetor cleaner with the connecting rods attached (the piston pins on most automotive pistons are pressed into the connecting rods). Varnish became trapped between the piston and the piston pin, freezing them together. To free them up again, it was necessary to press the pistons from the rods. Not only was this an unproductive use of time, but pistons can be damaged when pins are removed with a press.

Cleaning Ring Grooves. The carbon in the back of the ring groove must be removed; otherwise, the new rings might not compress enough to enter the cylinder during piston installation. This can be accomplished using a soda blaster or an old broken piston ring that has been ground on its end (**Figure 13.23**).

NOTE

Be careful not to remove aluminum from the rear of the ring groove after all the carbon is removed.

VINTAGE ENGINES

On older engines removal of carbon from piston ring grooves was done with a ring groove cleaner (**Figure 13.24**). Today's piston rings are very narrow; the cutter bit is so narrow that it is easily broken. The ring groove cleaning tool works very well on compression ring grooves but can easily nick oil ring grooves, which do not usually get as much hard carbon buildup anyway.

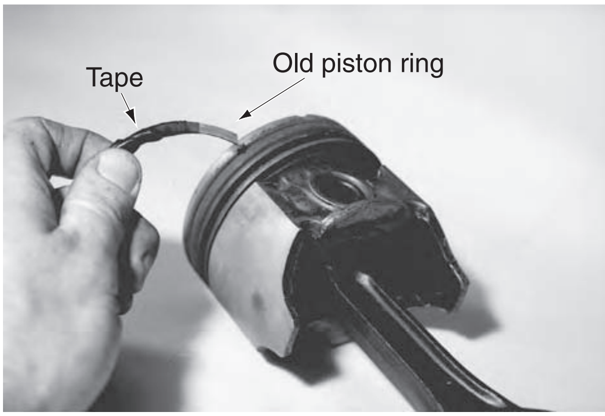


FIGURE 13.23 An old piston ring can be used to clean carbon from a ring groove. *(Courtesy of Tim Gilles)*

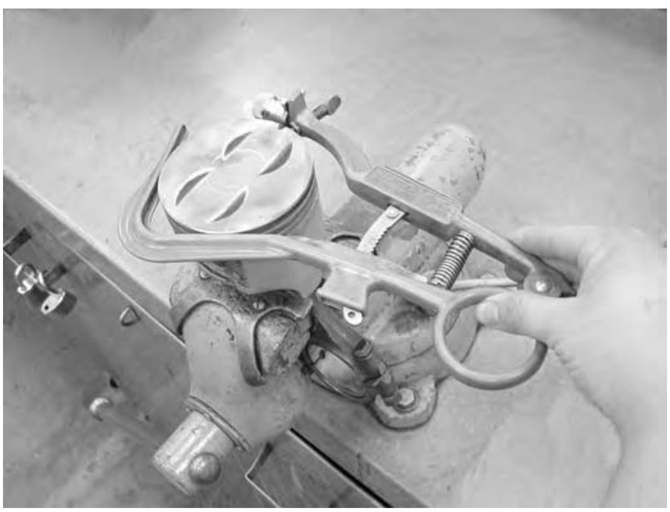


FIGURE 13.24 Cleaning the carbon from a ring groove of a vintage piston using a ring groove cleaner. *(Courtesy of Tim Gilles)*

After removing carbon from the ring groove, roll the ring around the entire groove to check for binding (**Figure 13.25**).

Cleaning ring grooves is easier if the piston and rod assembly is held in a vise. Be careful not to damage a slipper piston skirt. **Figure 13.26** shows the right way to clamp a slipper piston and rod in a vise. The jaws must be soft metal. Steel-toothed vise jaws can mark the connecting rod and weaken it. Damaging a metal surface raises stress, weakening the part. Inexperienced apprentices sometimes file notches in the beam of the connecting rod to identify the number of the rod, but this is a bad practice. Any stress raisers in the rod should be smoothed out.

FIGURE 13.25 After carbon has been removed from the ring groove, roll the ring around the entire groove to be sure it will move freely, without binding. *(Courtesy of Tim Gilles)*

FIGURE 13.26 Be careful when clamping a slipper skirt piston and rod assembly in a vise. *(Courtesy of Tim Gilles)*

Oil return holes sometimes become plugged and must be cleaned, or the engine will continue to use oil. Drilled oil holes can be cleaned with a drill bit that correctly fits the oil hole.

PISTON RINGS

Piston rings do a truly remarkable job in the engine. Most engines today use two compression rings and one oil ring (**Figure 13.27**). The top ring is exposed to the flame of combustion during every power stroke. In addition to sealing the tremendous combustion pressures, piston rings also help cool the piston and control oil consumption.

NOTE

According to Sealed Power Corporation, if $^{1}/_{10}$ of a drop of oil were consumed during each power stroke in a vehicle driven at 60 mph, an eight cylinder engine could consume about 90 quarts of oil in one 600-mile trip. Actual oil consumption per power stroke in an average engine is from $^{1}/_{1000}$ to $^{2}/_{1000}$ of a drop.

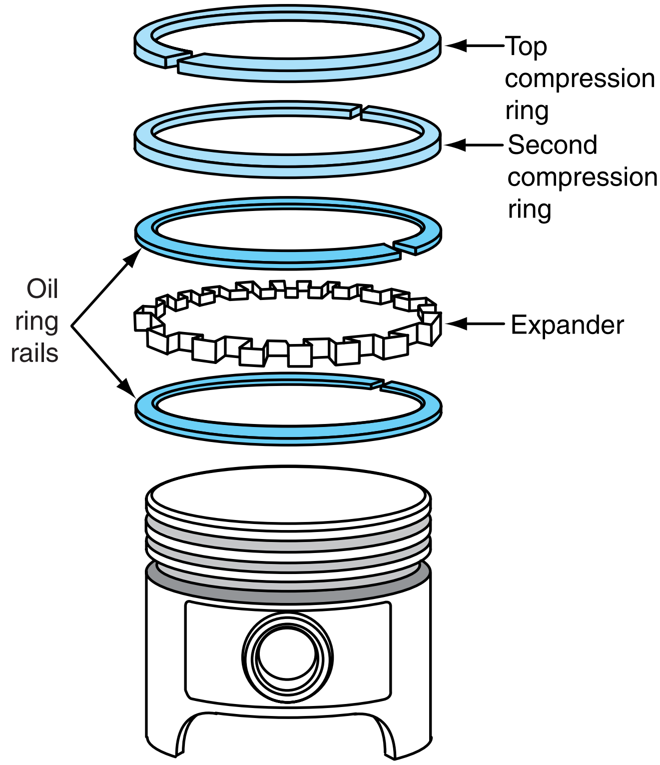


FIGURE 13.27 Most pistons have two compression rings and one oil control ring. Most passenger car engines have oil rings with two rails and an expander spacer as shown here.

The top ring controls most of the sealing of combustion. It controls peak pressures of 1000 psi at a temperature of about 350°F (177°C). The second ring experiences peak pressures of 200 psi at about 220°F (104°C), capturing what little pressure escapes past the top ring. It also scrapes oil back down the cylinder wall where it can be returned to the crankcase.

The top ring protects the other rings. It must stop blowby, or the second ring will have to perform the task and second ring wear will increase. The top ring is a premium ring (covered later), and the second ring is ordinary cast iron so it does not perform as well.

As long as the top ring seals, the piston stays in good condition. When excessive blowby and particles of combustion begin to leak by along with the flame, the oil rings will become stuck and plugged up and the piston and rings will rapidly deteriorate.

VINTAGE ENGINES

Knurling Pistons

The piston skirt diameter can be enlarged by knurling to compensate for wear to the skirts and cylinder walls (**Figure 13.28**). This procedure used to be common, but today it is only used to correct mistakes. A knurled piston requires only half the clearance of a stock piston. After knurling, remove the sharp edges of the knurl by rubbing the surface with an old piston pin, or by sanding the knurl lightly.

A piston skirt that has collapsed becomes smaller from excess heat and should **never** be knurled; it should be replaced.

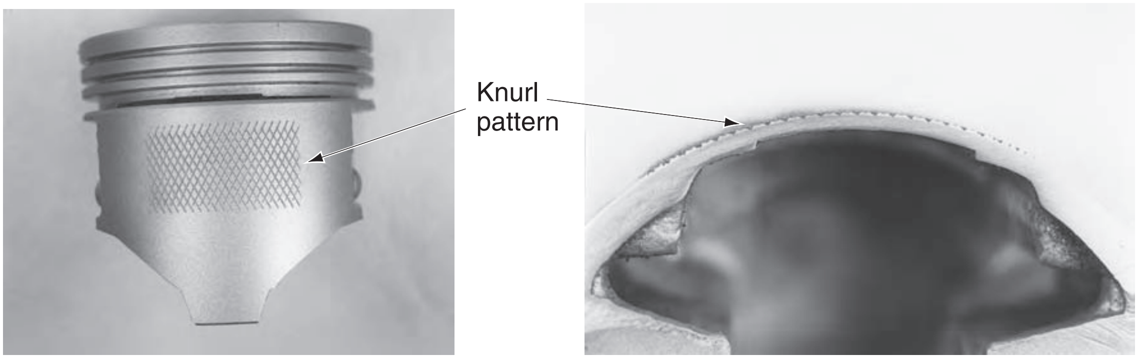


FIGURE 13.28 Knurling a vintage piston will increase its diameter. (*Courtesy of Tim Gilles*)

The *oil ring* runs at a temperature of about 220°F (104°C). Older engines often used three or four compression rings and oil rings at the top and bottom of the piston skirt.

Ring Oversizes

When engines are rebored, oversized pistons and rings are used. Rings are made for standard, 0.020", 0.030", 0.040", and 0.060" oversizes.

NOTE

Because 0.010" and 0.050" pistons are not available, if a 0.010" oversize is needed, a standard ring set is used; if a 0.050" is needed, a 0.040" oversized set is used. This will increase the ring gap by 0.030", however, so this practice is patchwork at best.

Metric piston oversizes are 0.50 mm (0.020"), 0.75 mm (0.030"), 1.0 mm (0.040"), and 1.5 mm (0.060").

Compression Rings

Compression rings are forced against the cylinder wall by combustion pressure at the top and back of the ring (**Figure 13.29**). It is important that the ring groove be square. A scratch in the bottom of a ring groove can leak as much as a more obvious scratch in a cylinder wall.

Rings are cast in groups. They are installed on a mandrel and machined out of round on a lathe. A slot is milled, which becomes the ring gap. When the ring is compressed, closing the large gap, the ring forms a spring-loaded circle.

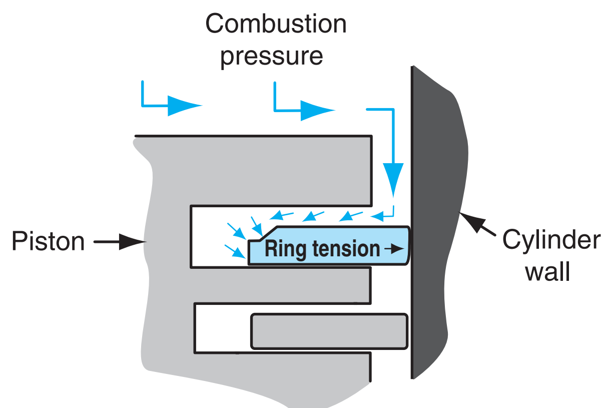


FIGURE 13.29 Combustion pressure forces the ring out and down against the bottom of the ring groove.

Ring Size Terminology

Rings have different widths and radial thicknesses (**Figure 13.30**). The term *width* refers to the height of the ring. The term *radial thickness* describes the depth of the ring into the groove.

The width measurement of oil rings is the actual width of the groove. When referring to compression ring width, however, the actual width of the ring is the measurement—not the width of the groove, which includes approximately 0.002" of clearance. Rings are made as narrow as possible in order to keep them light in weight.

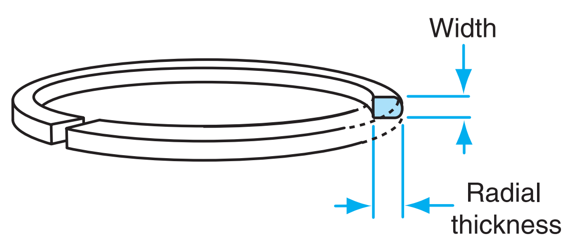


FIGURE 13.30 Piston ring terminology.

Ring Flutter

Four forces combine to push piston rings against the cylinder wall; combustion pressure, crankcase pressure, spring pressure, and inertia. When something upsets this balance, an uncontrolled oscillation called *ring flutter* can occur (**Figure 13.31**). Flutter can result in leakage, blowby, and, ultimately, a broken ring. When rings start to flutter, they lose their ability to scrape oil off the cylinder wall, causing a tremendous increase in oil consumption and blowby.

Heavy rings and rings in worn grooves have a tendency to flutter, which can occur when inertia from high speed causes the ring to stay against the top of the groove. It can also result from increased crankcase pressure that helps unseat the ring from the bottom of the groove.

Blowby that leaks past the top ring can be trapped by the second ring, causing the top ring to flutter. A recent trend is to use a "balanced ring set" with the second ring gap 1.5 to 2 times as large as the top ring gap. Oddly enough, this helps the top ring to seal. When blowby escapes past the top ring and is trapped by the second ring, the pressure that develops between the rings can unseat the top ring from the bottom of the ring groove. The result is more leakage past the top ring, compounding the problem. A larger second ring gap allows more blowby pressure to escape, helping to prevent ring flutter.

Some pistons have a specially designed ring land above the second compression ring with an accumulator groove to trap blowby and help prevent ring flutter (**Figure 13.32**). Certain second compression ring designs (covered later) also help prevent flutter.

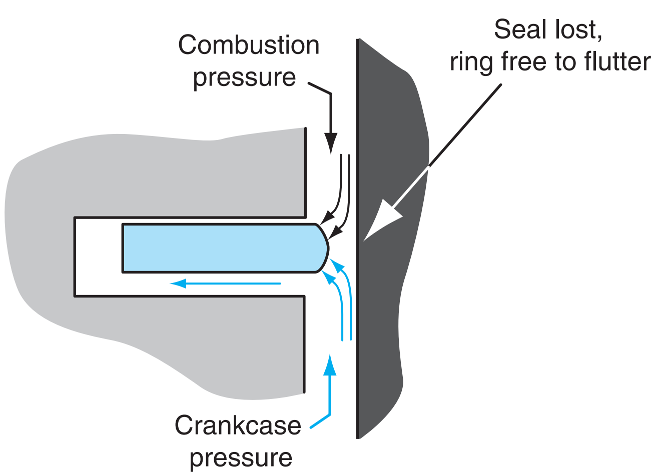


FIGURE 13.31 A ring that flutters can lose its seal.

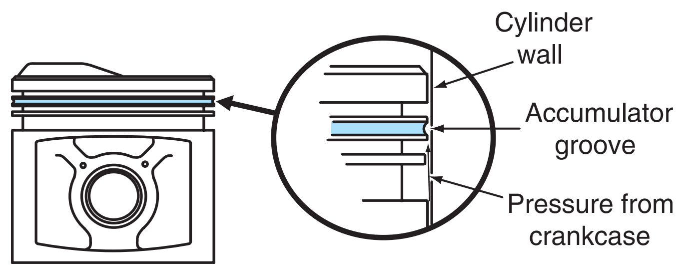


FIGURE 13.32 An accumulator groove between the piston ring lands traps blowby and prevents ring flutter.

Compression Ring Design. Several ring face designs are shown in **Figure 13.33**. The simplest cast iron rings are square. Some second rings have tapered faces. The barrel-faced design is common for top rings. Other rings are taper faced or have *chamfers* or *counterbores* that cause the ring to twist when compressed (**Figure 13.34**). The intent of these features is to cause the ring to contact the cylinder wall with only a narrow part of its face. This creates higher sealing pressure on the power stroke while maintaining lower friction on the other three strokes. These rings will seat quickly and their downward scraping action will help to control oil.

Napier Rings. Some second rings use a "napier" lower edge with a stepped ridge that provides an aggressive scraping edge like a squeegee (see Figure 13.33). Its hook design increases the scraping effect

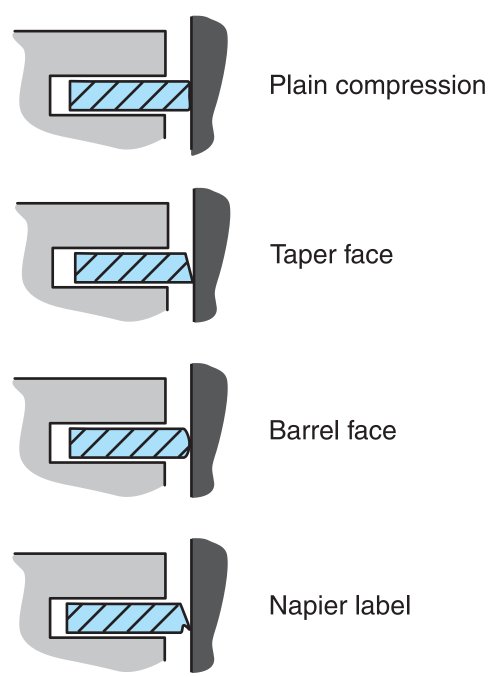


FIGURE 13.33 Several compression ring face designs.

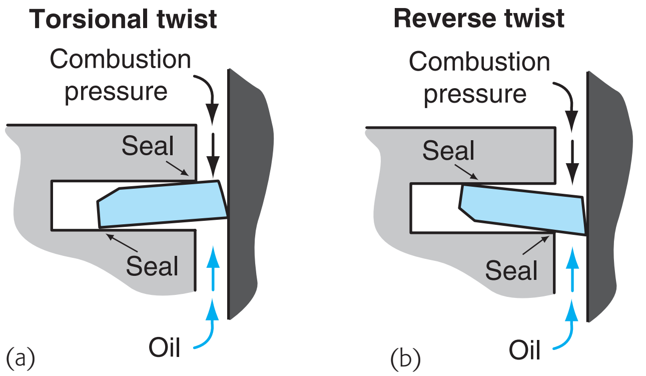


FIGURE 13.34 Chamfers and counterbores cause rings to twist in different directions. (a) Torsional twist. (b) Reverse twist.

as the piston moves down in the cylinder. It is used on some lower compression ring applications to help reduce top ring flutter and lower oil consumption. The part of the ring between the ring lands is rigid, whereas the face of the ring in contact with the cylinder wall is narrower, resulting in less sliding friction against the cylinder wall. Some earlier designs wore quickly because of the large hook and an excessive amount of ring twist. Later designs have minimized this problem.

Torsional Twist Rings. A torsional twist ring is chamfered on its top inside edge. It twists inward at its top edge as it is compressed into the ring groove. This results in a narrow line contact between the ring and its groove, which helps to control oil and combustion gases that could leak between the ring and ring groove. Torsional twist rings are forced flat against the bottom of the ring groove during full-throttle operation and against the top of the groove during high vacuum. Changing sides of the ring groove changes the operating characteristics of the ring from blowby control to oil control.

Reverse Twist Rings. Reverse twist rings are chamfered on their lower inner corner. They twist in a direction opposite to torsional twist rings. Because line contact between the lower edge of the ring face and the cylinder wall is desirable, the faces of these rings are more tapered. These rings do a better job of controlling oil, but the torsional twist ring controls blowby better. Some manufacturers use these rings more often on engines with a lower peak rpm. Other companies use reverse twist rings for nearly all applications.

NOTE

The second ring is most often a reverse twist taper-faced ring. The ring must be taper faced so the upper outside edge does not contact the cylinder wall. Installing these rings upside down will result in severe oil consumption. The second ring actually controls more oil than compression.

Barrel-Faced Rings. Another type of ring used in high output engines with short piston skirts is the barrel-faced ring. This ring has less than 0.001" of curve to its face, which is not visible to the eye, as it is in the sketch in Figure 13.33. Most premium top rings are barrel faced.

A barrel-faced ring can accommodate a slightly out-of-square ring groove. Like the twist-type rings, it creates high pressure against the cylinder wall because of the narrow contact area of its face. This helps during break-in of the new rings. When the ring moves from the bottom of the groove to the top of the groove, as the piston changes direction at TDC, the line contact between the ring and cylinder wall is maintained.

A barrel-faced ring is less likely to cause a ring ridge than other rings. Barrel-faced rings can also be beveled in either a positive or reverse twist design. Most original equipment barrel-faced rings are not beveled and can be installed in either direction.

Piston Ring Materials and Coatings

Piston rings are made of cast iron, ductile iron, or steel wire. Various ring coatings are used for different applications.

Cast Iron Rings. Rings are often made of plain cast iron. Iron rings are used in rering jobs when the cylinder walls have not been rebored. Iron rings are very forgiving of cylinder wall imperfections and they are very popular with technicians because they seat easily. When a plain cast iron ring is machined on the surface that rides on the cylinder wall, some manufacturers leave a threaded finish on the ring. The peaks of thread help the ring to seat rapidly to the bore. The threads also hold oil for break-in.

NOTE

The threaded finish can often be seen on the upper part of the face of a taper-faced second ring when an engine is disassembled for a rebuild.

Chrome-plated and moly rings do not have a threaded finish because they are lapped at the factory.

NOTE

Where premium rings are used in the top groove, iron rings are often used in the second groove.

Iron rings can become loose and their spring tension is reduced at higher temperatures.

Moly Rings. Some premium cast iron rings have a groove machined on their faces. A plasma spray gun is used to fill the groove with molten molybdenum (**Figure 13.35**), which solidifies as soon as it contacts the ring. These are called moly rings. The groove is cut into the ring because the moly does not stick to the ring's base material as well as chrome. The groove keeps the moly from coming off the ring. **Figure 13.36** shows the faces of moly rings.

After final machining, the moly coating is about 0.004–0.006" thick. Extended periods of detonation or high piston head temperatures can cause the moly to separate from the base material of the ring. Engines with a risk of failure from these conditions should use chrome rings.

Moly top rings are popular because their high melting temperature makes them extremely resistant to scuffing. Molybdenum has a melting temperature of 4750°F (2621°C); the melting temperature of iron is 2250°F (1232°C). When molten molybdenum solidifies on the ring surface, it becomes molybdenum oxide. This oxide is a ceramic and is very hard, unlike the metal molybdenum.

Moly rings are called self-lubricating because they have a porous surface that helps them retain lubricant for less wear. They are also said to seat instantly, because they are preground to make them perfectly round. Moly rings are ground rather than lapped; this prevents the porous surface from filling with lapping abrasive. As development of these rings has progressed, the porosity (5%) of the surface has become less and less. Older moly rings, which had more porosity (20%), trapped dirt and became abrasive.

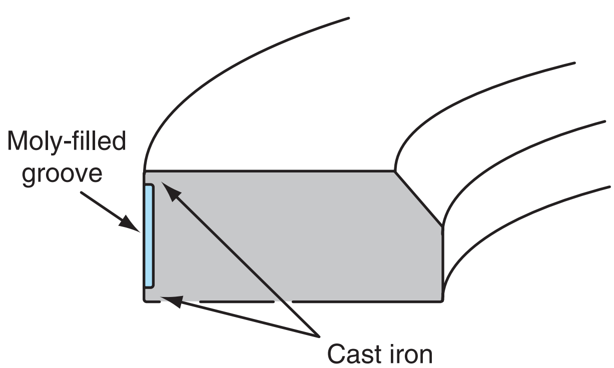


FIGURE 13.35 A moly (molybdenum) piston ring.

FIGURE 13.36 Moly rings. The black area is the moly; the shiny edges are the cast iron edges of the rings. *(Courtesy of Tim Gilles)*

Honing recommendations for moly rings differ. Be sure to check the ring manufacturer's hone-grit recommendations. Most manufacturers recommend a fine finish on the cylinder wall of less than 13 microinches with a 400-grit stone. There is a narrow band of iron that protrudes on both sides of the ring surface; the band is what seats into the cylinder wall. Molybdenum oxide is very hard and would not seat in on a fine cylinder surface.

NOTE

Moly rings and chrome rings should not be used in cylinders that are out of round at all. Also, if cylinder bores are tapered by more than 0.002", these premium rings should not be used.

Chrome Rings. Some rings are chrome plated (**Figure 13.37**). These rings have about twice the resistance to abrasive wear as moly rings but are difficult, or impossible, to seat in worn (oval) cylinders. They are lapped at the factory when new so they can

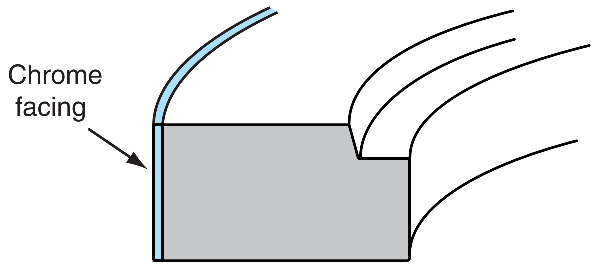


FIGURE 13.37 A chrome piston ring.

seat in true cylinder bores. Chrome-plated rings are especially recommended for engines used where excessive dirt will be encountered. They should *not* be used with either propane or natural gas fuels. They also have a problem that moly does not have—moly will not weld, but chrome can overheat and weld to the cylinder bore (scuffing). Also, do not file chrome rings at the gap. If wear to a chrome surface is suspected, apply copper sulfate to the chrome. It will react with any exposed iron under the chrome to form a thin layer of copper. Chrome rings typically last for the life of the engine with virtually no wear.

Premium Ring Combination. Moly has become more popular than chrome as a premium ring because under normal conditions it wears very well. A common piston ring setup found on passenger cars uses a moly barrel-faced top ring, a reverse torsion second ring, and a three-piece chrome oil ring (**Figure 13.38**).

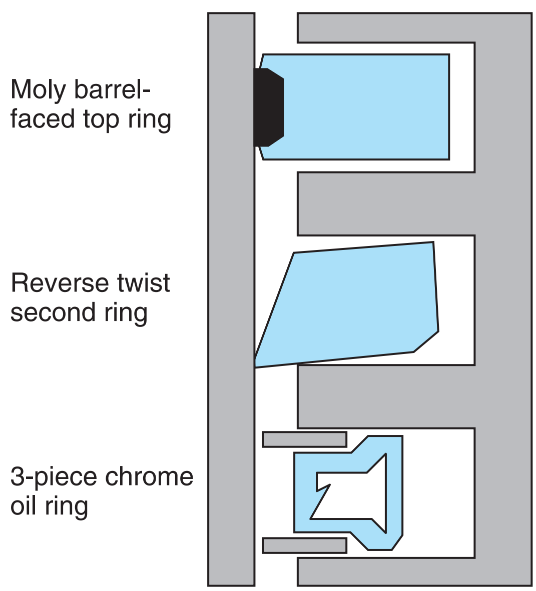


FIGURE 13.38 A common piston ring set with a moly top ring.

High Strength Rings

High strength rings are constructed of either ductile iron or steel. Higher strength helps protect against ring breakage, but these rings are more expensive than ordinary cast iron.

Ductile Iron Rings. Special ductile iron rings are often used in the top groove to withstand the higher temperatures in some of today's high heat engines. Plain cast iron becomes so hot that it can weld to the cylinder wall (scuff). Also, cast iron is prone to breakage when the cross section width of the ring is too narrow. Today's rings are often as narrow as 0.058" (1.5 mm). These rings are made of ductile material as are all rings on engines equipped with turbochargers. Ductile iron, also called nodular iron, is over twice as strong as plain cast iron (**Figure 13.39**). Ductile iron rings have a tensile strength of about 110,000 psi, compared to regular iron's 40,000 psi.

A disadvantage to ductile iron is that it tends to scuff or weld to cast iron cylinder walls; therefore, it is always coated with moly or chrome. This is why some engines do not have the option of a plain cast iron top ring.

SHOP TIP

To test a moly or chrome ring to see if it is ductile iron, simply twist it. If it is regular iron it will break in two.

Steel Rings. Steel rings are made of steel wire. Steel rings have nearly four times the tensile strength and fatigue strength of cast iron rings. Steel

FIGURE 13.39 A ductile iron ring is flexible. Ordinary cast iron rings break easily. (*Courtesy of Tim Gilles*)

is like ductile iron in that it must be coated so it can run against cast iron cylinder walls. Steel rings are hardened by gas nitriding or coated with chrome or plasma moly to provide a hard protective coating for a long life. One advantage to gas nitriding is that it does not deteriorate and flake off. Coated or hardened rings must be used in engines that run on alcohol because alcohol tends to cut the oil film.

New OE Piston Rings

Late-model low-tension piston rings differ, depending on the area of origin. North American engines usually have rings with moly facings, because its porosity allows it to hold oil and it is very resistant to high temperatures. Japanese engines tend to have nitrided ring facings, which are more costly. European manufacturers use a variety of rings with chrome, moly, or nitrided faces.

Ring designs by all of the world's manufacturers are becoming very narrow. Although some are as narrow as 1.0 mm (0.040"), top compression ring thickness is typically 1.2 mm (0.047") and second rings are 1.5 mm (0.059"). Oil rings tend to be 3 mm (0.118") with some as narrow as 2 mm (0.078").

NOTE

The Chevrolet small block has been around since 1955 and the 5.7 L (350 CI) small block provides an example of how the evolution of piston ring technology has presented an interesting challenge for engine rebuilders. Piston rings and ring grooves for this engine can be one of four designs, including deep groove, shallow groove, mixed groove (with top and second grooves of different depth), and metric. One ring type is not interchangeable with another.

High RPM Rings. Drag racers know that when a ring starts to flutter (see Figure 13.31), there will be a power loss because the ring cannot hold the cylinder's pressure. Cutting the weight of the ring can improve its ability to perform at higher rpm. There are three popular narrow ring widths used in racing: 0.062" (1/16"), 0.043", and 0.031" (1/32"). Up to 7500 rpm, a 1/16" top ring is best. It is popular for handling the loads required by turbos. Above 7500 rpm, the 0.043" ring is a better choice because it will not flutter as easily. The 0.031" ring is good up to 10,000 rpm. Formula 1 (F1) racing engines, which turn 18,000 rpm, use piston rings as thin as 0.6 mm (0.023").

Combustion Pressure Sealed Rings. Head-land rings (**Figure 13.40**) and the 0.031" *pressure backed* ring are combustion pressure sealed rings. The 0.031" ring has a 1/16" wide face but is L-shaped. The part of the ring that is in the groove is only 0.031" (**Figure 13.41**). Combustion pressure pushes the L-shaped ring against the cylinder wall and bottom of the ring groove.

Some racing pistons are *gas ported;* they have holes drilled from the head of the piston to the back

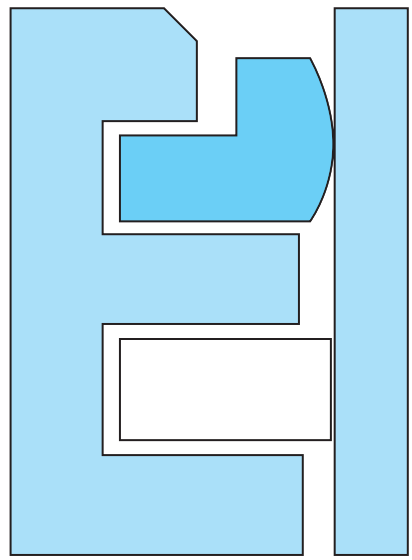


FIGURE 13.40 A head-land compression ring.

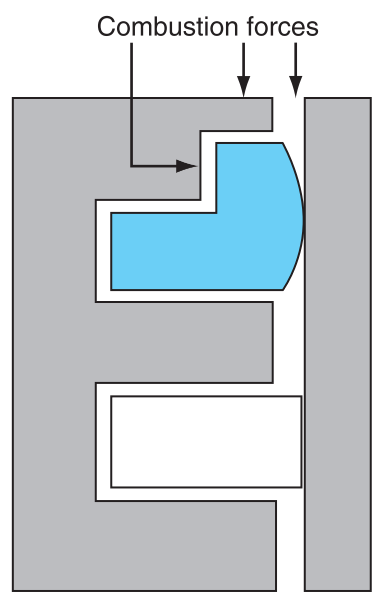


FIGURE 13.41 An L-shaped ring has a very thin width in the groove. It gets pressurized against the cylinder wall from the force of combustion.

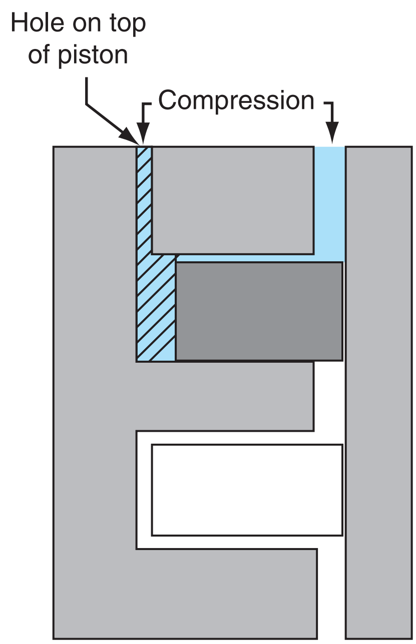


FIGURE 13.42 A gas-ported ring gets pressurized from behind through holes from the top of the piston.

of the compression ring groove (**Figure 13.42**). The force of combustion helps seat the ring against the cylinder wall but it causes accelerated wear, especially against the top side of the ring. Remember, ring wear is usually only on the bottom side.

Plasma Ring Coatings

Plasma Ceramic. A newer ring face coating is plasma ceramic. The facing, which is a composition of titanium oxide and aluminum oxide, is applied to nodular iron rings with a plasma torch at 30,000°F (16,649°C) to 40,000°F (22,204°C). With this process, materials that are not normally sprayable can be sprayed. This provides a combination of metal and ceramic that has even higher resistance to wear than chrome. The surface is ground to leave a ceramic face of 0.004–0.008". According to TRW, this makes for a ring that is five times as strong as a stock ring. The rings are said to resist detonation damage, cause less cylinder wear, and have excellent break-in characteristics. Cylinder preparation is the same as for moly rings.

Pressure-Balanced Rings. Pressure-balanced rings are high-performance, narrow-faced compression rings. Combustion pressure is applied to the narrow face area of the ring that contacts the cylinder wall (**Figure 13.43**).

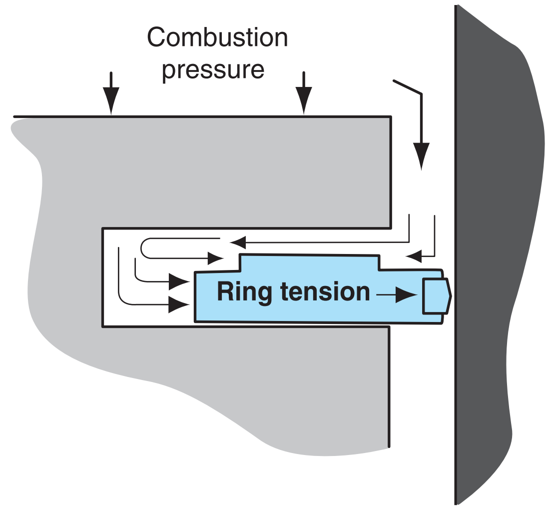


FIGURE 13.43 A pressure-balanced ring. The wide cross section provides stability; the narrow face reduces friction.

These rings were developed by TRW to reduce friction and improve fuel economy. But the mileage gains were achieved only at wide-open throttle so they are now manufactured as high-performance rings. They are more expensive because of the extra machining required. The facing on these rings is one of the new types made by the plasma spray process.

Oil Control Rings

The second compression ring assists the oil control ring in doing a remarkable job controlling oil consumption.

- An engine that uses a single drop of oil with every power stroke would use 1 quart of oil every 2 miles.
- Oil consumption increases with engine speed. A typical engine uses about seven times as much oil at 70 mph as it does at 40 mph, depending on the rear axle ratio.
- Vacuum during deceleration increases with compression ratio. Earlier, lower compression emission control engines developed only about 20 inches of vacuum, but today's higher compression engines can develop up to 25 inches. This makes the oil ring's job that much more difficult.

Oil rings fail if they become plugged because of blowby leaking past the compression rings, improper maintenance, temperatures that are too high or too low, fuel with too much lead or impurities, or improper air-fuel mixtures.

Most engines have only one oil ring located below the two compression rings. There are several oil ring designs. Some are single-piece cast types, but most oil rings in passenger cars and light trucks are of the three-piece type. These consist of a stainless steel expander and two chrome rails (**Figure 13.44**). Some of the expanders are highly polished and appear to be chrome. However, they are made of the same material as the non-polished expander and perform the same. Oil rings rarely have problems because they operate in a relatively cool, well-lubricated environment.

NOTE

A lack of regular oil maintenance will cause the accumulation of sludge and varnish that plugs oil control rings, resulting in an engine that burns oil.

The three-piece oil ring prevents oil from being drawn around the sides or back of the ring. Most of the oil is scraped off by the lower rail, so barely any oil must actually pass through the expander to the inside of the piston. A single-piece oil ring will move off the bottom of the groove during the high vacuum of deceleration. Heavy-duty engines do not use three-piece oil rings; they use cast iron oil rings.

The oil ring contributes the most friction to the engine. The chief advantage of the three-piece oil ring is that it can operate with less tension and, therefore, less friction. Low-friction rings have rails that are not as deep, and a weaker expander is used.

Low-Friction Piston Rings. Low-friction rings were introduced in 1985 to improve fuel economy. On vintage flat-tappet engines, most of an engine's friction was produced between its valve lifters and cam lobes. The rest of the friction came from sliding friction between the piston rings and cylinder walls. Also called low-tension piston rings or shallow groove rings, these lower-friction rings reduced cylinder wear rates considerably.

Low-friction rings are lighter and thinner than older rings. This makes them more resistant to ring flutter also.

Compression rings account for about 40% of the total drag on a cylinder wall. The oil ring accounts for the remaining 60% (**Figure 13.45**). Reductions in ring tension have been mainly in the oil ring. Low-friction ring sets have reduced ring pressures by 60% for the oil ring and 10% for the compression rings. The compression ring reduction was accomplished by reducing its width (height).

Low-friction rings are found on most passenger cars. Vintage engines (called carry-over engines) like the Ford 302 and 351, Chrysler's 318, and GM's 305 have lower-friction rings than they originally had as OE, but they are not true low-friction rings.

NOTE

Pistons designed for use with low-friction rings have ring grooves of shallower depth. Be sure the rings being used are the correct ones for the pistons.

Low-friction compression rings are less "forgiving" than standard rings and are less apt to follow the contour of tapered or eccentric cylinders. Cylinder

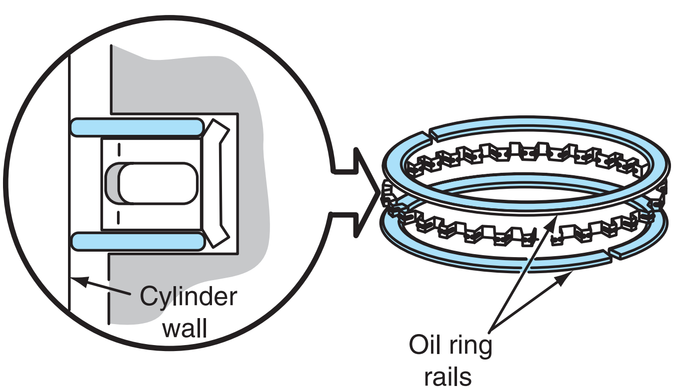


FIGURE 13.44 A three-piece oil control ring.

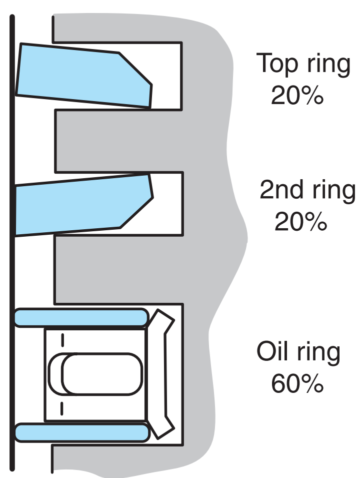


FIGURE 13.45 Percent of ring drag per ring.

walls must be straight and undistorted. The wear allowances for conventional rings do not apply to low-tension rings. There are no published aftermarket standards, but most OEM service manuals only allow a maximum of 0.002" of cylinder bore taper for low-tension rings. Desirable taper is 0.0005"–0.001". The use of deck plates is advised when honing thinwall block castings for use with these rings.

Low-Friction Oil Rings. Low-friction oil rings are anything with less than 13 psi of tension. Rings of 14 psi and higher are not considered low-friction.

NOTE

One high-performance auto manufacturer experienced problems with aggressive drivers who experienced high oil consumption under heavy loads. For these customers, the manufacturer changed from a 9-pound oil ring to a 13-pound oil ring and used a Napier ring in the second groove. Although this did not improve performance, it did help with the oil consumption problem.

With low-friction oil rings, oil throw-off to the cylinder wall is more closely controlled by the manufacturers. These engines do not have oil squirt holes in the connecting rods. Side clearances of the connecting rods are more important and there is usually a windage tray to minimize higher-rpm oil throw-off to the cylinder walls. A low-friction ring in a 350 Chevy would not work because there is so much oil throw-off. Popular domestic engines like the GM 3.8 liter and the Ford 4.6 liter use low-tension oil rings. The common ring width used to be $^{3}/_{16}$". The width of the ring rails on the low-friction rings on these and other engines is now commonly only 3 mm. This is so thin that it makes installation a bit more difficult. One of the advantages to low-friction oil rings, however, is that they can conform more easily to to the cylinder walls.

Ring Wear

The major cause of ring wear is abrasion. This can result from leftover honing grit, from running the engine with a missing or damaged air cleaner, or from using a contaminated oil fill spout. **Figure 13.46** shows oil rings worn by abrasives.

When inspecting rings for wear, look for the following:

- When wear is due to dirty air getting in, the top compression ring will show more wear and vertical abrasive lines will be visible.
- When ring wear is due to abrasives in the oil, the lower rings and cylinder wall will exhibit more wear and the top ring will have less wear.
- When abrasives cause wear, the bottom side of a ring will wear, leaving a lip on the outside edge (see Figure 13.19).

Ring Gap Clearance

Before installing new rings in a cylinder bore, check the ring gap. The ring butt gap should be at least 0.003" to 0.004" for each inch of cylinder bore diameter, unless otherwise specified in the repair manual. The chart in **Figure 13.47** gives the minimum clearances recommended by the Society of Automotive Engineers (SAE) for different cylinder bore sizes. The gap can be filed to fit if it is not wide enough. One manufacturer states that maximum butt clearance is not as critical and can actually be as much as 0.030" more than the minimum specifications without causing blowby.

To give themselves more latitude during production, manufacturers produce rings that have 0.005–0.010" more gap clearance than the minimum specification.

Too much gap clearance can point to a bore too large or the use of rings that are too small. Remember, the gap will increase about 0.030" for each 0.010" error in size.

The important thing about ring gap is the minimum specification. Too small an end gap can cause the rings to lock up in the bore, resulting in scuffing and ring failure. The ring ends will appear polished if this happens. In extreme cases, the piston can actually come apart at the oil ring groove.

Checking the gap is a good way to check on a ring supplier's quality control. Some high-performance engine builders believe that engine horsepower output and blowby are affected by the end gap. The maximum gap that can be tolerated is dependent on engine rpm and compression pressure. There are aftermarket high-performance rings that can be filed to provide the desired gap. The ring can be protected when filing a ring gap by holding it between pieces of cardboard in a vise, or

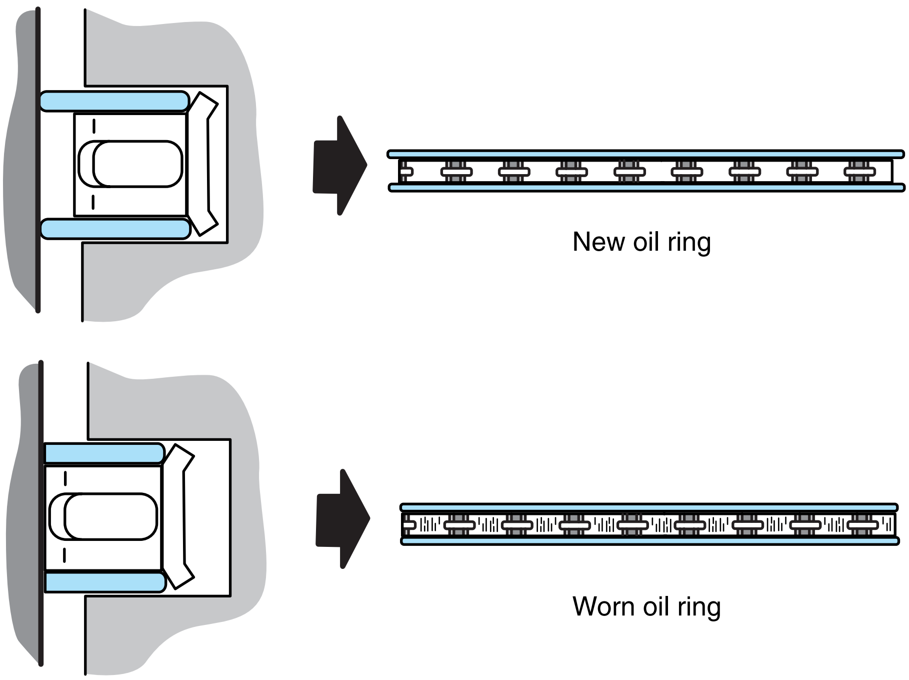


FIGURE 13.46 Oil rings worn by abrasive particles.

Cylinder Diameter	Ring Gap Tolerance
1" to 1 31/32"	.005 to .013
2" to 2 31/32"	.007 to .017
3" to 3 31/32"	.010 to .020
4" to 4 31/32"	.013 to .025
5" to 6 31/32"	.017 to .032
7" to 8"	.023 to .040

FIGURE 13.47 SAE recommended top ring gap clearance (approximately 0.003–0.005" per inch of bore diameter). The second ring gap is often larger to prevent ring flutter.

a piston ring filer can be used (**Figure 13.48**). Compression rings help with oil control more than oil rings help with compression, so a reasonable end gap is desirable.

To measure gap clearance, install the ring in the cylinder and square it up with a piston. Then measure the gap with a feeler gauge (**Figure 13.49**). The ring must be positioned in the unworn portion of the bore below ring travel. An increase of 0.002" in the bore size would increase the gap by about 0.006" (see Chapter 11). Installing standard rings in a 0.030" oversized cylinder bore would result in an end gap increase of approximately 0.090". The end gap is tapered (**Figure 13.50**), so be sure to measure at the outside edge of the ring for an accurate measurement.

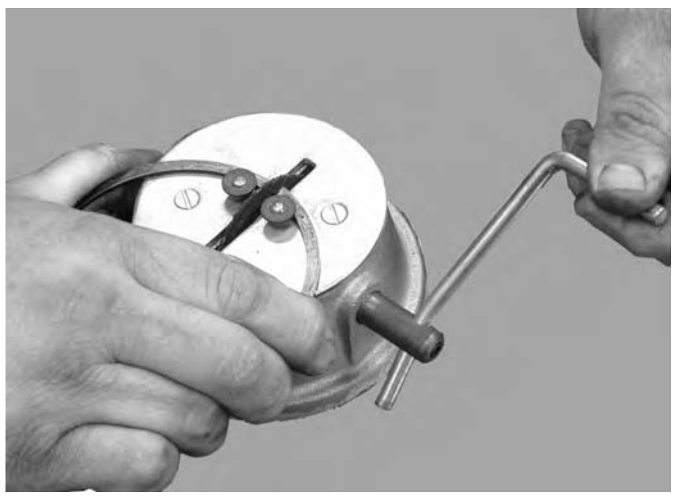


FIGURE 13.48 A ring filer can be used to customize the ring gaps on some high-performance piston rings. *(Courtesy of Tim Gilles)*

A common customer error is to install oversized rings in badly worn cylinders. But because of the tapered cylinder wear, oversized rings would lock up as the piston travels down the cylinder wall.

NOTE

As an interesting experiment, check the gap on a worn ring to see how much metal it has lost.

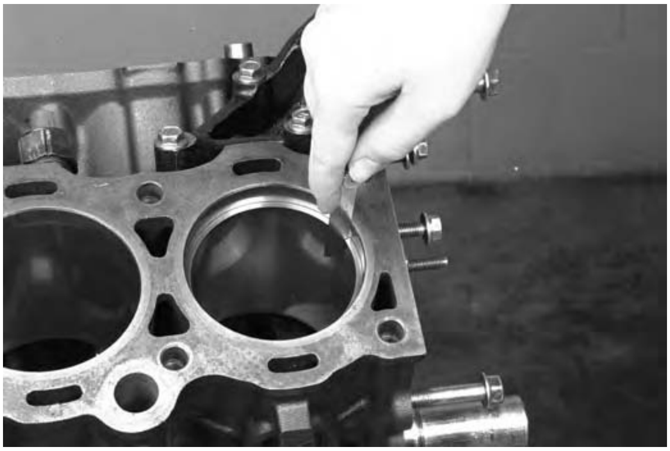


FIGURE 13.49 Measure ring gap with a feeler gauge. *(Courtesy of Tim Gilles)*

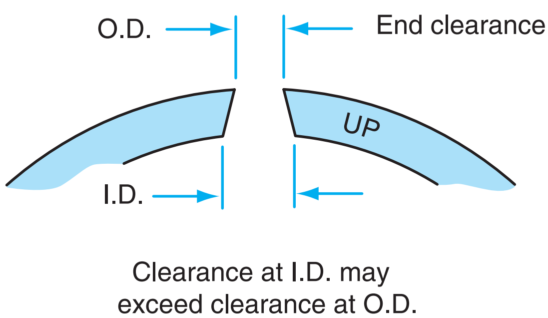


FIGURE 13.50 Piston ring end gap taper.

An approximation of wear may be made as follows: If the gap of an old ring is 0.050" and the gap of a new ring is 0.020", divide the difference by 3(π) and then by 2 (wear from both sides).

0.050"	Old Ring Gap
–0.020" / 0.030"	New Ring Gap Difference
$\frac{0.030"}{3(\pi)}$	= 0.010" Conversion of Circumference to Diameter
$\frac{0.010"}{2}$	= 0.005" Ring Face Wear

Figure 13.51 shows rings that were too small for the cylinders in which they were run. Notice the dark area near the gap.

Oil Ring End Gap . End clearance for chrome-plated steel rail oil rings is forgiving. According to Engine Tech Inc., cylinders that are 3.000" and larger have an oil ring gap tolerance of from 0.015" to 0.055". Later model metric rings have a maximum end gap of 1.25 mm (0.050"). Oil ring rails are too hard to file. If the gap is too small, another set of rings will be necessary.

Installing Rings on Pistons

It is easier to install the oil control rings before installing the compression rings. Work your way up from the bottom of the piston to the top.

Install the Oil Rings. Install the oil control rings before the compression rings as shown in **Figure 13.52**. Some aftermarket oversized pistons are "compensated" in the ring groove but most are not. This means that if the piston is 0.060" oversized, it will have ring grooves that are 0.030" deeper. A compensated piston will have a groove that is the same depth as stock. Noncompensated pistons cause problems during installation because if the ring falls all the way into the groove, it can pop out on the other side of the piston. This cannot happen once it is in the cylinder. It just makes installation more difficult.

Sometimes there can be enough room to install the ring in the groove but there is not enough room behind the ring to allow for expansion when the

FIGURE 13.51 Rings that are too small for the cylinder will have the appearance of carbon deposits near the gap.

piston heats up. There should be at least 0.010" clearance behind the ring.

- Install the expander, being careful not to overlap its ends (**Figure 13.52a**). The ends are usually painted different colors to make it obvious to the installer if they are accidentally overlapped. Some expanders are filled with a Teflon button on their ends to prevent improper assembly (**Figure 13.52b**). In the absence of a recommendation, position the expander gap above one end of the piston pin.
- Next, install the rails. Installing the top rail first is easiest (**Figure 13.52c**). While holding your finger over the butted ends of the expander, install the top rail. Position its gap above the skirt on one side of the expander spacer gap. Positioning the gap above the skirt is especially important on the lower piston ring. Low-tension oil rings are shallower and the gap is supported better by the larger area of the ring groove above the skirt. Some pistons have "as cast" oil ring grooves where the lower ring land does not extend as far out over the pin boss as it does above the skirts. If the lower rail is positioned in this area, it can pop out.
- Install the lower rail with its gap placed above the skirt on the opposite side of the expander gap (**Figure 13.52d**).

FIGURE 13.52 (a) Install the oil ring expander. (b) These colored plastic inserts prevent the ends of this oil ring expander spacer from being accidentally overlapped during installation. (c) Roll the oil ring rails into place. (d) Correct oil ring installation. *(Courtesy of Tim Gilles)*

When the engine will not be assembled right away after the rings are installed on the pistons, protect them from accidental damage and contamination (**Figure 13.53**). Be certain to lubricate the compression rings thoroughly (see Chapter 17).

Install Compression Rings. Compression rings are installed with the aid of a ring expander (**Figure 13.54).** If a ring expander is not available, a shop towel can be used as shown in **Figure 13.55**. It is important not to "spiral" or roll the rings during installation; they can become distorted to resemble a lock washer (**Figure 13.56**). Overexpanding plain cast iron rings during installation can very easily result in a broken ring.

Rings that are not square on all sides must be installed with their identification marks facing up (**Figure 13.57**). Compression rings help to control oil. One compression ring installed upside down can double an engine's oil consumption.

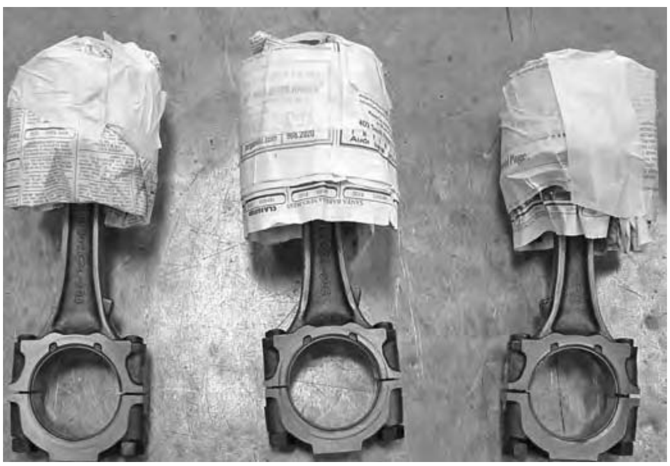


FIGURE 13.53 If the piston assemblies will not be installed immediately, store them in paper so the rings will not get dirty or become damaged. *(Courtesy of Tim Gilles)*

FIGURE 13.54 A piston ring expander. *(Courtesy of Tim Gilles)*

FIGURE 13.55 Using a shop towel to install a compression ring. *(Courtesy of Tim Gilles)*

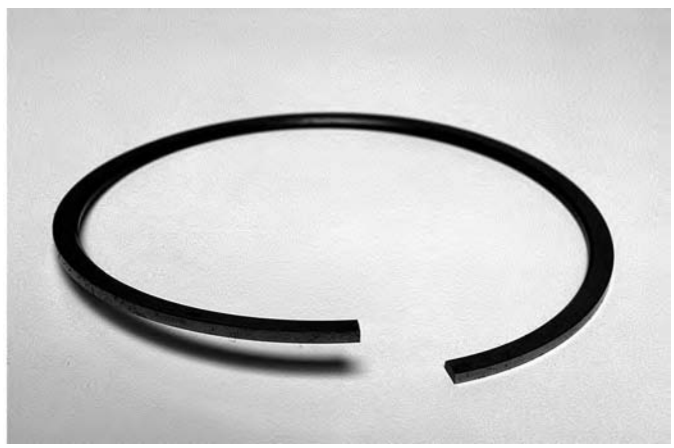


FIGURE 13.56 Incorrect installation can ruin a piston ring.

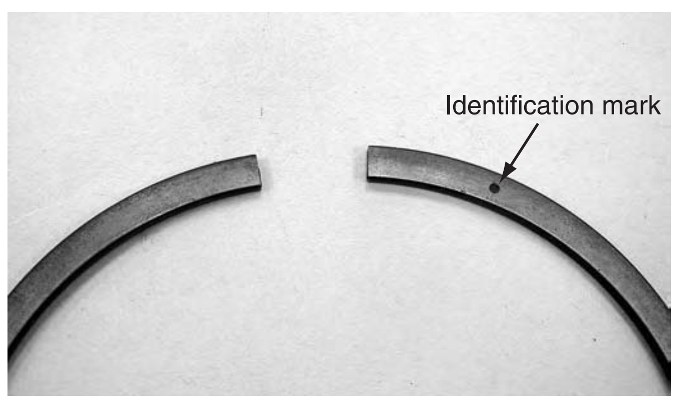


FIGURE 13.57 Be certain to check for ring identification marks. They are installed facing up. *(Courtesy of Tim Gilles)*

Ring Gap Position. The gaps are placed at different locations on the piston. The positions shown in **Figure 13.58** are popular in the aftermarket.

Compression Ring Gaps

- Gaps should not be located above the piston pin unless the piston has a full round (trunk) skirt.
- Gaps on an opposed engine design should not be faced down; oil can run into the combustion chambers through the gaps.
- Some say that ring gaps should be faced toward the cam on V-type engines to prevent extra oil consumption.

According to information published by engineers at Dana Corporation in an issue of its publication, *Tech Tips:*

- The reason for the practice of staggering ring end gaps is to guard against scuffing when an engine is started for the first time.
- As the engine operates, rings will rotate from the positions where they were first installed.

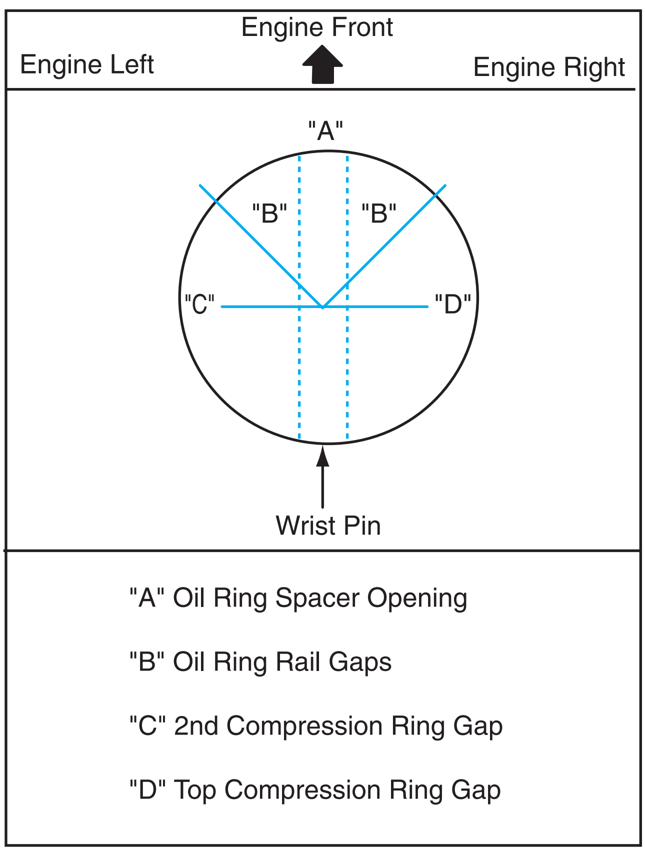


FIGURE 13.58 This is a generic chart of ring gap placements popular in the aftermarket. Follow the instructions that come with the rings.

- End gap position is *not* a cause of oil consumption.

When bores are more than 0.005" out of round, rings tend to align themselves. Some rebuilders position ring end gaps away from the major thrust side. This is said to prevent a cosmetic scratch caused by a sharp edge on a new ring.

NOTE

There are many differing opinions on ring gap placement. The most prudent policy is to follow recommendations of the vehicle manufacturer when available.

PISTON PINS

The piston is attached to the connecting rod with a piston pin (also called a wrist pin). The piston pin is lubricated from either a hole in the top of the pin boss (see Figure 13.1) or through an angle-drilled hole that runs from the oil ring groove to the pin boss.

Lack of lubrication can damage the piston and pin. The piston pin is chrome-plated, high-grade carbon steel. Because the piston has such a high silicon content, it is harder than the pin, so when there is wear, it usually is to the pin (**Figure 13.59**).

Piston Pin Retaining Methods

Automobile piston pins are either pressed-fit in the connecting rod or full floating (**Figure 13.60**).

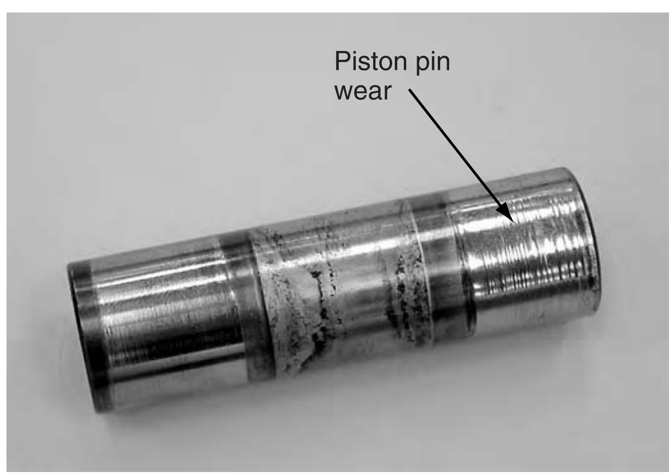


FIGURE 13.59 This badly worn piston pin caused an engine knock. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Older piston pins often wore out the pin bores in their pistons, although pins would rarely wear unless the rest of the piston was worn too. A common practice on vintage engines was to machine the piston pin bores of both the piston and the connecting rod oversize and install a new oversized pin. Today, the cost of machining the top groove, the skirt, and the pin will probably exceed the cost of a new piston, but this is sometimes a necessary option when restoring older vehicles with limited availability of parts.

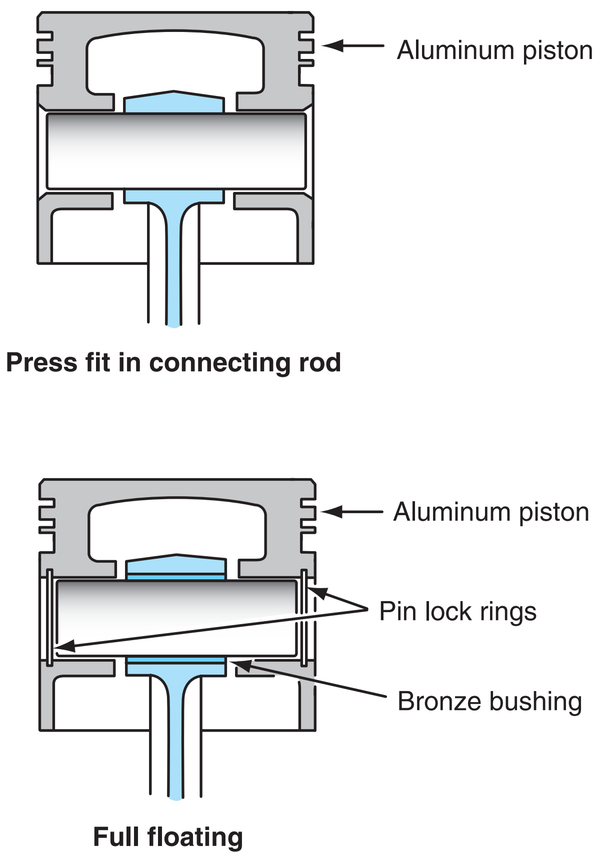


FIGURE 13.60 Piston pins are either pressed into the rod or full floating (pivoting in both the piston and rod).

Vintage piston pins were sometimes secured by a bolt at the top of the connecting rod.

Pressed-Fit in Rod. The most common method of attaching the piston pin is to have it *float* (pivot) in the piston with a very close clearance (about 0.0005"). A pin with this fit feels almost tight when cold but will move freely when hot. The pin is pressed into the rod with a force of about 2 tons (4000 lb). The interference fit is about 0.001".

NOTE

A pressed-fit is also known as crush.

Pressed-fit pins and pistons are separated from rods using a pin press (**Figure 13.61**). Sometimes the same tool is used to install new pistons. (A rod heater, covered later, is a better choice for piston and rod assembly.) Using too much force when pressing a new piston-and-rod assembly together can distort a piston, causing the pin fit to be too tight. A pin fit that is too tight can result in a rod bearing failure. Also, many replacement piston pins have a ridge in the middle of their bores. This makes it difficult to use the correct tooling.

A safer way to install pressed-fit pins is to use a rod heater to heat the eye of the rod. A new pin will slip easily into place without the risk of ruining a piston. An installation gauge helps to center the pin in the piston. The furnace shown in **Figure 13.62** heats two rods at once and has an automatic pin depth fixture.

FIGURE 13.61 Installing a press-fit piston pin. *(Courtesy of Tim Gilles)*

FIGURE 13.62 A rod furnace used for installing pressed-fit piston pins into connecting rods. *(Courtesy of Tim Gilles)*

Be sure to thoroughly clean the eye of the rod before attempting piston pin installation. A brake hone used by hand (no drill motor) with some solvent works very well. Just clean off burrs or high spots.

CAUTION

Removal of only a small amount of material from the eye of the rod can eliminate the pressed-fit.

It is a good practice (especially when using a rod heater to install the pin in the rod) to measure and compare the sizes of the old and new piston pins. If oversized piston pins were used in the old pistons before, the rod eye will also be larger, and the new pins will not fit the rod tightly.

When original pistons are to be reused during an overhaul, it is best to simply leave the pistons and rods assembled. Pressing them apart serves no useful purpose and risks ruining an otherwise good piston.

NOTES

- Do not glass bead blast pistons while the pistons are assembled to the connecting rods.
- Do not soak the piston-and-rod assembly in parts dip because the pin might seize on the piston.

Full-Floating Pins

A **full-floating pin** floats in the "eyes" of both the rod and piston. One advantage to a full-floating pin is that it is more forgiving than a pressed-fit pin when a rod is slightly out of alignment. Another advantage is that if the pin seizes in either the piston or the rod, it will still be able to float freely. A typical full-floating rod has a bronze bushing. Bushing service is covered later in the chapter.

NOTE

Very hard *diamond-like carbon (DLC)* coatings can be applied to materials to protect them from wear and reduce friction by about 70%. A DLC-coated full-floating piston pin can be used without a pin bushing. The process, which leaves a very smooth hard surface that is only 3 microns thick, has been used in NHRA and NASCAR engines. Nissan has used cam followers coated with DLC to reduce friction in a production engine.

Retainers (lock rings) are required to prevent the pin from sliding out and damaging the cylinder wall.

There are inexpensive wire lock rings as well as the higher quality retaining rings. Lock rings with a round cross section are used with piston pins that are radiused on the ends to push the retainer into the groove. Snaprings, sometimes called truarc lock rings, have one square, flat side and one side that is slightly radiused (**Figure 13.63a**). Install these retainers with their flat ("sharp") sides out. Piston pins used with these lock rings are square on the ends.

During combustion, stress forces the piston down against the lock ring, so its opening should face the bottom of the piston (**Figure 13.63b**). This allows the full bearing area to be applied against the greatest area of stress. When lock rings come out of their grooves during service, the cause is usually excessive crankshaft end thrust, a tapered rod journal, or a misaligned connecting rod. If the piston pin is pressed into the rod, lock rings should *not* be used.

Another type of retaining ring made of a coil of flat wire is the spiral type, sometimes called Spirolox retaining rings (**Figure 13.64**). They are removed with a screwdriver, starting at the gap. They are installed by winding them into the groove while pressing against the ring until the entire ring is in the groove (**Figure 13.65**).

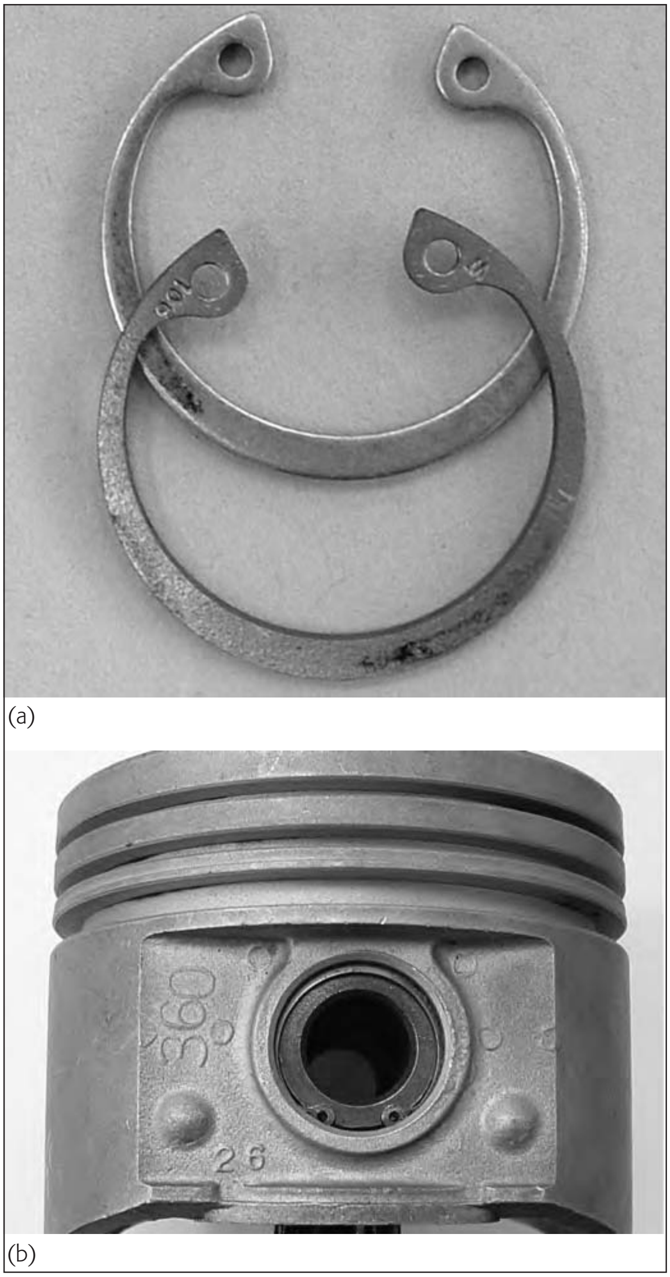


FIGURE 13.63 (a) One side of a snapring is round. (b) Lock rings are installed on full-floating pins with the open end facing down. *(Courtesy of Tim Gilles)*

SHOP TIP

For easier installation of the spiral lock ring, stretch it about ¾" first (**Figure 13.66**).

High horsepower engines like those used in funny cars and dragsters use aluminum inserts that ride between the ends of the piston pin and cylinder wall (**Figure 13.67**). This type of piston pin retention prevents a failure that could result from another

FIGURE 13.64 A spiral lock retaining ring. The tab is provided to allow removal with a screwdriver or dental pick. *(Courtesy of Tim Gilles)*

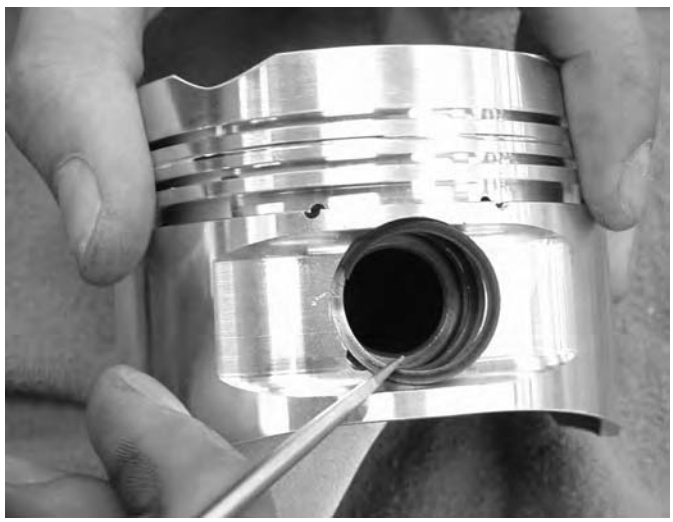


FIGURE 13.65 Installing a spiral lock pin retaining ring. *(Courtesy of Tim Gilles)*

FIGURE 13.66 Stretch a spiral lock ring to make it easier to install. *(Courtesy of Tim Gilles)*

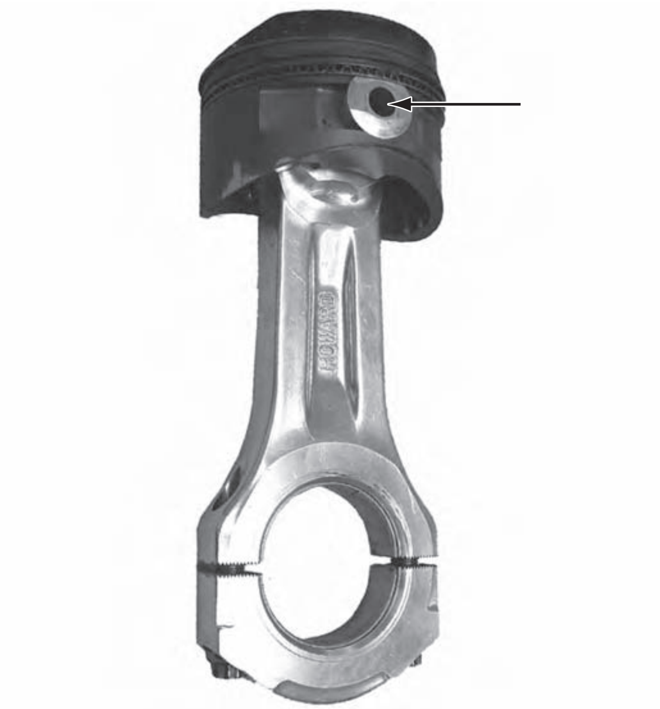


FIGURE 13.67 A piston-and-rod assembly from a top-fuel dragster uses an aluminum spacer at each end of the piston pin. *(Courtesy of Tim Gilles)*

type of retaining ring coming out under the tremendous loads experienced on the piston assemblies in a 6000-horsepower engine.

SHOP TIP

Full-floating pins often fit snugly in the piston when cold. To remove the piston pin easily, first heat the piston in hot water.

Direction of Piston on Connecting Rod

Be sure to keep track of the direction the connecting rod faces in relation to the top of the piston. Pistons have a notch on the side of the piston head that faces the front of the engine (**Figure 13.68**).

SHOP TIP

A good way to keep track of piston/connecting rod direction during piston replacement is to put the piston notch to the right and then mark the side of the rod cap that is facing up with a felt marker or electric engraver. This will make it easy to install the new pistons properly. On a V-type engine, half the numbers will be up and half will be down.

CONNECTING RODS

Connecting rods are usually made of forged or cast steel. Some racing rods are made of forged aluminum (see Figure 13.67). Forged rods are stronger than cast rods, but casting has been improved to the point that some late-model passenger car engines use cast rods because they cost less. Rods are generally made in an I-beam shape for strength.

The big end of each rod is precisely ground to achieve perfect oil clearance and crush on the rod bearings when the rod and bearing inserts are installed on the crank journal. Rod caps are not interchangeable. If they are interchanged, the oil clearances of the bearings can vary greatly and the crank might not even be able to turn.

SHOP TIP

On a V-type engine, if the rods and caps were not numbered during disassembly, try to match them up as closely as possible by looking to see if the chamfers on the edge of the bore line up.

- Rod bolts usually have slightly enlarged shanks to hold them tight in the rod (**Figure 13.69**). The cap has precise holes that line up with this enlarged area of the bolt to prevent misalignment of the rod and cap when they are assembled.
- The notches cut in the rod for the bearing locating lugs usually face each other when correctly installed (**Figure 13.70**). Incorrect installation of the rod cap can cause uneven bearing wear (**Figure 13.71**).

NOTE

Overtorque of rod bolts can cause them to fail during deceleration when the load is on the bolt instead of on the rod (**Figure 13.72**).

Sintered Powder-Forged Fractured Rods

Some newer connecting rods are powder forged. Iron powder, graphite, and copper are precast in molds that are close to what the final rod will look like. The mixture is heated to “sinter” the mixture together. Then they are forged in a forging press.

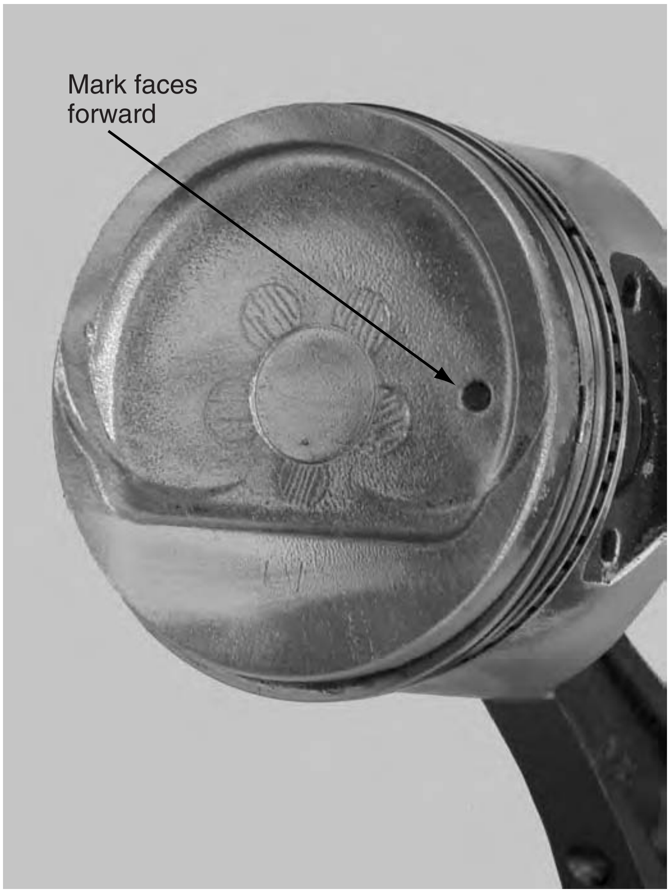


FIGURE 13.68 The piston has a mark that faces the front of the engine. *(Courtesy of Tim Gilles)*

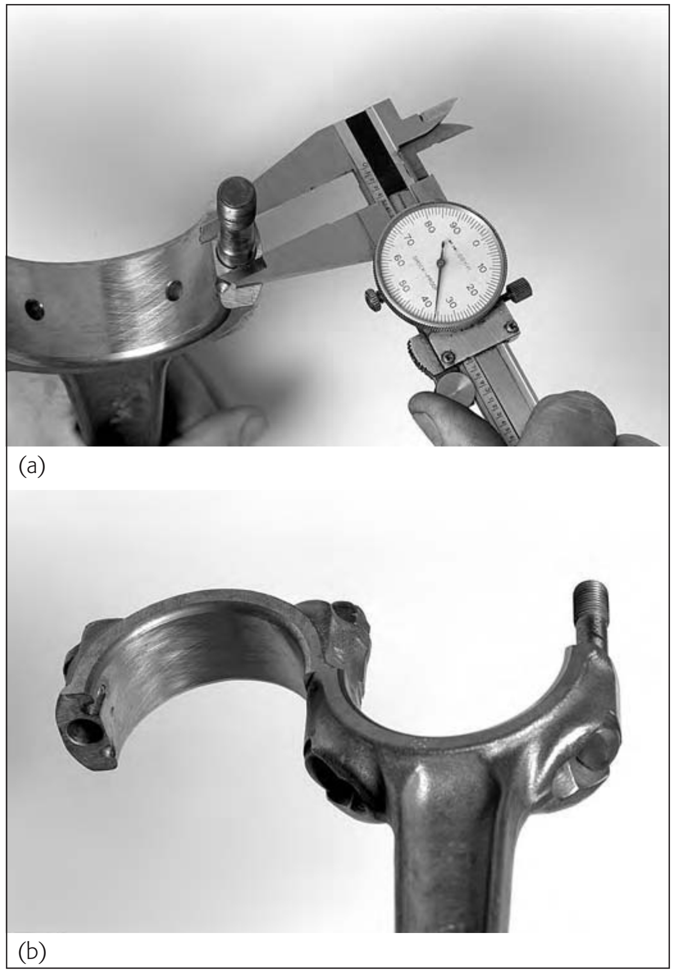


FIGURE 13.69 The shanks of rod bolts fit tightly in the rod cap for precise alignment of the machined halves. (a) The rod bolt usually has a larger area to align the rod cap. (b) The cap should fit snugly when pushed onto the alignment area of the rod bolt.

The rods are finished like other rods and there is less variation in weight between rods, which makes balancing them easier.

Unlike conventional rod forgings, sintered powder-forged rod caps are not sawed from the rods and machined. Two lines are scribed on the sides of the rod to create a stress raiser where the parting line will be. Then they are fractured at these lines by pulling them apart with a machine. The two halves of the rod fit each other as matched pairs (**Figure 13.73**). They do not move between each other so perfect bearing fit is maintained and a 400% increase in strength is claimed. Be careful not to drop a fractured rod; it will have to be replaced. Also, do not number the rods or rod caps with a number stamp. An engraver or a paint marker can be used instead.

If the connecting rod end of a sintered rod requires correction, it can be ground to fit a 0.002" oversized bearing set that is available for some of the more popular engines.

FIGURE 13.70 On most engines, bearing locating lugs face each other as shown. *(Courtesy of Tim Gilles)*

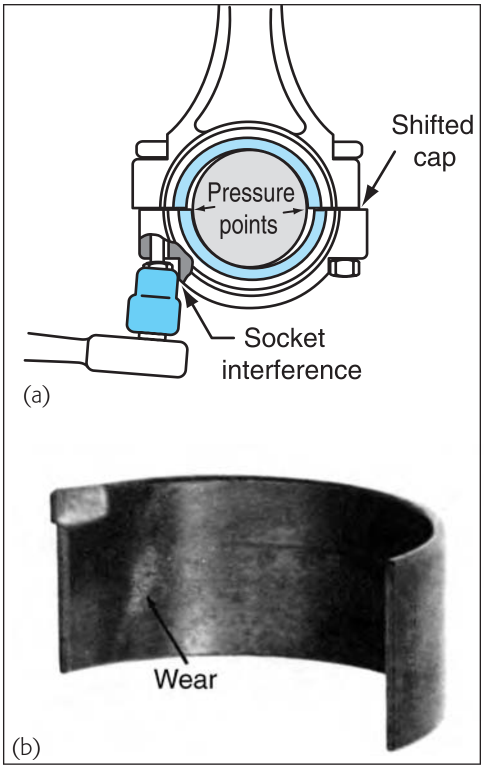


FIGURE 13.71 Bearing wear caused by the rod cap being installed backward, or by interference between the socket and rod cap during installation. (*Courtesy of Clevite 77 Engine Bearings, Clevite Engine Parts*)

Forged Racing Rods

High-performance steel connecting rods are typically forged from a premium material like 4340 steel. To ensure precise alignment, the cap is often doweled to the connecting rod. Higher strength premium rod bolts are used usually without nuts. These bolts use a higher torque specification and it is critical that the new torque setting be applied *prior* to machining to ensure that the rod bore remains round.

FIGURE 13.72 The rod bolt is the weak link in a connecting rod assembly. The load on the rod bolt occurs during deceleration when engine braking, especially at high rpm. *(Courtesy of Tim Gilles)*

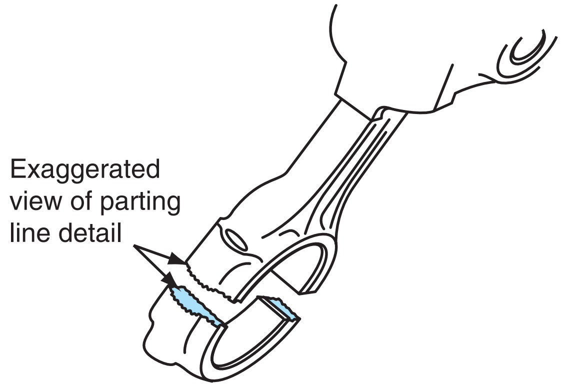


FIGURE 13.73 The rod cap is "fractured" from the rod on powder-forged rods.

The metal in the rod and cap are forged 90° to each other because it has been found that the rod cap is considerably stronger when its grain runs perpendicular to the connecting rod beam. **Figure 13.74a** shows a rough forged connecting rod prior to machining. **Figure 13.74b** shows forged connecting rods following all machining operations.

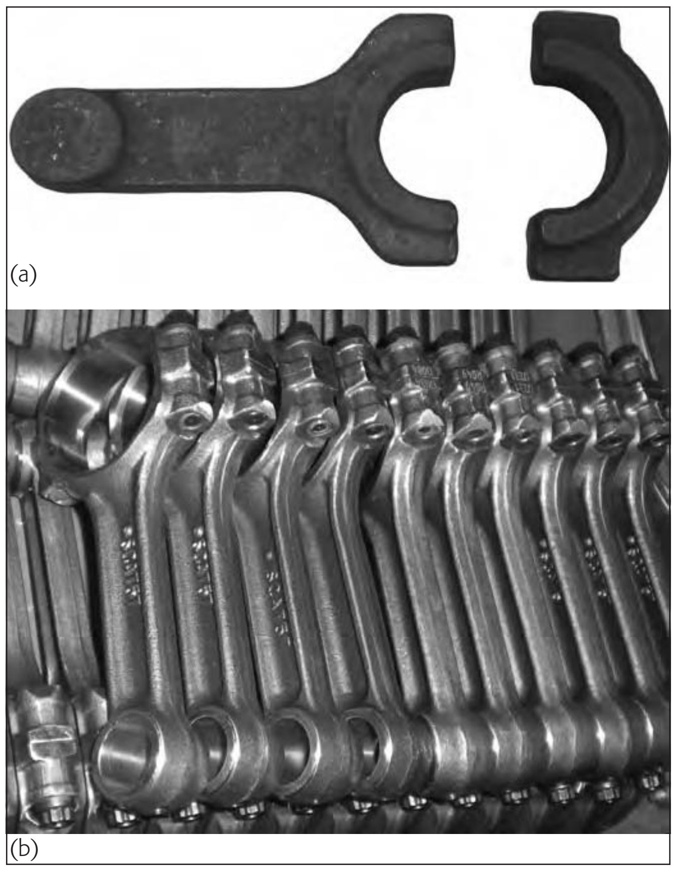


FIGURE 13.74 (a) A rough forged connecting rod prior to machining. (b) High-performance forged connecting rods after the completion of all machining operations, with new rod bushings and high-performance rod bolts. *(Courtesy of Tim Gilles)*

Rod Oil Holes

The connecting rods on some engines have a "spit" hole to provide cylinder wall lubrication at low engine speeds (**Figure 13.75**). This was found on most vintage engines and is common on four cylinder engines today. Some in-line engines have a hole drilled in the rod above the rod bolt, so that each rod can lubricate its own cylinder. Vintage engines often had a groove between the rod and cap (**Figure 13.76**).

FIGURE 13.75 Some connecting rods have an oil hole to pressure lubricate the cylinder walls at low rpm. *(Courtesy of Tim Gilles)*

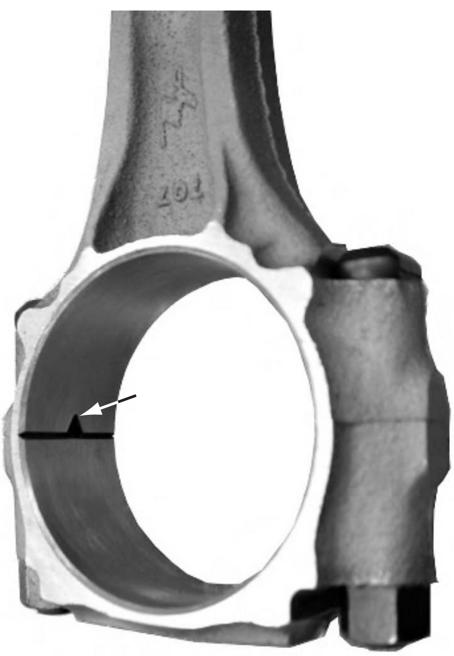


FIGURE 13.76 This notch allows pressurized oil routed around the rod bolt to be squirted on the cylinder walls. *(Courtesy of Tim Gilles)*

NOTE

Many late-model engines depend on increased rod side clearance to throw oil onto the cylinder walls at low speed and, therefore, do not have oil spit holes.

Preventing Piston Skirt Wear

Connecting rods on V-type engines throw oil onto the cylinder bank on the opposite side of the engine. A piston tends to exhibit more wear on its major thrust surface so oil thrown from the rod is directed toward this "working" surface. Squirt holes on V-engines point toward the cam but lubricate the cylinder walls on the opposite bank of cylinders (**Figure 13.77**).

The crankshaft on most engines turns to the left (counterclockwise or left-hand rotation) when viewed from the back side of the engine. From this vantage point, the major thrust surface is to the right. This is the opposite side from crankshaft rotation (**Figure 13.78**).

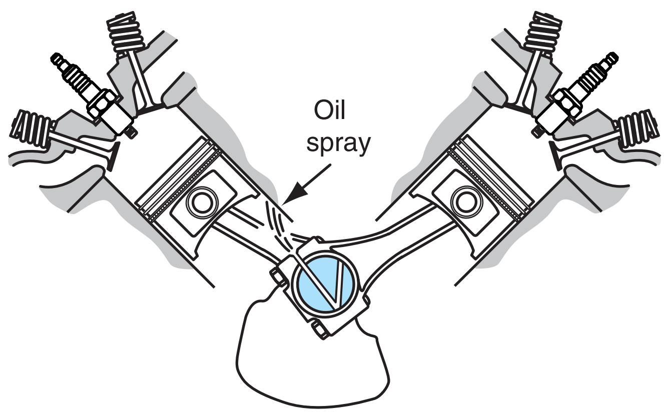


FIGURE 13.77 On V-type engines, oil thrown from the connecting rods lubricates the cylinders on the opposite bank.

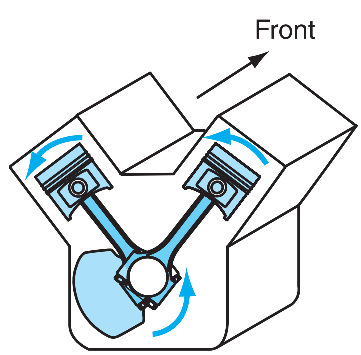


FIGURE 13.78 When viewed from the flywheel end, the major thrust surface is to the right.

NOTE

Remember Newton's third law: For every action there is an equal and opposite reaction. Have you ever noticed that the engine twists right when you step on the gas?

Offset Connecting Rods

V-type engines often have offset connecting rods when two rods share one crank journal (**Figure 13.79**). Do *not* install these rods backward. Rod bearings are usually off-center in the rod bore toward the middle of the crank journal, so that the edges of the bearings will not rub on the fillets on the sides of the journal (**Figure 13.80**). The fillet is the radiused (curved) area where the ends of the machined journal area meet the unmachined area. The rod bores usually have chamfers on their outside edges to correspond to the fillet on the rod journal. Additionally, the bearing has clearance on both sides of the rod (**Figure 13.81**).

Rod Service

Inspect connecting rods for obvious cracks, bends, or heat damage. Nicks or burrs that can cause stress raisers should be ground or polished. Rods from large or high-performance engines are routinely magnafluxed to check for cracks. Cracks usually occur on the "flashing" area of the rod beam, near the bolt holes, or where the beam joins the big or small ends of the rod.

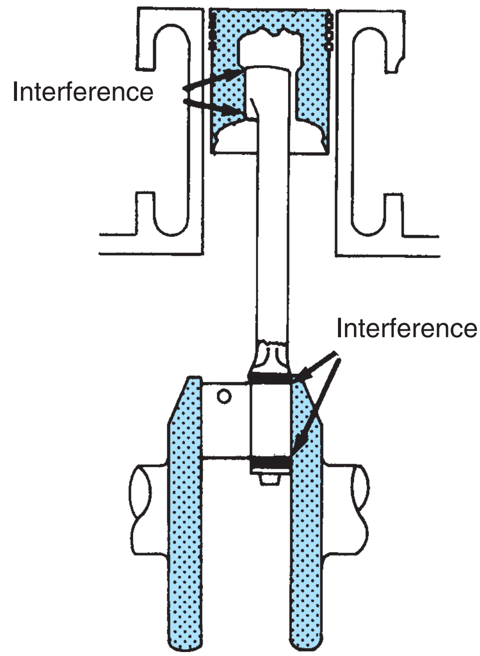


FIGURE 13.80 Installing an offset rod backward can cause interference at the side of the rod journal and the inside of the piston bore.

FIGURE 13.79 Some V-type engines have offset connecting rods. (*Courtesy of Tim Gilles*)

FIGURE 13.81 The bearing insert is narrower than the bearing bore. *(Courtesy of Tim Gilles)*

Residual Magnetism. Engine parts that have been magnafluxed, or a connecting rod that has had a spun bearing, should be checked for magnetism. Engine parts that have become magnetized must be demagnetized or they will attract metal particles that would otherwise be filtered out of the oil.

Alignment. Check the rod for alignment. Closely examine all pistons for unusual wear patterns that can indicate a twisted rod (**Figure 13.82**). A bent rod may show wear on opposite sides of the rod bearings (**Figure 13.83**), with more wear on the top bearing half (**Figure 13.84**). A bent rod can cause the piston pin to be pushed back and forth in the piston. On a piston with a full-floating pin, this can knock a lock ring out.

NOTE

If an engine has operated for 100,000 miles without an unusual wear problem, the rod can be reused with new bearing inserts.

Check rods suspected of being bent or twisted on a rod aligning fixture (**Figure 13.85**).

FIGURE 13.82 A twisted connecting rod caused this wear pattern on the piston skirt. *(Courtesy of Tim Gilles)*

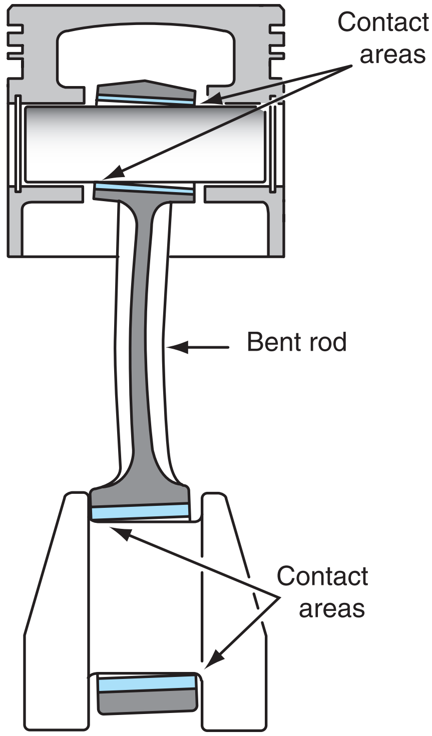


FIGURE 13.83 Wear caused by a bent or twisted connecting rod.

NOTE

Metal can be compressed, but it cannot be stretched. If you elongate a piece of metal, it is cracking rather than stretching. When a connecting rod is bent, its outer layer cracks, stretching its molecules apart. But if you bend it back to its original shape the molecules cannot be returned to their original places.

FIGURE 13.84 Bearing wear from a bent rod will show up more on the top bearing half. *(Courtesy of Tim Gilles)*

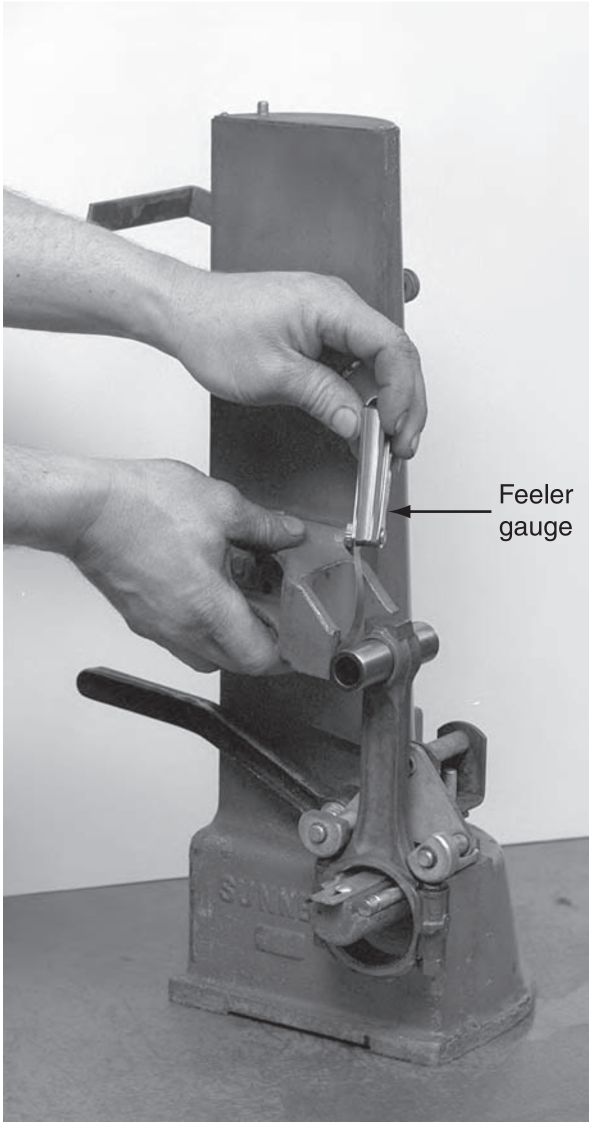


FIGURE 13.85 Checking connecting rod alignment.

Resizing Rods—Big End. Sometimes a big end of a rod must be resized. Resizing is necessary when the rod bearing has "spun" or the big end has "stretched." Rod stretch causes the rod to draw closer together at the parting line. Bearing wear is sometimes apparent at the ends of the inserts (**Figure 13.86**). Rods are measured for roundness with a special gauge (**Figure 13.87**). The gauge measures in tenths of thousandths. Usually, rods can be up to 0.001" out of round before resizing is necessary.

Adjust the rod gauge to measure absolute center. Then use a micrometer to zero the gauge to the proper rod size.

- When the big end of the rod is resized, both the rod and cap have a small amount of metal (usually less than 0.002") removed on a rod and cap grinder (**Figure 13.88**). Alignment between the rod cap and the upper half of the rod is crucial. The two halves are held in a special fixture while they are torqued together to be certain they are correctly aligned (**Figure 13.89**).
- After reinstalling the cap on the rod, the now smaller rod bore is honed out with a rod hone (**Figure 13.90**) until the original diameter of the rod bore is reached.

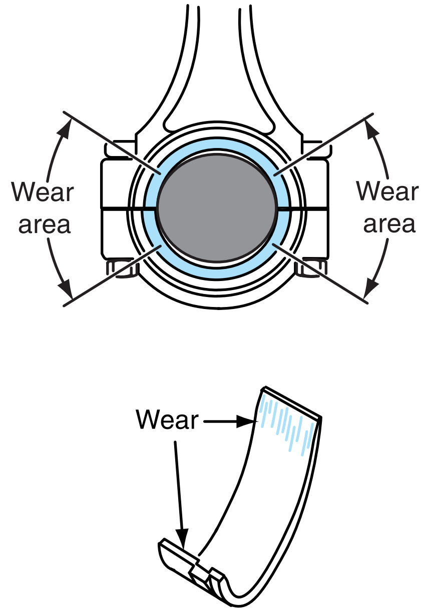


FIGURE 13.86 Rod stretch causes bearing wear at the parting line.

FIGURE 13.87 A precision gauge for measuring connecting rods for roundness. (*Courtesy of Tim Gilles*)

FIGURE 13.88 The parting surfaces of the rod and cap are ground on a special grinder. (*Courtesy of Sunnen Products Company*)

FIGURE 13.90 Honing connecting rods to size. (*Courtesy of Sunnen Products Company*)

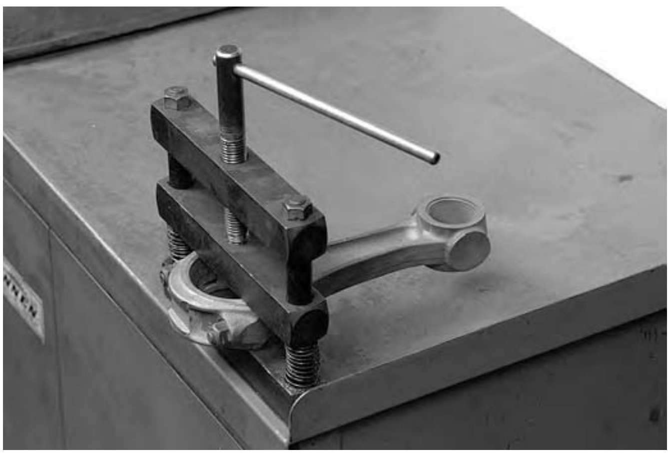


FIGURE 13.89 The connecting rod is held loosely in the aligning fixture while the nuts are torqued to specification.

Figure 13.91 This honing machine has a power stroking feature to ensure correct rod alignment. *(Courtesy of Tim Gilles)*

- Narrower rods are often honed in pairs to minimize the possibility of causing a taper in the rod bore.
- Some machines have a power stroking feature that eliminates the possibility of honing misalignment (**Figure 13.91**)

SHOP TIP

When resizing the big end of a connecting rod it becomes warmer as it is ground, resulting in a bore that measures approximately 0.0003–0.0004" smaller than the specified diameter after it cools. Experienced machinists grind rods oversized by 0.0003–0.0004" to compensate for this. Some mass production rod rebuilders have a refrigeration system to keep hone oil at about 70°F (21°C).

NOTES

- Before a connecting rod can be ground, its pressed-fit rod bolts are pressed or pounded out. Do not remove rod bolts again after resizing because the roundness of the rod bore will be affected when the bolts are reinstalled.
- After grinding the parting faces of a connecting rod, chamfer the edges of the bolt holes on the parting faces to prevent a burr from being driven out during rod bolt installation.

VINTAGE ENGINES

In the past, misaligned connecting rods were commonly corrected by bending. Metal seems to have "memory," which accounts for why aligning things that are bent is not always successful over the long haul. For instance, when a connecting rod is bent, the molecules in the metal get stretched. When it is bent back into its original position, however, the molecules do not bunch back together in the same place again.

SHOP TIP

When resizing a connecting rod, following this procedure will provide extra clearance at the parting lines of the rod and cap. Position a shim between the connecting rod and rod cap and torque the rod bolts. Then hone the connecting rod until the bore is round and oversized by the thickness of the shims. Finally, remove the shims, retorque the rod and cap, and measure the bore to verify the size.

Rod Small End Bushing Repair. When the connecting rod small end on a full-floating type is repaired, a bronze bushing is pressed into place and then expanded (rolled in) (**Figure 13.92**). The bushing is faced off flush with the rod, and the bore is then honed to the proper size. Only non-steel backed bushings can be rolled in; steel-backed bushings cannot. If the eye of the rod is smooth, rolling in will not be necessary

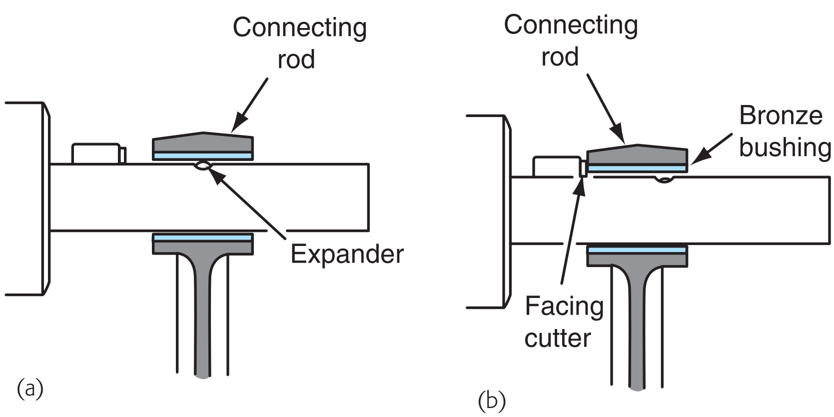


FIGURE 13.92 (a) The rod bushing is expanded to seat it into the rough bore. (b) Excess metal from the bushing is then trimmed with the facing cutter.

KEY TERMS

cam ground
full-floating pin
hypereutectic
piston compression height

STUDY QUESTIONS

1. Where is the largest diameter of the piston found?
2. Which is larger: the diameter of the head or crown of the piston or the diameter of the skirt?

3. Which ring groove wears the most?
4. Why is there a hole or slot in the oil ring groove?
5. What is the name of the style of piston skirt that is cut away on the sides to allow clearance for the crankshaft counterweights?
6. What is the name of a piston that has a full skirt all the way around its bottom?
7. Does a 0.030" oversized piston weigh the same as the original standard piston?
8. Why is the piston pin bore offset from the piston centerline?
9. How is a top ring groove checked for excessive wear?
10. What is the name of the piston pin retaining method where the piston pin has a bushing in the connecting rod and lock rings at the ends of the piston bore?
11. What is the most common method of retaining the piston pin?
12. What tool is used to check piston ring end gap clearance?
13. How much can the cylinder bore be out of round when using moly or chrome piston rings?
14. Which type of cylinder arrangement sometimes uses offset connecting rods?
15. Piston balance is more important with in-line engines than with V-type engines.
    a. True
    b. False

ASE-Style Review Questions

1. Technician A says that cast pistons run cooler than forged pistons. Technician B says that cast pistons are stronger than forged pistons. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

2. Technician A says that installing a compression ring upside down can cause oil consumption. Technician B says that the top compression ring groove usually suffers more wear than the other ring grooves. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

3. Technician A says that some piston rings have chamfers or reliefs cut into them to cause them to twist. Technician B says that chrome rings should not be used in out-of-round cylinders. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

4. Which of the following statements is/are true when installing full-floating piston pin lock rings?
    a. They should be installed with their openings facing up.
    b. They should be installed with the rounded side facing outward.
    c. Both A and B
    d. Neither A nor B

5. Technician A says that the full skirt piston used on long stroke engines is called a “slipper” skirt. Technician B says that a piston skirt that is cut away on its sides to clear the crankshaft counterweights is called a “trunk” skirt. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

6. Technician A says that all piston pins are offset from the centerline of the piston. Technician B says that most piston pins are pressed-fit in the connecting rod. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that conventional piston rings wear the bore more than low-tension rings. Technician B says low-tension rings must have less cylinder bore taper than conventional rings. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says the piston skirts are cam ground so piston to cylinder wall clearance is maintained as the piston expands with increasing engine temperature. Technician B says that piston skirts have slipper skirts to control expansion. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that most V6s use offset connecting rods. Technician B says that rods that have been resized must use oversized rod bearings. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Two technicians are discussing pressed-fit piston pins. Technician A says that a pin press is used to remove piston pins. Technician B says that a rod furnace is used to remove piston pins. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 14

Lubrication

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Analyze wear and damage to lubrication system parts.
- Explain lubrication system theory.
- Select and perform the most appropriate repairs to the lubrication system.

Introduction

The lubrication system is a very important support system in an engine. Failure in the system will result in severe engine damage. A vehicle owner should be reminded that periodic maintenance of the lubrication system is vital to the dependable, long-term operation of a rebuilt engine.

The lubrication system is perhaps the least understood area of engine repair. Too often, when engines are repaired, important aspects of this system are neglected. This neglect can result in a very expensive failure.

In a typical lubrication system (**Figure 14.1**), oil is drawn in through the pump screen and then forced by the pump through an oil filter to the engine's *main oil gallery*. Oil from the main gallery provides lubrication to the camshaft and cam bearings. In a typical pushrod engine with stud mounted rocker arms, oil is also pumped to the hydraulic lifters. From the lifters, the oil moves through hollow pushrods to the rocker arms and valve guides.

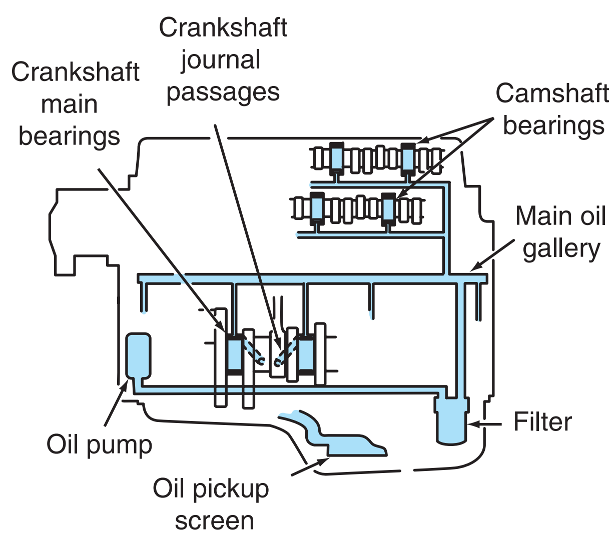


FIGURE 14.1 A typical lubrication system.

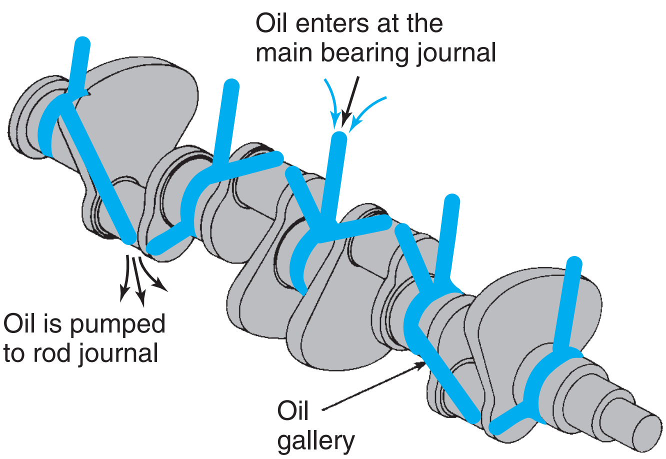


FIGURE 14.2 Oil flow through a crankshaft.

Cylinder head oiling in OHC engines is through a passage in the block, through the head gasket to an oil gallery in the head. Some OHC engines have shaft-mounted rocker arms that are oiled in a similar manner.

The crankshaft receives oil at its main bearings. The oil is pumped through drilled oil galleries from the main journals to the rod journals (**Figure 14.2**). The cylinder wall and piston are lubricated by oil thrown or sprayed from the rod journals. The timing chain, the distributor, and the oil pump drive gear are all splash lubricated.

Adequate lubrication in an engine is achieved only by the distribution of clean oil under pressure. *Oil pressure* can only be created when there is *resistance to the flow* of oil from the oil pump; bearing clearances are the primary resistance to flow in an engine. Proper clearances must be maintained or oil will not reach all areas of the engine when the engine is idling and the pump is turning slowly. Excessive oil *clearance* near the oil pump—at a main bearing, for instance—will result in insufficient oil pressure at the rocker arms or valve lifters, which are farther away from the pump. Noisy hydraulic lifters can be an indication of an oil pressure problem.

NOTE

In an oiling system, the more leaks there are along the way, the less volume and pressure that remain at the end of the line. Compare this to a soaker hose commonly used in the garden. Although it may spray a distance of 10 feet near the faucet, it might spray only a foot at the far end. When new, an ideal oiling system will be capable of supplying an equal volume of pressurized oil at each end.

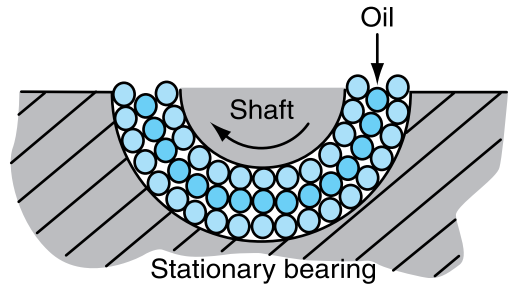


FIGURE 14.3 An oil film separates parts.

OIL

Oil is used primarily to reduce friction, which varies with the roughness of the surfaces and the force exerted on the oil film. In theory, all moving parts are separated by a thin layer of oil (**Figure 14.3**). If oil is properly maintained and a minimal amount of dirt accumulates in it, then very little wear should occur. Under normal conditions, a breakdown in lubrication occurs only when the engine is first started in the morning. The crankshaft rubs on the bearing until a wedge of oil is reestablished when pressurized oil reaches the bearing (**Figure 14.4**). A few seconds can pass before the engine's oil pump can distribute oil to the entire engine. This condition is known as **dry start**, when parts can rub and wear results.

NOTE

The amount of wear that occurs during the short amount of time at initial engine startup is equivalent to that caused by hundreds of miles of freeway driving. Today, vehicle

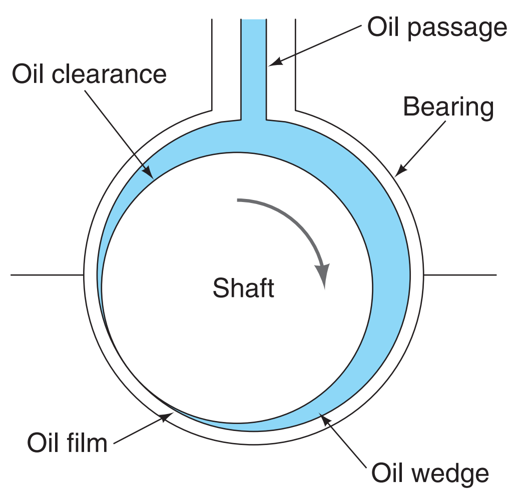


FIGURE 14.4 A wedge of oil lifts the shaft off the bearing.

VINTAGE ENGINES

The first oil additives were developed in the 1930s to deal with residual wax in the oil. More additives were developed during World War II. Over the years, this additive package has been improved. The result is that engines last longer and longer.

manufacturers require the use of thinner oils, which reach engine components more quickly after startup.

ENGINE OIL

Engine oil is more than just basic crude; it contains a complicated additive package. Oil not only provides lubrication: It cools, cleans, and prevents rust from forming inside the engine. It also fills hydraulic lifters and helps seal the piston rings against the walls of the cylinder.

Crude oil contains wax, most of which is removed during the refining process.

Oil Level

The correct oil level keeps the oil pickup screen submerged in oil under all operating conditions. If the oil level is allowed to drop too low, serious engine damage can result. The crankshaft bearings can be damaged or the piston can become *scuffed*. **Figure 14.5** shows what can happen when an engine is run for an extended time while low on oil.

If the oil level in the crankcase is *too high*, the spinning crankshaft can dip into the oil, throwing it onto the cylinder walls in such quantity that the oil rings are overwhelmed. This can result in excessive exhaust smoke. In addition, as the crankshaft hits the oil, it churns it up, mixing it with air. Aerated oil does not provide sufficient oil pressure and can result in collapsed hydraulic lifters or even a broken crankshaft.

When checking engine oil level, the vehicle should be on a level surface. The engine should be warm and should have been off for at least 5 minutes, allowing oil throughout the engine to drain back to the oil pan. The dipstick must be pushed all of the way down against its seat. If the oil level reading on the dipstick is unclear, try looking at the backside of the dipstick, or dip it again and attempt to read it one more time. If the oil level is low, check to see if the vehicle is due for service before adding a quart of new oil.

Oil Viscosity

Viscosity, a measurement of a liquid's resistance to flow, is a term used to describe the thickness or body of engine oil. The Society of Automotive Engineers (**SAE**) designates engine oil viscosity ratings. The container for oil with a viscosity rating of 30 will be imprinted with "SAE 30." Viscosity is measured at 212°F (100°C) and has a higher number rating if the oil is thicker. For instance, SAE 30 oil is thicker than SAE 10 oil. Oil with a higher viscosity number is stickier and more resistant to flow.

When a "W" accompanies the rating, as in SAE 20W, it means that the oil's viscosity has been tested at 0°F (–18°C); also, this oil is called a *winter-grade* oil.

FIGURE 14.5 These pieces of engine parts were found in the oil pan of an engine that ran low on oil on a highway trip and blew up. (*Courtesy of Tim Gilles*)

VINTAGE ENGINES

The SAE oil viscosity classification was adopted by the petroleum industry in 1911.

NOTE

Viscosity is determined using a device called a viscometer that compares the time required for a measured amount of reference fluid to pass through a calibrated opening at a specified temperature. Different methods are used for measuring engine oil viscosity; in Europe the Engler method is used and in North America a Saybolt viscometer is used.

Multiple Viscosity Oils

Some oils have only one viscosity rating, but most new engine oils are multiple viscosity, often called *multi-vis*. The following is an interpretation of the rating of typical SAE 10W-30 multi-vis oil:

SAE = Society of Automotive Engineers

10W = The viscosity of the oil when measured at 0°F (–18°C) (the "W" means winter grade)

30 = The viscosity of the oil when measured at 212°F (100°C)

SAE 10W-30 has a base rating of 10 when cold. It will flow freely at temperatures as low as –20°F (–29°C).

Oil normally thins when heated. As it becomes thinner, its viscosity number becomes lower. An additive package containing **polymers** is blended into the oil. Polymers expand when heated to allow the viscosity of cold oil to be more closely maintained as it warms. This ability of oil to resist change in viscosity with rising temperature is called its **viscosity index**. A viscosity index improver can deteriorate enough in use to cause multi-vis oil like 10W-40 to become 10W-30.

Multi-vis oil helps combat engine wear because it flows more quickly to the bearings when the engine is first started. This is an especially important feature during cold weather. The oil pickup has a screen with a relief opening that can allow oil that is too thick or dirty to pass through to the oil pump and engine parts. The theory is that thick or dirty oil is better than no oil at all. Thick oil can also bypass the oil filter. Information about the pump screen and oil filter is covered later in the chapter. **Figure 14.6** shows how oils of different viscosity ratings flow. With some

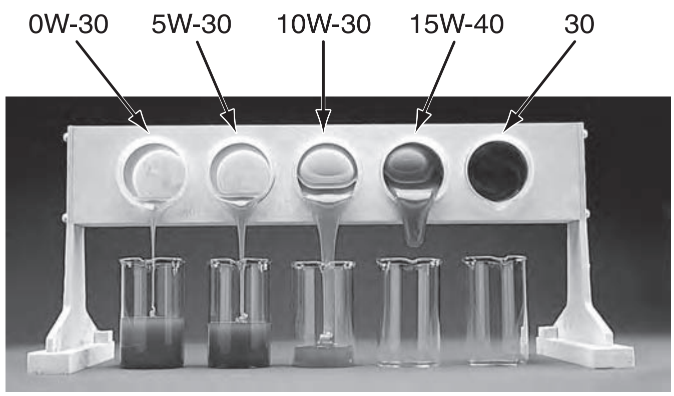


FIGURE 14.6 These oils were chilled to –31°F (–35°C) for 16 hours. The photo was taken 30 seconds after the caps were removed from the containers. (*Courtesy of Imperial Oil Limited*)

VINTAGE ENGINES

In the past, some manufacturers' recommendations included SAE 30 in temperate climates (above 40°F [4°C]) because it flows acceptably at that temperature. Due to advances in lubrication technology, this is no longer the case.

FIGURE 14.7 The oil filler cap often has the manufacturer's recommendation for oil selection. (*Courtesy of Tim Gilles*)

overhead cam engines, using oil with a viscosity higher than 5W-20 can result in failure of the cam and cam followers or problems with variable valve timing.

NOTE

Always follow the manufacturer's recommendations for oil selection (**Figure 14.7**).

Oil viscosity is also critical on diesel engines with electronically controlled hydraulic fuel injection. The oil needs to flow at the correct rate if it is to operate the injector as designed.

Oil Pressure

Pressure cannot develop unless there is a resistance to flow. As an engine wears, clearance between the crankshaft and bearings increases. At low engine rpm, the oil pump can no longer pump sufficient oil to fill this extra clearance. The result is that oil pressure is low whenever the engine rpm drops to idle speed. As the engine is accelerated, the oil pump (which is driven by the camshaft or the crankshaft) turns faster, so oil pressure will rise back to normal. Because multi-vis SAE 20W-50 oil is thicker both when hot and cold, it can provide higher oil pressure to an older, idling engine with increased bearing oil clearance. However, this same oil will flow more slowly (than an SAE 10W-40) to the bearings of a new engine when the engine is first started in the morning.

ENGINE OIL LICENSING AND CERTIFICATION

The SAE decides when new oil specifications are needed. The American Society for Testing and Materials (ASTM) sets the performance specifications according to the SAE's needs. The American Petroleum Institute (**API**) administers the licensing and certification of the oils. Prior to 1992, these three organizations were the only ones responsible for the specifications and classifications of engine oils. In 1992, the *International Lubricant Standardization and Approval Committee (ILSAC)* was formed to provide manufacturers minimum lubrication performance standards for gasoline-fueled (GF) passenger car and light truck engine oils. ILSAC includes the American Automobile Manufacturers Association (AAMA), the Japanese Automobile Standards Organization (JASO), and the Engine Manufacturers Association. Today, these six organizations comprise the Engine Oil Licensing and Certification System (EOLCS), which is administered by the API.

Starburst Symbol

The API licenses engine oil marketers to display its starburst certification mark (**Figure 14.8**) on their containers provided they meet ILSAC GF-4 requirements. Since 2005, no oils can display the starburst symbol unless they meet GF-4 standards. GF indicates "gasoline fuel." GF-4 became the ILSAC gasoline-fueled engine oil standard in 2004 with GF-5 slated as the factory fill for 2010 vehicles. The starburst signifies that the oil meets the requirements necessary for it to be recommended by vehicle manufacturers. Many manufacturers recommend only

FIGURE 14.8 The starburst symbol is displayed on oils meeting ILSAC GF-4 requirements.

oils displaying the starburst symbol. The manufacturers are particularly concerned that oils not damage catalytic converters, which now carry a warranty of 150,000 miles. Phosphorus, an effective longtime antiwear additive, is implicated in shortening catalytic converter life, so it has been replaced with other additives. This is discussed later in the chapter.

Oil Service Ratings

The API sets the service ratings of oil, which progress from SA through SM. Straight mineral oil, with no additives, is classified "SA." SA and SB graded oils are only for very light-duty applications and although they are sometimes found on market shelves, are obsolete for automotive engines. Using SA or SB oil by mistake can ruin an engine. Customers should be advised against their use. SM oil has many high-quality additives and will work well in any engine, except cam-in-block engines with flat tappets.

Gasoline and diesel engines have different rating systems:

- The "S" means the oil is for engines with spark ignition.
- Diesel engine oils are rated from CA through CI. The "C" means commercial or that the oil is rated for engines with compression ignition. The latest diesel engine rating is CI-4 PLUS.

The API has a service symbol "donut" made up of three sections (**Figure 14.9**). The top half lists the API performance, SM or CI, for instance. The center of the donut lists the SAE oil viscosity. The bottom half identifies if the oil is energy conserving when compared to reference oil.

FIGURE 14.9 The viscosity and API rating of the oil are printed on the oil container using this standard industry symbol.

European ACEA Oils

The ACEA engine oil standards were developed by European auto manufacturers. ACEA stands for European Automobile Manufacturers Association (when translated from French to English). The test sequence has 11 laboratory categories and 9 engine categories. Some of the categories exceed the standards of ILSAC oils, but many of the standards are the same as the ASTM tests for American oils. Very few oils sold in the United States list ACEA on the label and it is considered safe to use ILSAC GF-4 oil with the starburst label in the engines of most European cars sold in North America. Still, always be sure to check the manufacturer's recommendation carefully.

Energy-Efficient Oils

The ASTM certifies oil as *energy conserving* (*EC*) if it passes certain tests. Energy conservation ratings began in 1994 and are restricted to multigrade oils with a hot viscosity of less than SAE 30, such as SAE 5W-30 or SAE 10W-30. These oils can provide a 1% to 4% improvement in miles per gallon over regular oil. Although improvements of this smaller amount would be practically impossible for a car owner to observe, these oils help the manufacturers meet government fuel economy standards. An energy conserving oil that states "ECII" on its label will have better than a 2.7% fuel economy increase over regular oil.

OIL ADDITIVES

Oils (other than SA) contain an additive package that can make up as much as one-third of the volume of an oil container. Important parts of the additive package include:

- *Pour-point depressants* that allow the oil to flow in very cold weather
- *Corrosion and rust inhibitors* that help the oil to stick to metal surfaces
- *Antifoam additives* that help dissipate bubbles that form as oil is moved around the engine
- *Friction modifiers* that reduce the friction between moving parts, resulting in less heat, reduced wear, and improved fuel economy
- *Oxidation inhibitors* that prevent oil from thickening
- *Antiwear additives* that combine chemically with engine metals during periods of high load

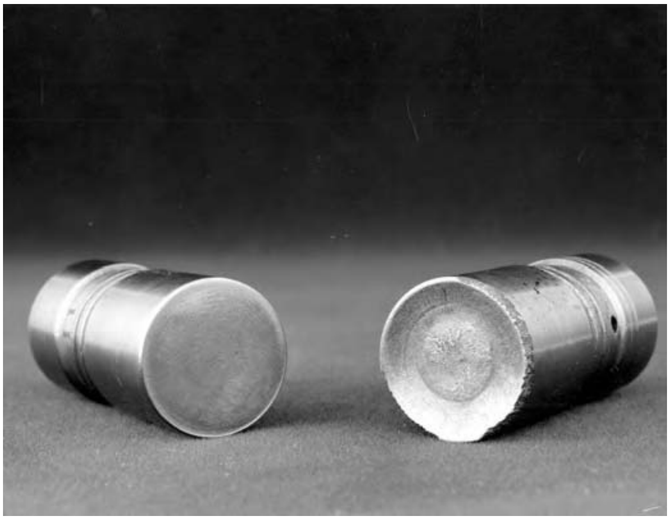


FIGURE 14.10 Antiwear additives protect the cam and lifters in a pushrod engine from wear. The lifter on the right is severely worn because it was used with an SA oil. (*Courtesy of Texaco Research and Development*)

Change in ZDDP Content			
		Zinc	**Phosphorus**
SH	1996	0.130	0.120
SJ	2001	0.110	0.100
SM	2005	0.087	0.080
Shell Rotella	2006	0.140	0.130
Pennzoil Racing	2006	0.196	0.180
Quaker State Racing	2006	0.200	0.180
Chevron Delo	2008	0.127	0.114

FIGURE 14.11 A chart listing some of the zinc and phosphorus amounts in oils of different ratings and brands.

When the oil film becomes too thin or starts to break down under load, this is known as **boundary lubrication**. During boundary lubrication, antiwear additives combine chemically with engine metals to provide a lubricating layer to protect wear surfaces such as piston rings and cylinder walls, rocker arms and valve tips, and the cam and lifters, especially in flat tappet pushrod engines (**Figure 14.10**). During the power stroke, once the usable power of combustion has been transmitted to the connecting rod journal, exhaust lobes in high-compression engines must force exhaust valves open while combustion pressure is close to 1200 psi. Antiwear additives also protect lower main bearings and upper rod bearings against combustion loads.

NOTE

The reduced amount of antiwear additive in the latest oils can result in an increase in camshaft and lifter wear in older engines that do not have roller lifters. These engines should use racing oil or truck oil that has more zinc dialkyldithiophosphate (ZDDP).

In addition to its function as an antioxidant, ZDDP has been commonly used as an antiwear additive. In the additive package, phosphates make up about 75% of the zinc amount. Both zinc and phosphates have been reduced by about one-third in recent years due to their negative effect on catalytic converter life. Manufacturers feel that ZDDP in the amount of earlier concentrations is no longer necessary due to the use of lower friction roller valvetrain parts in newer engines. Racing engines with flat tappets, like NASCAR, use specially formulated racing oils with more ZDDP and moly and less detergent, because detergent picks up some of the zinc. **Figure 14.11** is a chart listing some of the zinc and phosphorus amounts in oils of different ratings and brands.

NOTE

According to Chevron Research, engine blowby is the major cause of camshaft wear. Nitric acid is created when NO_x and water in the blowby gases react. The nitric acid reacts chemically with antiwear additives in the oil to reduce their protective film. The acid also corrodes cast iron, releasing iron carbide particles that abrade (wear) the unprotected cam and lifters.

Detergents

Detergents keep small particle contaminants suspended in the oil. If the particles are large enough, they will be trapped by the oil filter. But if they are too small, they will not be removed from the engine until the oil is replaced.

As oil decomposes at high engine temperatures, a chemical reaction between oil and oxygen can result in a gummy varnish mixture that can stick piston rings and plug oil passages. Detergents make these deposits oil soluble so that they can be suspended in the oil and trapped by the filter.

NOTE

Detergents in oils are similar to those found in household cleaning products. The difference is that they are oil soluble rather than water soluble.

Sludge. *Sludge* is a mixture of moisture, oil, and contaminants from combustion. It can clog the oil screen and oil lines if allowed to accumulate. Moisture is a product of combustion and it can also accumulate from condensation. When an engine gets warm enough, the positive crankcase ventilation (PCV) system removes the water vapors. Short trips allow the accumulation of sludge. Accumulated fuel and moisture do not get a chance to evaporate in an engine that never fully warms up. The oil level on the dipstick can be artificially high due to high water or gasoline content.

NOTE

It takes 10 to 15 minutes for the cylinder walls to warm to the point where evaporation begins to take place.

Dispersants

The dispersant additive causes the oil to become discolored because it keeps sludge-forming particles in suspension in the oil. An excessively rich air-fuel mixture can cause soot contamination, which turns oil black.

Oxidation Inhibitors

Oil oxidizes at temperatures in excess of 250°F (121°C), becoming thicker and forming varnish deposits. The oxidation rate of oil actually doubles with every 20°F (–7°C) rise in temperature above 140°F (60°C) until about 800°F (427°C), when carbon forms. *Antioxidants* combat the effects of heat on the oil. If the oxidation inhibitor becomes depleted, the oil becomes thicker.

Excessive oil temperatures can be caused by:

- Lean air-fuel mixtures
- Retarded ignition timing
- Using the air conditioner
- An automatic transmission-equipped vehicle pulling a trailer

In high-performance engines, temperatures in excess of 500°F (260°C) in the piston ring area are not uncommon. When possible, oil temperature should be kept below 220°F (104°C). The cooling system temperature required for water to vaporize out of the oil is 185°F–195°F (85°C–91°C). The ideal cooling system temperature for oil is, therefore, about 195°F (91°C).

NOTE

Oil temperature is usually 10°F to 25°F (–12°C to –4°C) hotter than coolant temperature. Fuel and moisture are effectively removed at oil temperatures of between 215°F and 220°F (102°C and 104°C).

VINTAGE ENGINES

In the late 1960s there were several cases where crankcase oils thickened until they solidified. These oils were used in vehicles that had high compression and high output. Changes in the radiator grille design of these vehicles caused under-hood temperatures to become extremely high. This resulted in a change in API oil service ratings, calling for much more of an oxidation inhibitor, the chemical ZDDP. The API rating change went hand in hand with the development of high compression engines and higher exhaust cam lobe loading with flat tappet camshafts.

VINTAGE ENGINES

Until the mid-1970s lead was used in some gasolines as an octane booster. It turned to light gray salts during combustion. This appeared as a gray deposit in the oil pan.

Oil without additives (SA oil) is referred to as nondetergent oil. Some mechanics used to suggest using nondetergent oil until the first oil change. The use of lower quality oil was recommended in the late 1950s to help the older style, plated piston rings to seat. Today's piston rings are lapped and do not require this. Another reason was that detergent additives compete with zinc, so non-detergent oil was used with supplemental zinc, like GM's Engine Oil Supplement (EOS). Today, the recommendation is to use the warranty-approved product for the entire life of the engine. Most service technicians use SM oil exclusively for everything but flat tappet engines, which need extra zinc and should use SL oil to protect the camshaft and lifters. If the engine has a roller cam, more zinc is not necessary.

"Will detergent oil in a vintage engine that has previously used nondetergent oil cause the loosening of many large, built-up deposits?" This idea has been proved to be mostly false. However, if a vintage engine is very dirty, change the oil at 1000-mile intervals for the next two oil changes after switching to detergent oil.

Some engines in recreational vehicles, trucks, and high-performance automobiles are factory equipped with an auxiliary oil cooler, beneath the oil filter (**Figure 14.12**), connected by a hose to engine coolant. Oil coolers are also available in the aftermarket. Some are mounted in front of the radiator and cooled by air.

NOTE

Oil coolers are full flow; they do not bypass. If an engine has had bearing, camshaft, or oil pump failure, the oil cooler must be replaced because it cannot be successfully flushed. Failure to replace it can lead to a repeat failure of the rebuilt engine.

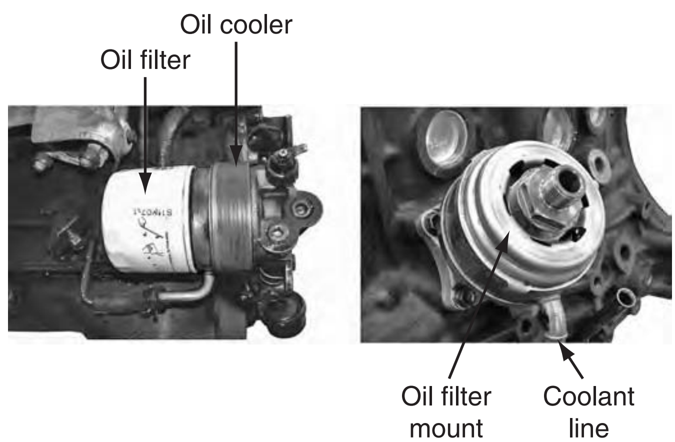


FIGURE 14.12 Auxiliary oil coolers connected to engine coolant are found on some RVs, trucks, and high-performance cars. (*Courtesy of Tim Gilles*)

VINTAGE ENGINES

A good deal of normal engine oil cooling takes place when air passes across the surface of the oil pan. Some British sports cars had engines mounted with the oil pan above the frame. The bottom of the vehicle was flat and enclosed by sheet metal. These engines depended on an auxiliary oil cooler to prevent catastrophic engine damage. Without an oil cooler, crankshaft failure could be anticipated in as little as 100 miles.

CASE HISTORY

A machine shop rebuilt an engine for an automotive repair shop. A few days later, the repair shop owner returned with the severely burned crankshaft from the engine. The engine had survived for only 15 miles before failing. Further investigation by the machine shop determined that the auxiliary oil cooler was blocked. Compressed air would not go through it, so oil could not flow through it to the oil galleries. Unlike an oil filter, there is no provision for oil to bypass a blocked oil cooler. The crankshaft and bearings, lacking the support of an oil film, failed in only a few miles. Luckily, the customer had not continued driving when she noticed the oil light and the pistons, rings, and heads could still be used with the new crankshaft and bearings.

FIGURE 14.13 Synthetic oils. (*Courtesy of Tim Gilles*)

Synthetic Oils

Synthetic lubricants have been available for many years, but their use has not become widespread until recently, as synthetics have become the factory fill in more and more vehicles (**Figure 14.13**). Compared to conventional mineral oil molecules, which are of different sizes and shapes, synthetic oil molecules are nearly the same. Less friction and heat are created as synthetic oil molecules move against each other. They can withstand higher loads without breaking down and losing their structure. They exhibit exceptional low and high temperature characteristics, have a better viscosity index, and provide increased fuel economy, power, and lower oil consumption.

Conventional oils have wax, which prevents easy oil flow at low temperatures. Most of this wax is removed during the refining process. Synthetics do not have mineral oil's wax or impurities, so they are

VINTAGE ENGINES

The first synthetic hydrocarbon was created in the late 1800s. Germany was the leader in synthetic oil development. In 1913, a German scientist named Friedrich Bergius developed a process for producing synthetic oil from coal. In the late 1920s, Standard Oil of Indiana developed and produced commercial synthetic oils through the polymerization of olefins. During the 1930s, Union Carbide developed polyalkylene glycol (PAG), a synthetic lubricant still used today in air-conditioning systems. Synthetic lubricants became well known during World War II, when they were used successfully in German tanks and jets. As World War II approached, Germany lacked access to sufficient fuel and oil supplies. In 1936, Adolph Hitler's government embarked on a major synthetic fuel and lubricant program. By 1939, synthetic hydrocarbons were commercially produced from carbon monoxide and hydrogen. In the 1940s, the United States Naval Research Laboratory developed ester-based stocks. These oils were superior at the high and low temperatures encountered by jet aircraft engines.

especially suited to very low temperature uses, where they retain their ability to flow. Some of the better conventional oils are rated to flow at −38°F (−39°C), whereas synthetics are rated to flow at −65°F (−54°C). Synthetic oils can also withstand higher temperatures. This makes them especially suited for racing engines or engines in passenger vehicles with high under-hood temperatures or turbochargers.

Engines using synthetic oils experience lower oil consumption, due to the uniform size of the synthetic oil molecule. Conventional oil molecules range from large to small and the smaller molecules can sometimes leak past the piston rings into the combustion chamber. There they are burned off, leaving thicker oil and ash from the combustion process. Ester-based synthetic oils do not leave ash deposits when burned in the combustion chamber.

Synthetic oil's primary drawback is its price. Conventional oils are refined from crude, whereas synthetic oil production requires a more complex manufacturing process. Chemists continue to improve synthetic oils. The first synthetic motor oils were esters. Polyalphaolefin (PAO)-based synthetics have displaced them because of their lower cost and formulating similarities to conventional mineral oil. The better fully synthetic oils are usually a combination of esters and PAOs, with the ester content varying from 5% to 25%.

NOTE

Synthetic oils start as simple and pure materials that are synthesized to produce custom, predetermined molecular structures. Less expensive semi-synthetic oils are a mixture of conventional and synthetic oils that share some of a synthetic's improved properties.

Lubrication is provided by the oil's base stock, which is pure oil before it is supplemented with additives. Synthetic engine lubricants can be made of two primary base stocks: esters and PAOs. Both are branched hydrocarbons. PAOs are less expensive than esters. PAOs are made of hydrocarbons and are similar to the petroleum molecule. Their high temperature performance is the same as that of petroleum oil, and they produce ash when they burn, contaminating the oil.

Another class of synthetic lubricant is ester, which is more expensive. Ester has been the exclusive lubricant of jet engines since they were first developed. A jet engine breathes high-altitude air, which is 50°F to 60°F (10°C to 16°C) below zero. It must also deal with internal temperatures approaching 600°F (316°C). Piston air compressors also live in a hot environment, so an ester-based synthetic is their preferred lubricant.

Acid esters are a product of reactions between acids and alcohols. There are many different ester molecule possibilities because of the high numbers of acids and alcohols available, so custom lubricants can be designed to fit a particular application. The primary difference in structure between an ester and PAO is the ester's multiple linkages, which cause its molecules to have polarity. One end of the oil molecule is negatively charged, and the metal in engine parts is positively charged. This causes oil and engine parts to attract, resulting in more lubricity and protection during startup. Polarity also causes ester molecules to be attracted to one another. Thus, more energy is required to cause them to change from a liquid to a gas. This means they have a lower vapor pressure that results in a lower flash point and evaporation rate. Generally, when an ester has more ester linkages, its volatility is lower so less oil is burned in the combustion chamber.

Esters can cause swelling in some elastomer seals. In mixed PAO and ester oils, this is controlled in the formulation of the base stocks. PAOs sometimes have the opposite effect on elastomer seals, shrinking and hardening them. When synthetic oil was used in some engines made prior to 1980, seal leakage sometimes occurred. Modern synthetic rubber seals are better suited for use with synthetic lubricants.

The API defines five groups of lubricating oils. Groups I through III are conventional petroleum-based oils. Group IV is PAO synthetic, and group V includes the rest of the synthetics, such as ester, PAG, and others.

One advantage to synthetic oil is that it can be changed less frequently. ExxonMobil says Mobil 1 synthetic oil is good for 25,000 miles or 1 year, but it recommends replacing the filter at regular intervals to get rid of combustion by-products and contaminants. One of the important reasons for changing oil is to remove dilution and contamination. When a vehicle is relatively new, be certain to follow the manufacturer's oil change recommendations so you do not void the warranty.

CHANGING ENGINE OIL

One factor in the life of an engine is whether the engine oil is drained and refilled at regular intervals. Oil does not wear out, but it becomes diluted and contaminated (**Figure 14.14**). Contaminated oil will wear out engine bearings and seals permanently. In a cold engine, contaminants condense on the cylinder walls and migrate to the crankcase where they are mixed with the engine oil.

According to Quaker State Oil Company, every 100 gallons of gasoline burned in an engine produces

VINTAGE ENGINES

On engines with throttle body fuel injection or non-fuel injected engines with a carburetor, a paper gasket fits where the air filter housing rest on the air horn. A missing or damaged gasket can allow unfiltered air to enter the engine.

FIGURE 14.14 This engine suffered from a lack of adequate oil maintenance. (*Courtesy of Tim Gilles*)

the following by-products in addition to exhaust gases:

90 to 120 gallons of water

3 to 10 gallons of unburned gasoline

½ to 2 pounds of soot

¼ to 1 pound of resins and varnishes

1 to 4 pounds of nitrogen and sulfur acids

6 to 10 ounces of insoluble lead salts (if leaded gasoline)

1 to 2 ounces of hydrochloric and hydrobromic acids

NOTE

Sometimes, when an air filter is changed, dirt from the outside of the dirty filter is carelessly allowed to enter the fuel system's air intake. The equivalent of two aspirin tablets of dirt causes more wear than 75,000 miles of normal driving.

Leaking vacuum accessories and lines can also result in dirty air being drawn into the engine's cylinders.

Dirt is the number one cause of engine failure.

FIGURE 14.15 Contamination by unfiltered air is indicated by vertical scratches in the cylinder wall above the bottom limit of piston ring travel. (*Courtesy of Tim Gilles*)

- When dirt enters through the engine's air inlet from a vacuum leak or a leak in a fuel injector's rubber hose to the air cleaner, scratches will be visible above the level of piston ring travel in the cylinder (**Figure 14.15**).
- Dirt that enters the engine when it is pulled in by the crankcase ventilation system past a leaking gasket will mix with engine oil, causing additional wear to internal engine parts. This external leakage will not leave scratches on cylinder walls, however.

Benefits to Changing Oil

There are several benefits from changing engine oil:

- An oil's additives are depleted over time and changing the oil replenishes them.
- Because the oil filter takes out only particles larger than a certain size, periodic oil changes help to clean the smaller contaminants from the oil.

- Unburned contaminants like fuel and acids are removed with the oil.
- Sludge is removed.

Oil Change Interval

Internal combustion engines produce many byproducts during operation. *Blowby gases* (gases that leak past the piston rings into the crankcase) contain acids as well as unburned and burned fuel. When moisture combines with these materials, sludge forms inside the engine. If the engine is never fully warmed up or if oil is not changed often enough, more sludge develops. A vehicle driven primarily on the freeway—where it runs more efficiently—can have less frequent oil change intervals (7500 miles or more) than one that is driven primarily on short trips. One thing that has become even more important with newer engines with variable valve timing is engine maintenance. Regular oil changes with high-quality, low-viscosity oil are mandatory. Lack of maintenance can result in sludging of the oil galleries and failure of the VVT mechanism to operate.

NOTE

For city driving, it is a good practice to change the oil every 90 days or 3000 miles. Oil is inexpensive insurance against engine damage. On late-model vehicles, this old recommendation might not be best, however. There is concern that antiwear additives in the oil can damage the catalytic converter (CAT). More frequent oil changes can result in more contamination of the CAT.

Changing Brands of Oil

Oils with the same API service rating are usually compatible. But today's oils can be made up of one-third additives, so a chemical reaction is possible. Although the chemical reactions have *not* been found to be serious:

- It is a good idea to avoid mixing brands of oils *between* oil changes.
- Changing brands of oil is best done when the oil is being changed.
- When there is not a choice of brands available, it is better to add any brand of high-grade oil than to operate the engine with a low crankcase oil level.

Changing Oil

It is best to change oil while it is still hot because detergents in the oil will suspend contaminants, allowing them to be removed with the oil. While the oil is draining, the filter can be changed. Check the lubrication manual for the capacity of oil that the crankcase holds and the API and viscosity classifications of the oil.

SHOP TIP

If an engine's oil is to be changed, remove the oil filler cap and place it somewhere obvious. Make a habit of not replacing it until all of the new oil has been added after the oil change.

When changing oil:

- Check the condition of the drain plug gasket. It is usually made of a synthetic material like nylon or a soft metal such as aluminum or copper. Drain plug gaskets are usually reusable, but at the first sign of wear or damage they should be replaced.
- Use care not to strip the threads in the oil pan.

SHOP TIP

When starting a thread into a hole, first turn counterclockwise (direction of loosening) until you feel the thread drop into place. Then tighten the plug.

- Always turn the drain plug all of the way into the thread *by hand*. Only use a wrench to torque the plug when its gasket has begun to be compressed against the oil pan. This will avoid the possibility of accidentally stripping a thread.

Oil Condition Sensing

Many late-model vehicles have an oil monitor system that uses a computer-based software algorithm to compute the necessary oil change interval and illuminates a message on the instrument panel when an oil change is required (**Figure 14.16**). The oil change interval is based on the mileage since the last oil change and the type of driving experienced by the engine. Oil degrades according to a predictable schedule so the oil life monitor considers a base

FIGURE 14.16 Instrument panel reminder when oil change is required. (*Courtesy of Tim Gilles*)

FIGURE 14.17 A new message that appears when reminder has been reset. (*Courtesy of Tim Gilles*)

number of ignition firings and counts down from there using the algorithm. The countdown tightens the oil change interval based on sensor inputs of coolant temperature, vehicle speed, incoming air temperature, and load.

Some systems have a staged warning light. A typical first stage sets a warning light saying "service oil soon"; the second stage says "service oil now." These systems are very conservative, allowing the customer at least an additional 1000 miles before the oil begins to break down.

Some European manufacturers use capacitance or conductivity oil quality sensors to measure the condition of the oil. American manufacturers use sensor input, data storage, and calculations, called look-up tables, to determine when oil needs to be changed. General Motors first used its system in 1988 and uses these systems on all of its new vehicles today. In mixed city and highway driving, the average motorist can expect to change oil at intervals ranging from 4000 to 7000 miles. Freeway driving oil change intervals are typically 7000 to 10,000 miles.

Oil Monitor Reset

Following an oil change, a procedure must be followed to shut off the light and reset the monitor so it can begin measuring conditions for the next oil change reminder. Procedures vary between vehicles and are listed in service information libraries and in various aftermarket booklets. One typical reset procedure requires the throttle pedal to be floored three times within 5 seconds while the ignition key is in the "on" position. The indicator on the instrument panel will flash a message saying that the monitor has been reset (**Figure 14.17**).

OIL PUMPS

The oil pump on pushrod engines and some OHC engines is driven by a gear on the camshaft. Some OHC oil pumps are driven by the crankshaft (**Figure 14.18**). The cam gear driven pumps are usually attached to the bottom of the distributor by a tang or hex drive shaft (**Figure 14.19**). Most distributors have a gear on the bottom that meshes with a drive gear on the camshaft.

There are three common types of oil pumps: the *external gear* (**Figure 14.20**), the *rotor* or *gerotor* (**Figure 14.21**), and the *internal/external gear* (**Figure 14.22**). Internal/external gear and gerotor pumps are used on OHC engines, especially when the engine has distributorless ignition. The outer rotor of a gerotor pump is centered to the crankshaft or camshaft drive. The inner rotor is mounted off-center and has one less lobe than the outer rotor, so the outer rotor rotates at 80% of the speed of the inner rotor. As the inner rotor turns, the chamber of the pump enlarges, creating a vacuum. Oil will rush in, filling the low-pressure area. The pump chamber reaches its largest volume when the lobes and tips of the rotors seal both the inlet (low-pressure) and outlet (high-pressure) sides. As the rotor continues to turn, the chamber volume becomes smaller and oil is pushed through the discharge port.

A gerotor pump has smooth pumping action. With each rotor revolving on its own center, inherent balance is not a problem and pressure remains more constant instead of constantly fluctuating. The

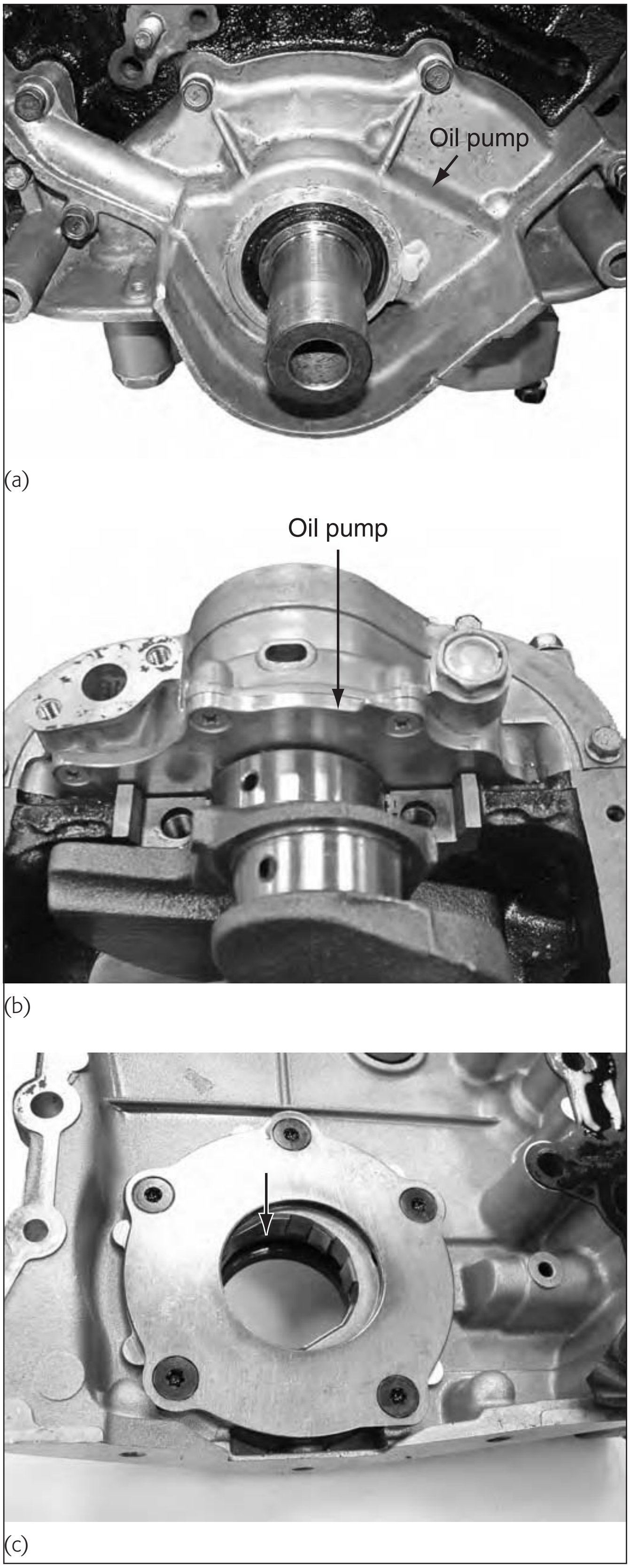


FIGURE 14.18 (a) A crankshaft-driven oil pump. (b) View of a crankshaft-driven oil pump from the crankcase side. (c) The drive gear of a crankshaft-driven oil pump. (*Courtesy of Tim Gilles*)

FIGURE 14.19 Two common distributor oil pump drives. (*Courtesy of Tim Gilles*)

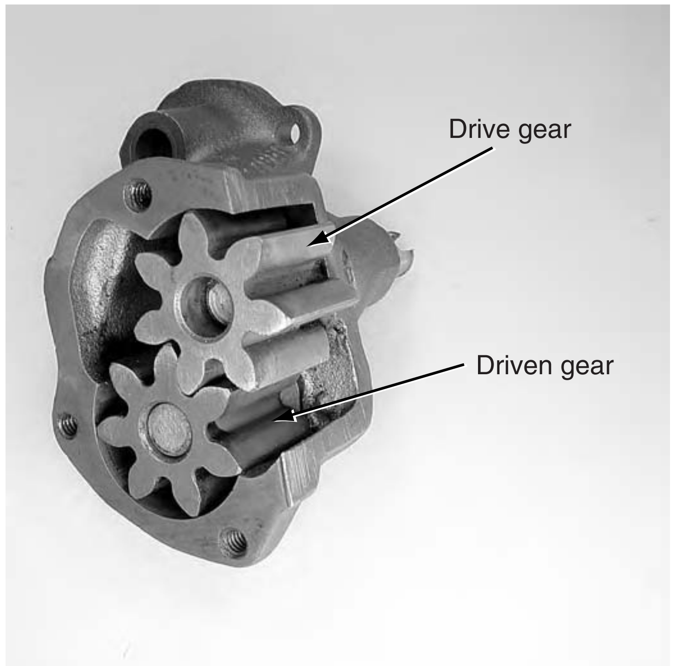


FIGURE 14.20 An external gear oil pump. (*Courtesy of Tim Gilles*)

FIGURE 14.21 A crankshaft-driven gerotor oil pump. (*Courtesy of Tim Gilles*)

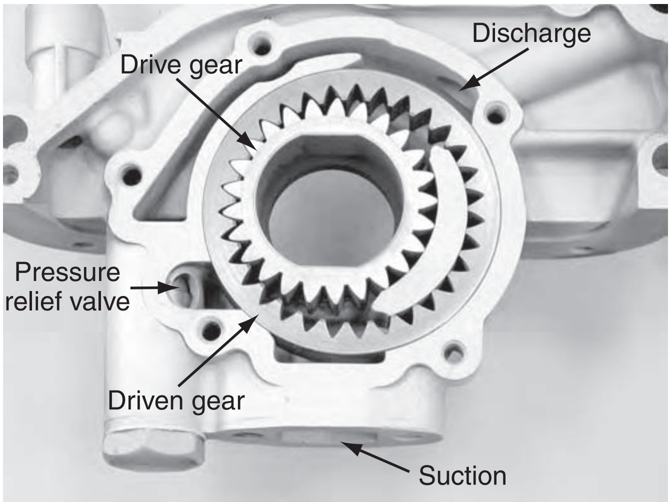


FIGURE 14.22 A crankshaft-driven internal/external gear oil pump. (*Courtesy of Tim Gilles*)

constant pump speed results in less aeration of the oil. Whereas spur gear oil pumps change their volume at about each 7° of rotation, gerotor pumps do not. Also, fewer moving parts and low rotational speed (600 rpm at 3000 shaft rpm) means less wear. Cast iron pumps are considered to be better than aluminum pumps because they wear less and do not expand as much when heated. Also, their relief valves are less likely to stick due to distortion.

Crankshaft-driven gerotor and internal/external pumps turn at twice the speed as camshaft-driven pumps, which provide more oil flow at idle. Crankshaft-driven pumps save space, having thinner gears because the pump turns twice as fast as a camshaft-driven pump. When worn, these pumps can sometimes be serviced without replacing the pump body; the internal gears or rotors are simply replaced.

Pressure Relief Valve

The oil pump must be capable of supplying oil under sufficient pressure to all areas of the engine at idle speed. The faster the pump turns, the more oil it pumps. For this reason, it must have a relief valve to relieve excessive pressure when the pump turns at higher speeds (**Figure 14.23**)

- Most oil pump relief valves limit maximum oil pressure by diverting excess oil back to the inlet side of the pump.
- Maximum oil pressure is controlled by the valve moving in its bore against the tension of the relief valve spring.

Oil Pressure

An engine's oil pressure provides a good indication of the condition of its bearings and oil pump. Excess clearance can result in lower oil pressure when the engine is idling and the oil pump is turning more slowly. If oil thins too much as the engine

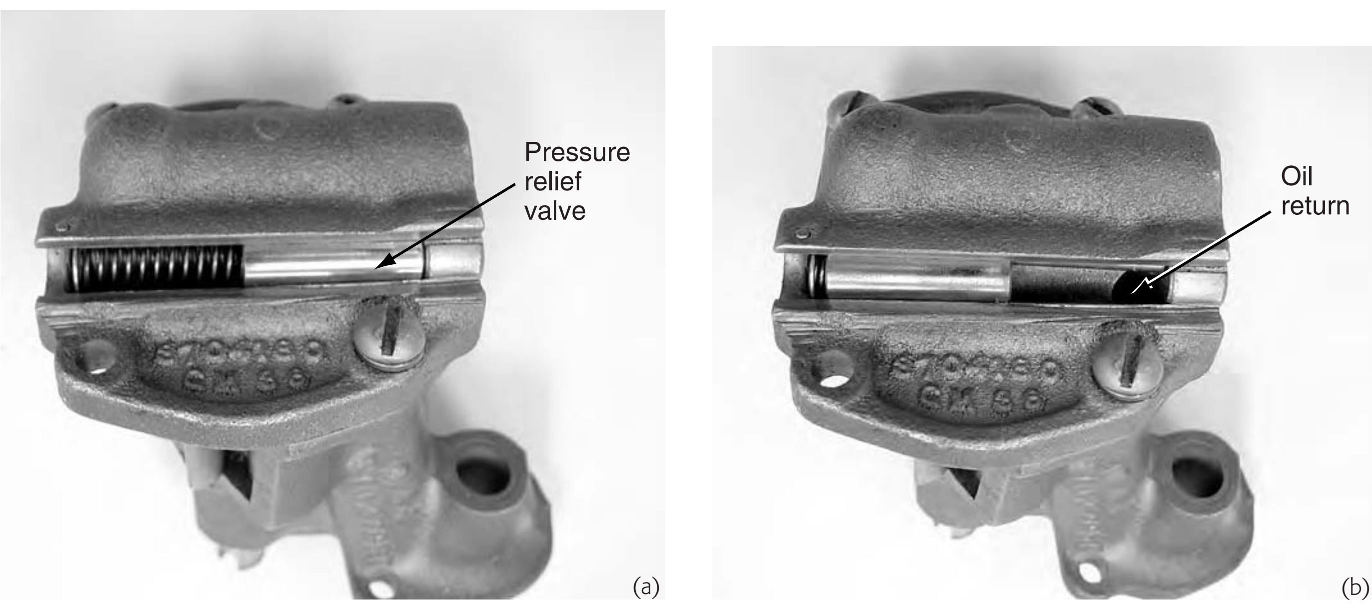


FIGURE 14.23 Oil pump pressure relief valve operation. (a) Pressure relief valve in the closed position. (b) When the valve is open the oil return to the crankcase is uncovered. (*Courtesy of Tim Gilles*)

warms up, the problem can become worse. Low oil pressure at idle can also result if the relief valve is stuck in the "open" position. The opening is so large that the pump cannot fill the system at low speed, although pressure will usually build to normal levels at higher engine speeds.

Long periods of idling with low oil pressure can lead to cylinder wall lubrication problems. Throw-off from the connecting rods cannot supply the cylinder walls with enough oil for adequate lubrication (see Chapter 12).

NOTE

Most manufacturers recommend a minimum of 10 psi of oil pressure for every 1000 rpm.

Satisfactory oil pressure at idle is normally in the neighborhood of 25 psi, but pressure indicator lights do not normally come on until pressure drops below 10 psi. An engine idling at 800 rpm should have a minimum of 8 psi oil pressure.

NOTE

The oil indicator lights on some engines do not come on until pressure drops below 4 psi.

To test oil pressure against manufacturers' specifications, remove the indicator light sending unit and install an external gauge (see Chapter 3).

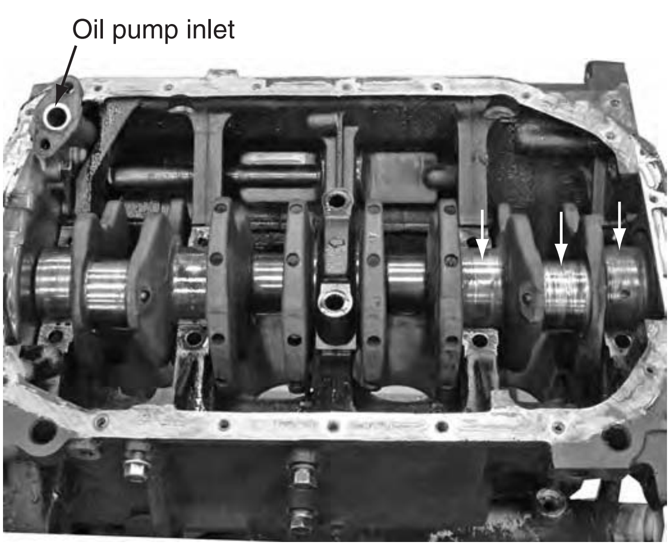


FIGURE 14.24 The failed journals on this crankshaft are the furthest from the oil pump. (*Courtesy of Tim Gilles*)

SHOP TIP

When an engine has run low on oil, engine failure usually occurs at a point furthest from the oil pump (**Figure 14.24**).

Oil Pressure Too High. High oil pressure results when the relief valve sticks in the "closed" position. An engine with too much oil pressure can have oil consumption and bearing problems. Extra oil is thrown onto the cylinder walls because of the higher oil pressure. This extra oil can get past the piston rings into the combustion chambers. Occasionally, bearing lining material can be etched from a bearing by excessive oil pressure.

- Oil pressure can be normal at idle but will increase beyond desired levels as engine rpm increases.
- High pressure can cause oil leaks and can blow out oil gallery core plugs, which will result in no oil pressure at low rpm.
- Sometimes an oil filter can burst from too much oil pressure.

Pump Screen and Pump Failure

The oil pump sump screen, or pickup, must be checked to be sure it is clean (**Figure 14.25**). A new

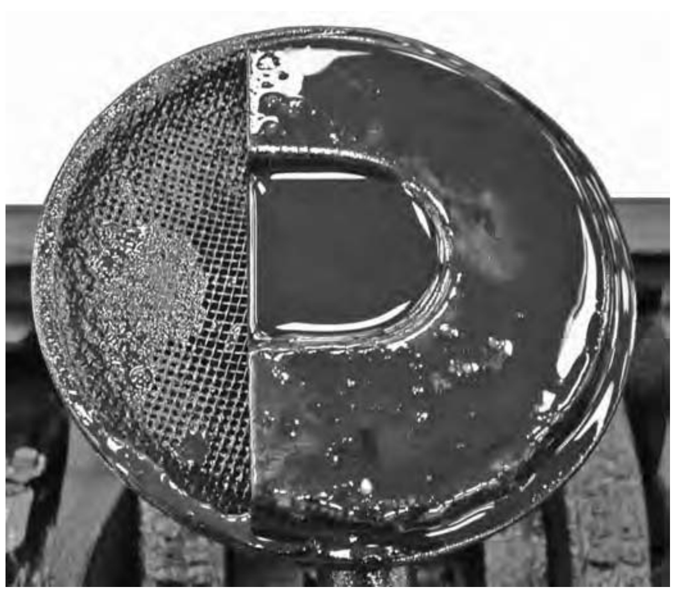


FIGURE 14.25 This restricted oil pump screen should be replaced. (*Courtesy of Tim Gilles*)

oil pump does not come with a new screen. Screens can be very hard to clean properly. Some rebuilders replace every screen with a new one. A plugged screen (**Figure 14.26**) can ruin a new engine in a very short time. When a pressed-fit screen is installed a special tool can be used (**Figure 14.27**). Be careful not to distort the pump housing by clamping it in a vise (**Figure 14.28**). Clearance between the gears and housing is less than 0.005". A slight distortion of the pump can cause interference between the gears and housing.

Screen Bypass Valve. Many screens have a bypass valve that can open when the screen becomes plugged (**Figure 14.29**) or when the oil is cold and too thick to flow freely. The bypass valve is normally seated against the cross strap on the screen. If a screen bypass valve has opened and remains open the screen will have to be replaced.

Make sure that the bypass is not stuck permanently open on a newly cleaned screen (**Figure 14.30**). When the screen is restricted and the bypass opens, a large (about ½") opening results. This opening allows large particles to enter the pump because oil goes to the pump before it goes to the filter (**Figure 14.31**). Be certain that a screen does not have any loose or damaged wire mesh that could break loose and cause oil pump failure.

FIGURE 14.26 When a customer's oil light came on, this restricted pump screen was found to be the cause. The source of the restriction was carbon that was flaking off of the insides of the crowns of the pistons. (*Courtesy of Tim Gilles*)

FIGURE 14.27 Installing a new pickup screen on an oil pump.

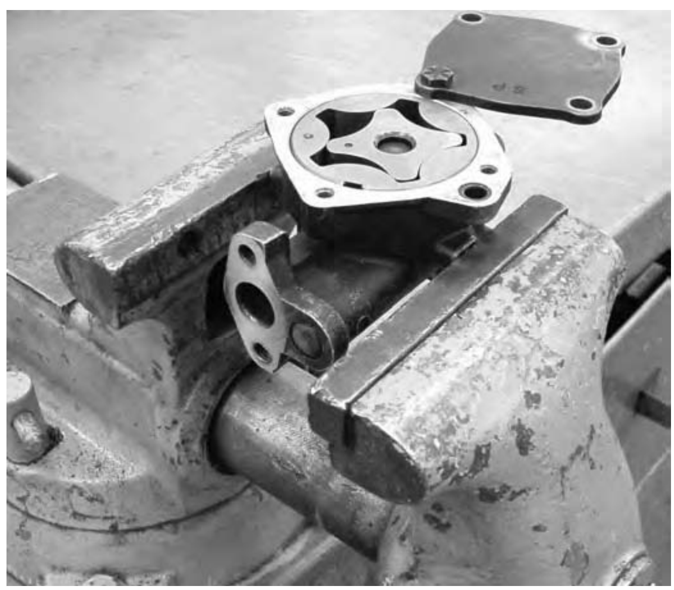


FIGURE 14.28 Be careful when clamping an oil pump in a vise. Clamping the body on the outside of the gears or rotors can distort it, resulting in interference and pump failure. (*Courtesy of Tim Gilles*)

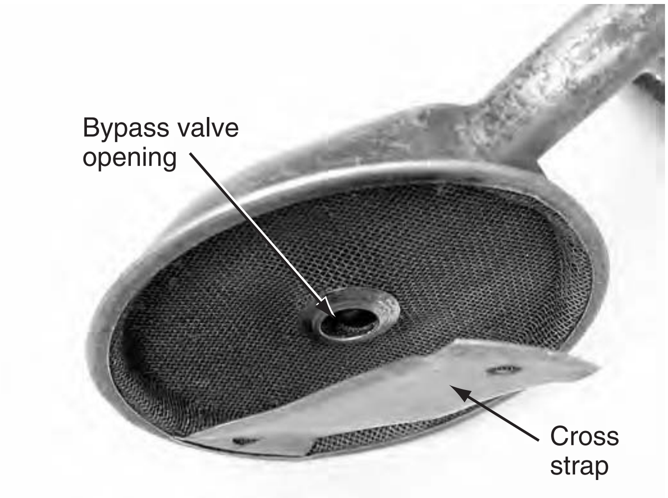


FIGURE 14.29 Bypass valve and cross strap. (*Courtesy of Tim Gilles*)

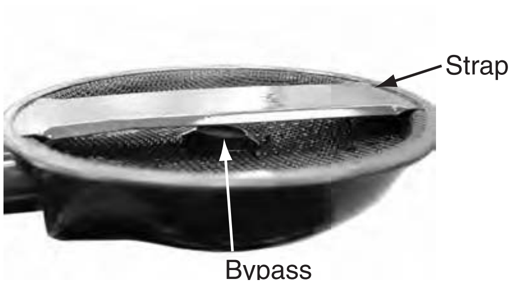


FIGURE 14.30 This pump screen is defective; the bypass should be seated against the strap. (*Courtesy of Tim Gilles*)

Oil Pump Failure. Oil pumps usually wear or seize because of improper engine maintenance, or because pieces of a metal part, such as a failed camshaft or bearing, get into the pump (**Figure 14.32a**). Sometimes a hex drive shaft will twist off when a foreign object becomes wedged in the pump (**Figure 14.32b**).

Another major cause of pump failure is when it draws in plastic material, such as nylon timing sprockets (see Chapter 9) or deteriorated valve stem seals. Seals become brittle with age and can find their way into the oil system (**Figure 14.33a**). Aged or damaged umbrella seals can break up during engine operation, but O-ring seals usually enter the system during a careless seal replacement job. Plastic pieces can ruin the oil pump (**Figure 14.33b**) or cause a pump relief valve to stick.

CASE HISTORY

A technician was replacing a timing set in a small block Chevrolet. The flat rate manual includes time on this job for removal of the oil pan. From previous experience, the technician knew that he could complete the job without removing the pan. He simply loosened the pan bolts and pried the timing cover out. This cut his time on the job. A short time after the job was completed, the car returned to the shop once again, this time for a failed oil pump and resulting severe engine damage. Pieces of the old timing sprocket were found in the pump screen and oil pump.

Pieces of foreign material can also get into the system due to incomplete cleaning of the cylinder block. Be sure to clean out all oil galleries with a rifle brush (see Chapter 11).

CASE HISTORY

An apprentice machinist was rebuilding an engine that had spun a rod bearing. He neglected to carefully clean the oil galleries. After the engine was installed and started, metal from the galleries mixed with the engine oil. The result was severe damage to the crankshaft and bearings.

Air in the System

Some screens are threaded into the pump or block. Use Teflon® tape or liquid thread sealant on the threads to prevent air from leaking in. Check the tube that connects the screen to the oil pump for holes, which can allow air to enter the system (**Figure 14.34**). Bolt-on oil pickup screens usually require a gasket (**Figure 14.35**). Be sure to remove the old gasket carefully. The gasket is only needed on the inlet side of a pump. The outlet side often has

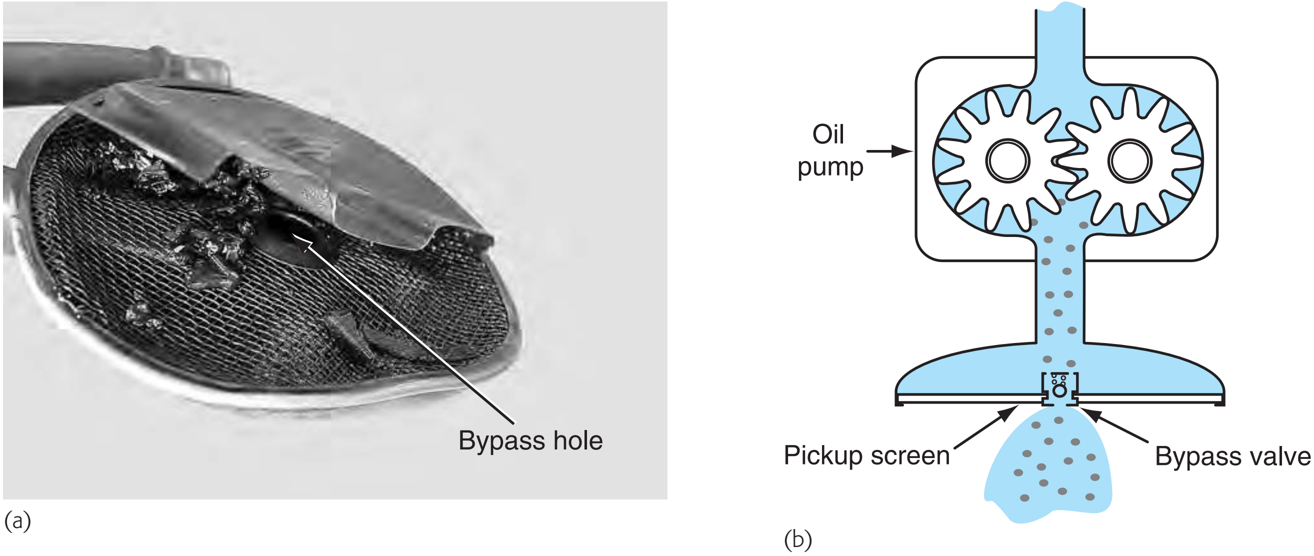


FIGURE 14.31 (a) This pump screen is full of large pieces of foreign material. (*Courtesy of Tim Gilles*) (b) When the bypass valve opens on a cold morning, the foreign material will be sucked into the oil pump.

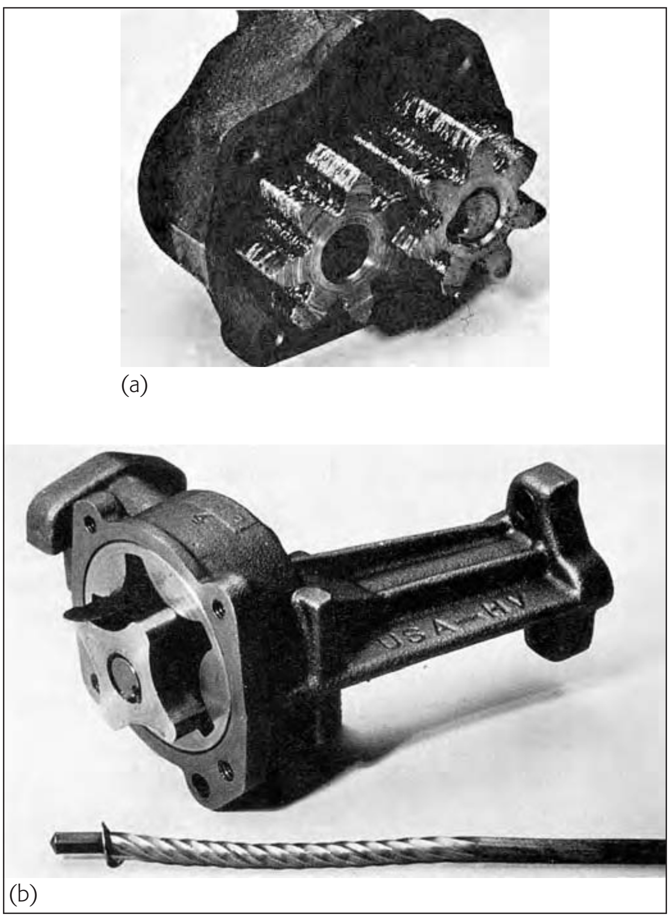


FIGURE 14.32 Oil pump failure caused by foreign material. (a) This gear-type pump was destroyed when metal particles entered the pump from a failed part elsewhere in the engine. (b) The hex drive on this rotor pump was ruined when foreign material jammed the pump. (*Courtesy of Federal-Mogul Corporation*)

no gasket because it is not necessary. The idea is to keep air from entering the pump on the *inlet* side. **Figure 14.36** shows where a gasket would, or would not, be on a typical crankcase-enclosed oil pump. Some screens are pressed-fit.

If the screen does not fit tightly, is damaged, or is dirty, it should be replaced. Position the screen ¼" to ½" from the bottom of the oil pan. This will prevent it from drawing in sediment that has accumulated in the oil pan.

NOTE

Do not hammer on the pump when installing the screen. The pump housing can be damaged. Clearances within the pump are so small that interference between the gears or rotors and housing can result if the pump is improperly clamped in a vise or pounded on.

Checking Oil Pumps for Wear

A feeler gauge is used to check an oil pump for wear (**Figure 14.37**). Clearances listed here are approximate and are used only in the absence of specifications.

Rotor pump clearance tolerances are:

- 0.010" between the inside and outside rotors (**Figure 14.37a**)

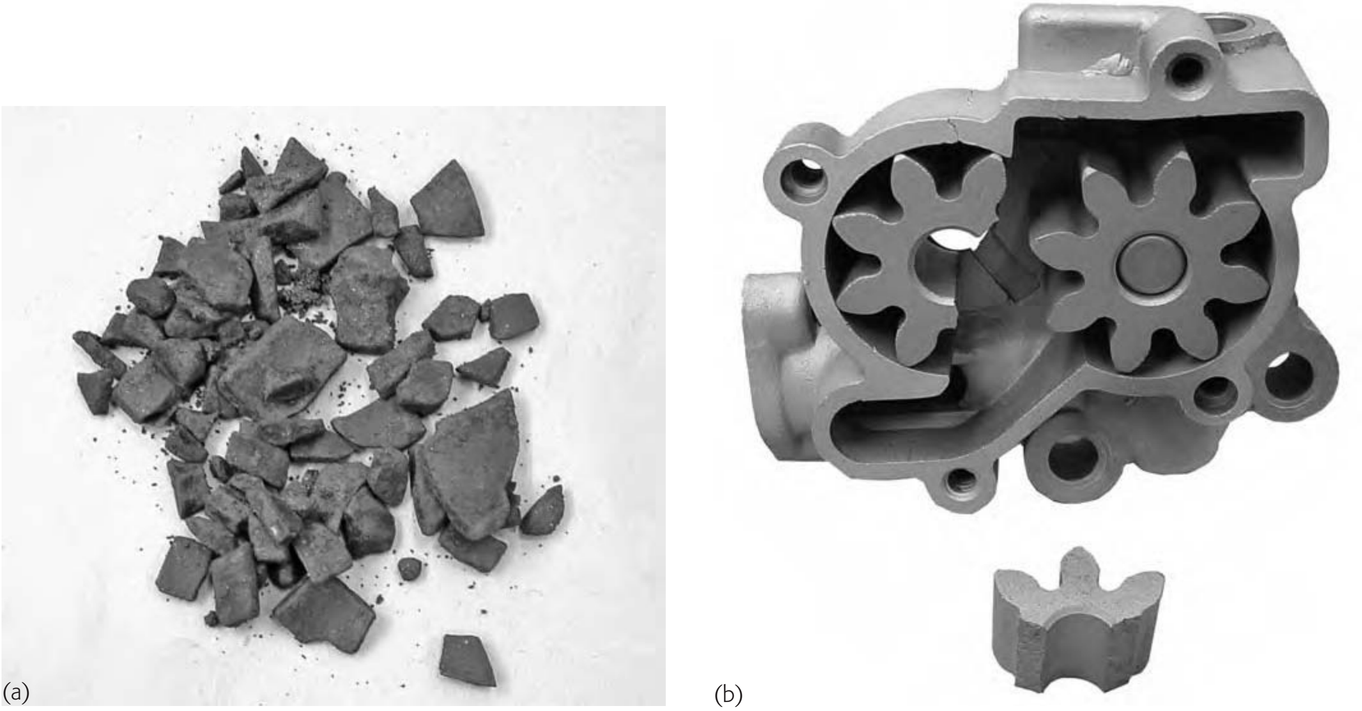


FIGURE 14.33 Plastic material in the oil pump. (a) These pieces of broken umbrella valve guide seals were removed from an engine's oil pan. (b) Foreign material lodged in this oil pump, causing one of the gears to break. (*Courtesy of Tim Gilles*)

- 0.014" between the outside rotor and housing (**Figure 14.37b**)

Gear pump clearance can be checked by inserting Plastigage between the cover and gear ends.

- End clearance should be no more than 0.003".
- Side clearance between the gear and housing should be less than 0.005" (**Figure 14.37c**).

FIGURE 14.34 Air must not enter the oil pump. Air can be drawn into the lubrication system if there is a leak in the pump pickup.

Internal/external gear pumps are checked in three places (**Figure 14.38**). Follow manufacturer specifications. Typical body-to-outer gear clearance is 0.004" to 0.008". Inner gear-to-crescent clearance

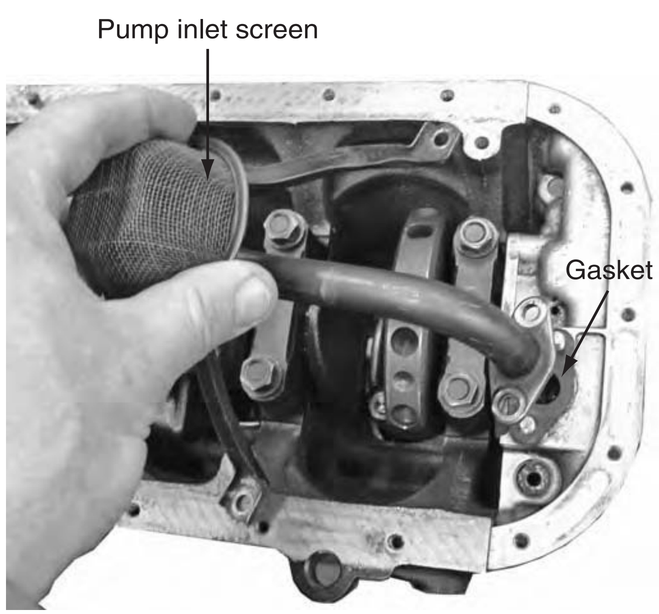


FIGURE 14.35 A bolt-on pump screen requires a gasket. (*Courtesy of Tim Gilles*)

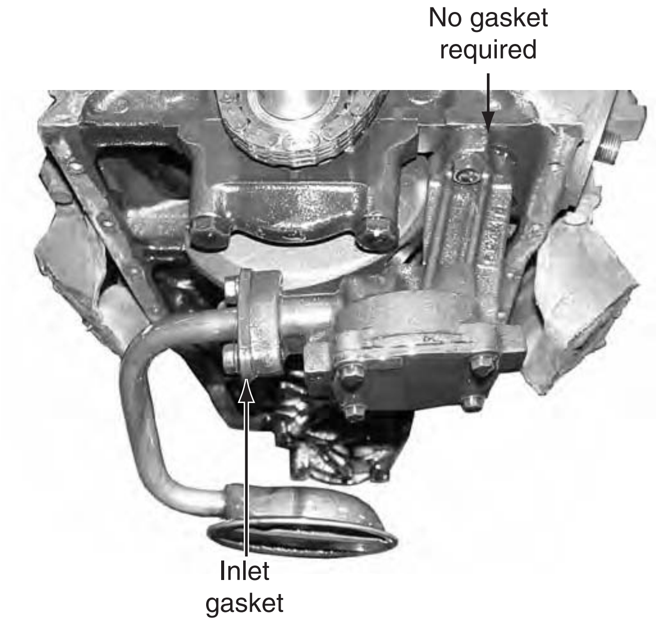


FIGURE 14.36 Gasket location on a typical crankcase-mounted oil pump. The inlet side requires a gasket; the outlet side does not. (*Courtesy of Tim Gilles*)

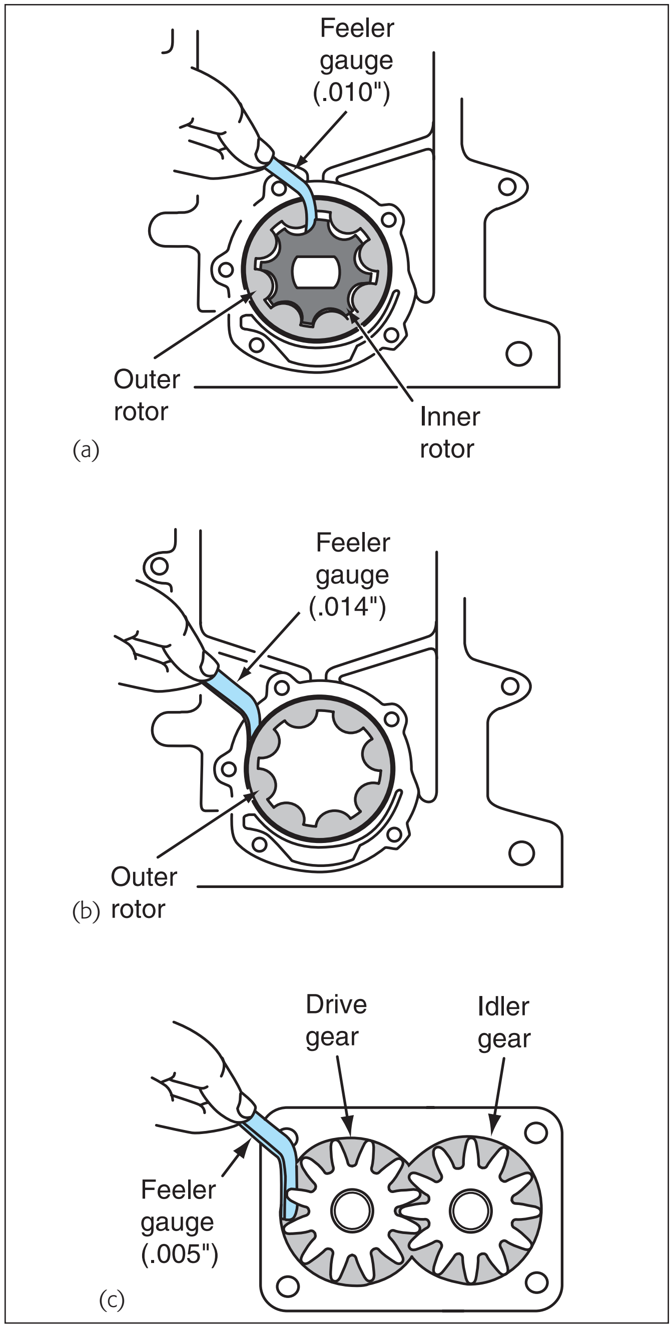


FIGURE 14.37 (a) Checking clearance between the inner and outer rotors. (b) Checking clearance between the outer rotor and the pump housing. (c) Checking housing-to-gear clearance in a gear-type pump.

is 0.009" to 0.013" and outer gear-to-crescent clearance is 0.008" to 0.012".

Installing the Oil Pump

Oil pumps are filled and tested at the factory before shipment. Before installation, fill the oil pump cavity with engine assembly lubricant **Figure 14.39**) to ensure that it will prime and will not be damaged by running dry when the engine starts. Turn it by hand to make sure that it has not been damaged by previous mishandling. The pump housing can be easily distorted during installation of pressed-fit oil pickup screens. This can cause interference between the gears, or rotor, and the pump housing.

- Always check relief valve operation when installing a new pump (**Figure 14.40**).
- Be sure to retorque the pump cover to specification before installation.
- General Motors uses a nylon sleeve to align the pump drive fork and drive tang. If the sleeve is omitted during assembly, the tang and fork can become misaligned, which can cause the fork to break. High-volume oil pumps use a metal sleeve to align the pump drive fork and drive tang.
- Be sure that the pump is properly aligned before bolting it on. A cocked pump can result in a broken mount tab, leakage and pressure loss, or pump damage (**Figure 14.41**).

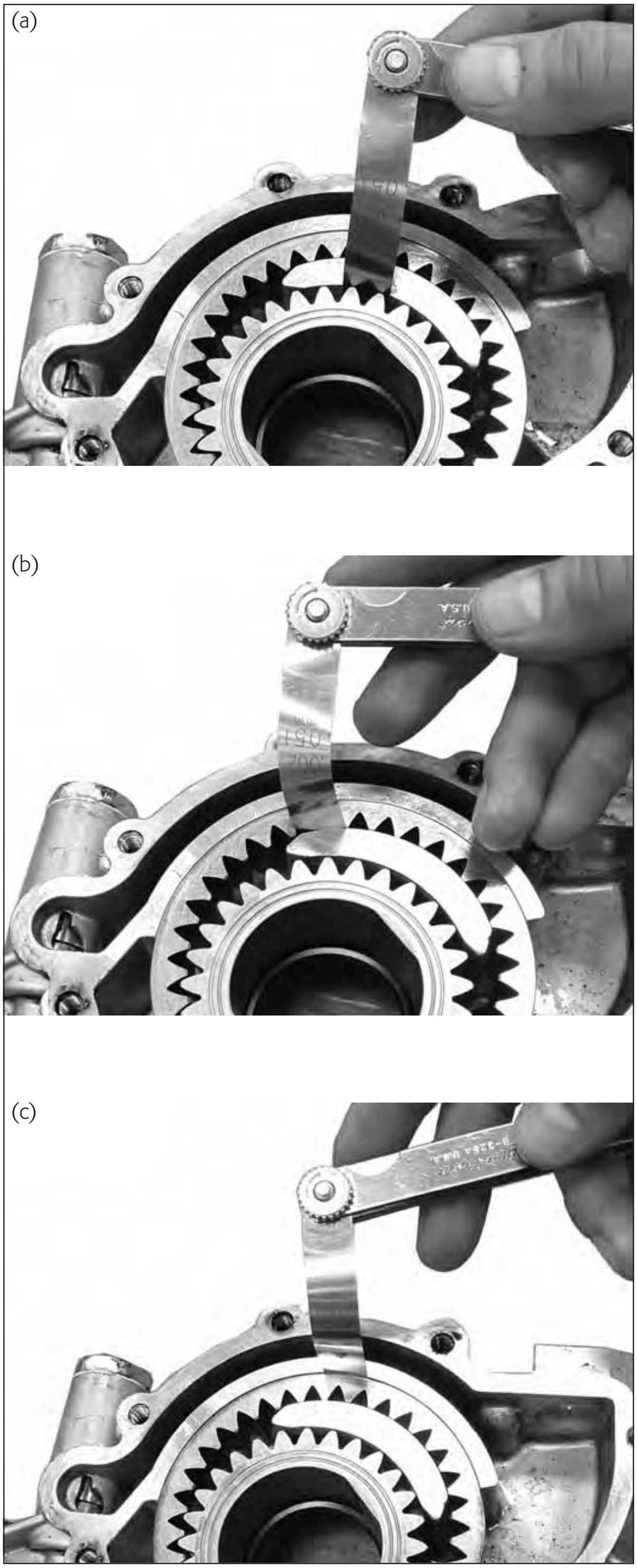


FIGURE 14.38 Checking internal/external gear pump clearance. (a) Between the inner gear and crescent. (b) Between the crescent and outer gear. (c) Between the outer gear and housing. (*Courtesy of Tim Gilles*)

CASE HISTORY

A technician installed a rebuilt engine in a Dodge van. Due to limited space, the short block was installed in the vehicle first. Then the heads were installed and the rest of the assembly was completed. After the engine was started up, intermittent low oil pressure was diagnosed. The hydraulic lifters would occasionally run low on oil at idle and begin to make noise. Ultimately, the oil pump was removed for inspection. To do this, the engine had to be moved high enough for the oil pan to be removed. Because there was not enough clearance between the transmission and the floor of the vehicle, the transmission had to be unbolted from the engine and moved toward the rear of the vehicle. When the oil pump was removed and disassembled, a broken relief valve spring was found. The pump was new and had been installed with the engine rebuild. As many a seasoned technician or machinist has remarked, "Trust no one"! Check all new and used parts carefully before installation.

FIGURE 14.39 This pump has been filled with engine assembly lubricant to allow oil to feed the main oil gallery sooner. (*Courtesy of Tim Gilles*)

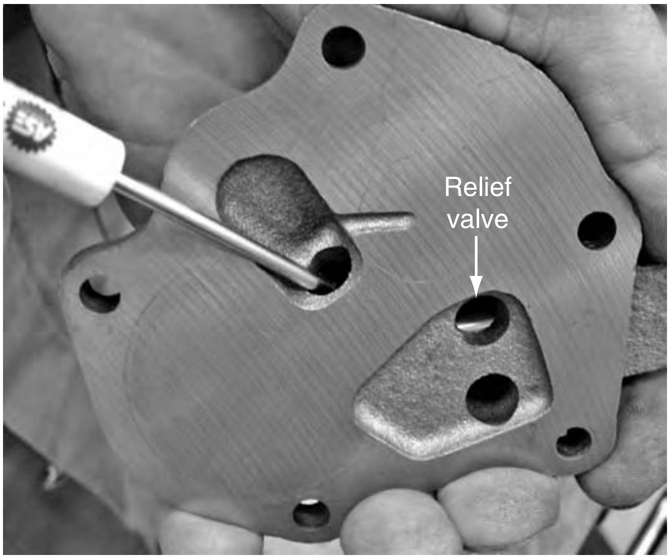


FIGURE 14.40 Checking pressure relief valve operation. Be careful not to scratch the valve bore. (*Courtesy of Tim Gilles*)

Positive Displacement Pumps

A positive displacement pump, like those used in automobiles, has a fixed output per revolution. The faster it turns, the more oil it pumps.

FIGURE 14.41 Pump damage caused by careless installation.

SHOP TIP

A rule of thumb for oil pressure is 10 psi for each 1000 rpm. Some engines have different requirements, so check manufacturers' specifications.

High-Volume Oil Pumps

The output per revolution of an oil pump depends on the diameter and thickness of the rotors or gears. Oil pumps with about 20%–25% more volume are available but may not necessarily provide an advantage. Consider the application carefully before replacing a standard pump with a high-volume one. High-volume pumps deliver more oil per revolution due to the increased size of the pump cavity (**Figure 14.42**).

One of a high-volume oil pump's advantages is in reducing oil temperature because more oil can be carried through the bearings at high speed. Oil flow is critical in keeping parts cool, especially under adverse conditions.

A high-volume pump will have the same operating pressure as a standard pump if its relief valve spring is of the same pressure. But it would be able to provide more oil to a worn engine at idle. This would result in an increase in idling oil pressure in such an engine.

High-volume pumps usually have stronger relief valve springs, so they operate at a higher oil pressure. One problem with these pumps is that

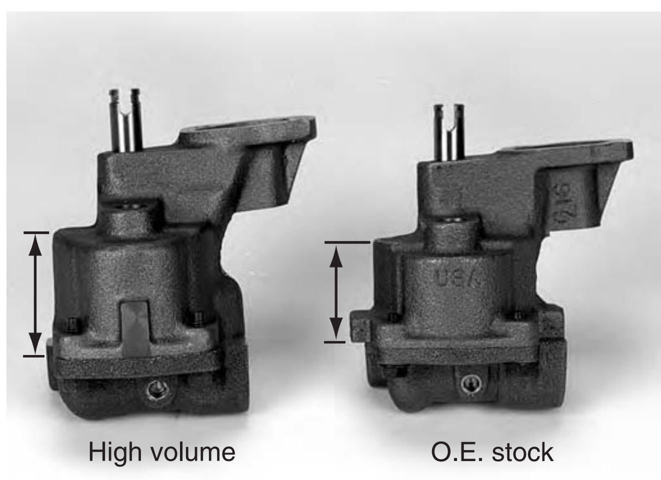


FIGURE 14.42 A high-volume oil pump is larger than a stock pump.

they can blow an oil filter or an oil gallery plug during a cold start.

High-volume oil pumps are required when SAE 50 oil is used. These pumps frequently break their drive forks during "jack rabbit" starts on cold mornings. A high-volume pump is used when an engine has greater than normal clearances. But the engine's oil capacity might need to be increased or the oil pan might run dry. Oil pan capacity is usually increased by 2 quarts.

A high-volume pump can cause wear problems on the back of the cam sprocket as it is pushed harder against the block due to the increased effort required for the pump to turn. Be sure that the surfaces are free of nicks and that the front cam bearing is installed properly to allow correct oiling. Always lubricate the thrust surface during assembly.

Dry Sump Systems

Wet sump lubrication systems provide sufficient oiling in most cases, but dry sump systems are needed when engines are used in extreme conditions. They are used on race cars and high-performance production cars like the Audi R8, Corvette ZR1, and Porsche 911. Dry sumps are also used in airplanes and in large diesel engines found in bulldozers and earthmovers. A typical automotive wet sump system carries several quarts of oil in the oil pan. When oil is sloshed hard to the rear or sides during hard cornering, the oil pump can run dry when the oil pickup screen is temporarily uncovered. Sloshed oil can also interfere with the rotation of the crankshaft, reducing horsepower output and splashing excess oil on the cylinder walls. Oil foaming and aeration can also result from the crankshaft cutting through oil.

Dry sump lubrication systems are more complex so they cost more to produce. They have one or more scavenge pumps to return oil from the oil pan to an external oil reservoir and a pressure pump to move oil from the reservoir to the oil galleries and bearings (**Figure 14.43**). A typical system has stacked belt-driven pressure and scavenger pumps on a single pulley. Additional pumps can be added to the back of the stack as needed.

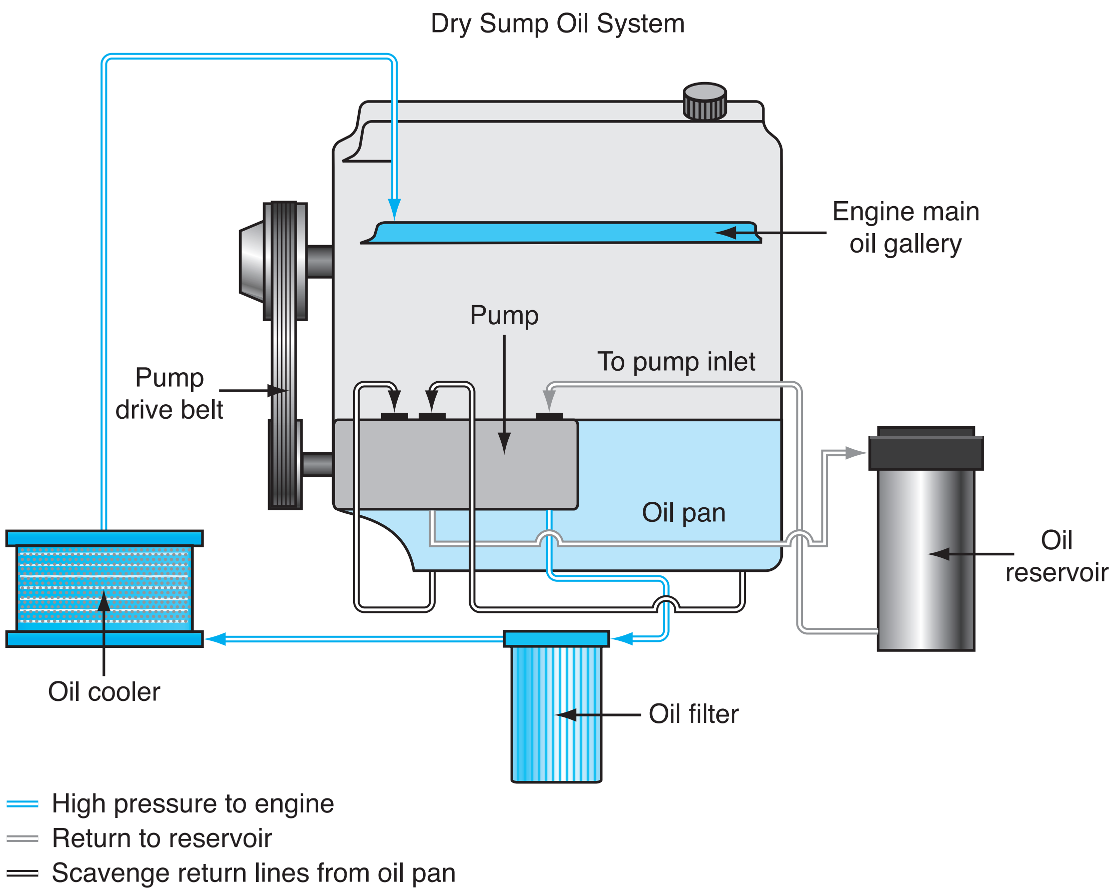


FIGURE 14.43 A schematic of a typical dry sump lubrication system.

In addition to protecting against oil sloshing, dry sumps have several advantages over wet sumps. When an engine's oil capacity is increased, cooler oil results. When oil temperature exceeds 240°F (116°C) the oil becomes thinner and air bubbles can form. Both of these conditions can cause problems with hydraulic lifter function, especially in combination with strong valve springs. The dry sump external oil reservoir can be made as large as necessary and it can be located anywhere on the vehicle. The oil pan is no longer reservoir for oil so it can be made smaller, lowering a race car's center of gravity.

Windage Tray and Baffles

At high speeds, the revolving crankshaft creates wind. This can cause air pockets around the pump screen, which can cause the pump to lose its prime. The objective is to keep the pump screen continuously immersed in oil. A windage tray helps to prevent these air pockets (**Figure 14.44**). Some windage trays bolt onto the main bearing caps or cylinder block; others are built into the oil pan.

Some oil pans also have built-in baffles that prevent the oil from sloshing back and forth when driving over hills or bumps or during hard cornering or braking. Be sure to check for pieces of foreign material trapped under a windage tray or baffle.

PRIMING THE LUBRICATION SYSTEM

The lubrication system should be primed before the engine is started after an engine rebuild. On older engines with distributor-driven oil pumps, do this before installing the distributor. Distributor-to-oil pump drives come in several styles; some have an offset tang and some are hex shaped (see Figure 14.19). To prime the oil system when the distributor is not in the engine, there must be a gear on the bottom of the distributor shaft. If there is no gear, the oil pump gear might still be engaged with the cam gear; priming by this method is not possible.

A priming tool can be made from an old distributor with the gear removed. Commercially made pump priming tools are also available.

To prime the system:

- Drive the tool with a slow drill in the normal direction of distributor rotation.
- After pressure builds in the system, rotate the crankshaft one complete revolution by hand on engines that have hydraulic lifters.
- Prime the system once more. This will allow all hydraulic lifters to fill up with oil.

The oil pump in a cam-in-block engine is usually driven by the distributor. To prime the system, the pump must be turned in the direction of normal distributor rotation. It will not fill with oil if it is turned in the wrong direction.

Some manufacturers recommend filling the pump cavity with petroleum jelly; others say that this will cause an air bubble in the pump, which will keep it from filling with oil. Some pumps (the internal/external in particular) are not self-priming and *must* be filled with low melting temperature assembly lube before installation. Follow the manufacturer's directions.

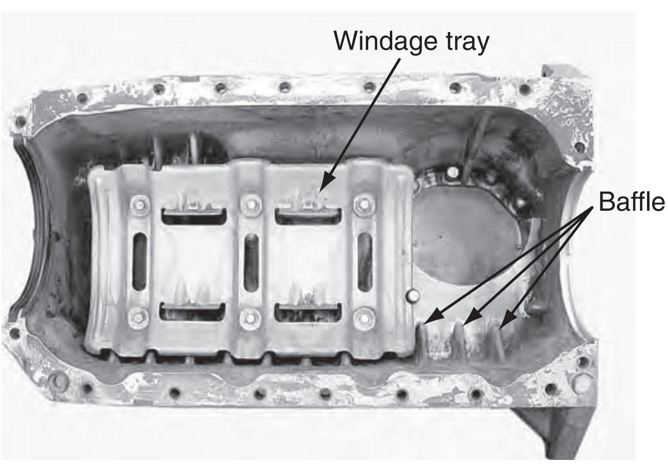


FIGURE 14.44 An oil pan with a built-in windage tray. (*Courtesy of Tim Gilles*)

Pressure Priming

In a static oil pressure test, a pressure primer (**Figure 14.45**) can be used to check for excessive bearing clearance as well as to prime the system. The primer can also be used to flush oil galleries during an in-vehicle engine repair job. The supply of oil in the primer tank should be enough to fill the new oil filter as well as the oil lines in the block.

- With the oil pan removed, block off the oil pump inlet to perform the test (**Figure 14.46**).
- Acceptable leakage from bearings can be from 20 to 150 drops in a minute. A more rapid flow indicates excessive clearance (**Figure 14.47**).
- Rotate the crank one-half turn and test again before condemning the bearing. If the oil holes

FIGURE 14.45 An oil pressure primer supplying the engine with oil through the oil sender opening. (*Courtesy of Tim Gilles*)

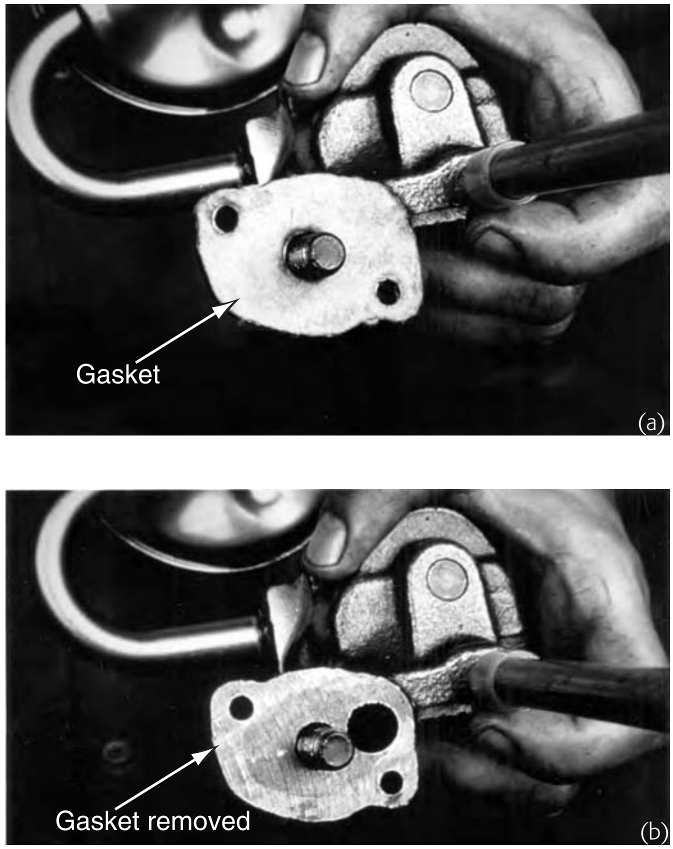


FIGURE 14.46 (a) The oil pump inlet is covered with a gasket during the pressure test. (b) Be sure to remove the gasket after priming is completed. (*Courtesy of Federal-Mogul Corporation*)

in the crank and block were indexed, the appearance of excessive leakage could result.

- An absence of oil flow indicates a blocked oil line or insufficient clearance.
- After priming is completed, be sure to remove the gasket that was installed to block oil to the pump.

Information on priming crankshaft-driven oil pumps is covered in Chapter 17.

OIL FILTER

An engine's oil filter prevents harmful abrasive particles in the oil from damaging internal parts of the engine. Most oil filters are the *spin-on* type (**Figure 14.48**). The sheet metal shell of the filter contains a filtering element, which is usually made of pleated paper. Oil flows through the paper from the outside to the inside, taking advantage of the entire surface area of the paper for maximum flow (**Figure 14.49**). A metal tube in the center of the filter keeps the paper element from collapsing inward when the oil is thick or contaminated (**Figure 14.50**).

Full-Flow Oil Filter

Today's passenger vehicles use the **full-flow oil filter** system. In full-flow systems, all of the oil supplied by the pump is *supposed* to flow through the

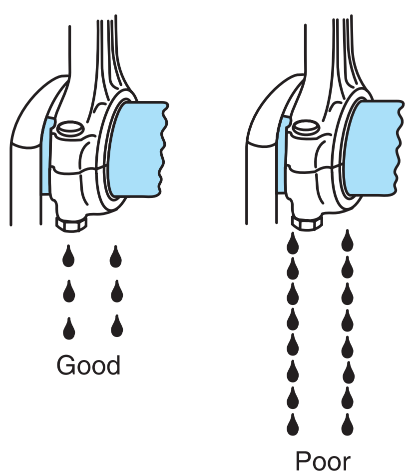


FIGURE 14.47 The amount of oil leakage depends on the amount of bearing oil clearance.

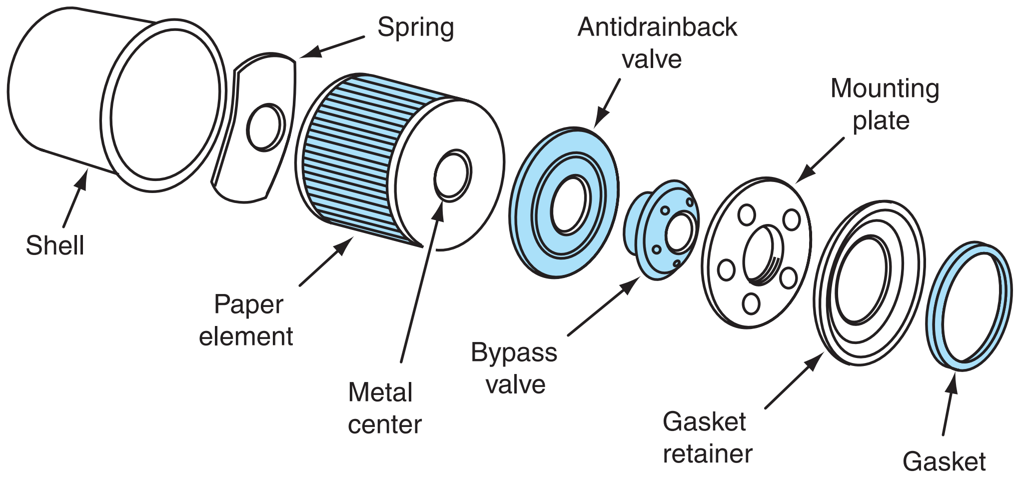


FIGURE 14.48 Parts of a pleated paper oil filter.

oil filter on its way to lubricate the engine bearings (**Figure 14.51**). The filter used is made of tough, treated paper that has a minimum resistance to flow. It is called a *surface-type* filter.

Because all of the oil supplied by the pump must first flow through the filter before it can reach the bearings, a full-flow filter must have a **bypass valve** (**Figure 14.52**). The bypass valve opens to let the unfiltered oil flow to the engine when:

- The oil is cold and thick.
- The filtering material is plugged due to a lack of proper maintenance. Some engines have a built-in bypass valve. Otherwise, it is incorporated into the filter.
- The bypass valve on most passenger car oil filters will open when resistance to flow reaches about 8 psi. At normal oil operating temperature, oil flowing at 4 gallons per minute through a paper filter will have a pressure drop that is less than 1 psi.
- Full-flow filters filter out only relatively large particles. A typical full-flow paper oil filter element will trap and hold any particle that is larger than 40 microns (100 microns is equal to 0.004″). A human hair is usually about 60 to 80 microns in diameter, so the size of filtered particles would be visible to the eye.

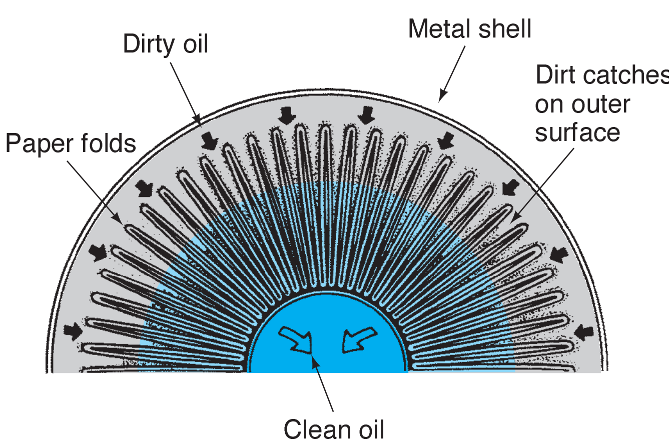


FIGURE 14.49 Oil flows through the paper in the filter. (*Courtesy of Dana Corporation*)

FIGURE 14.50 A metal tube prevents the filter from collapsing under oil pressure. (*Courtesy of Tim Gilles*)

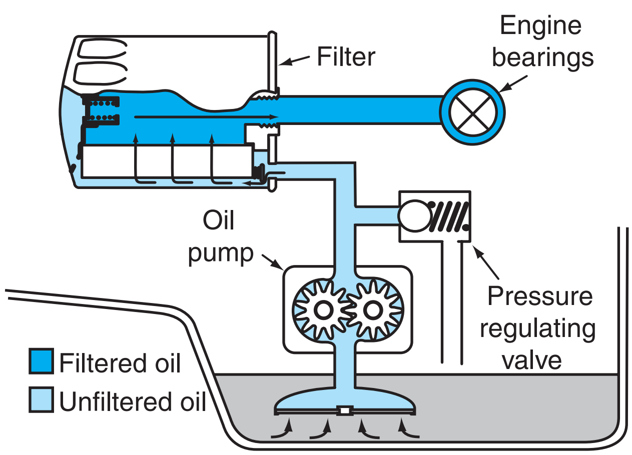


FIGURE 14.51 In a full-flow system, all oil is pumped to the filter.

Particles that are smaller than the filter can trap cause only minor wear when proper service intervals are maintained. They remain in the oil, held in suspension by the detergents and dispersants. If the filtering material was dense enough to filter out all of the smaller particles too, it would not be able to allow enough oil flow to be able to function as a full-flow filter.

Oil flows into the filter through the small holes that are in a circle in the filter base. It flows out through the large center hole (**Figure 14.53**). Many oil filters are mounted horizontally on the engine block. When the engine is shut off, about half of the oil in these filters can empty out through the filter inlet holes.

Horizontally mounted filters must have an **antidrainback valve** to prevent this from happening (see Figure 14.52). If the drainback valve fails or if the wrong filter is used, the lubrication system will be starved of oil until the filter is filled back up. On engines with hydraulic lifters or overhead cam engines that have hydraulic timing chain tensioners, this will result in a noisy condition in the morning.

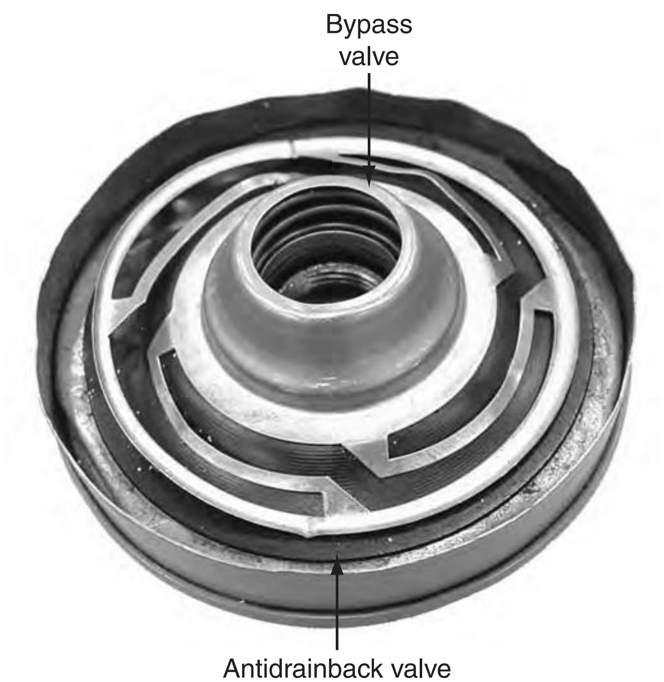


FIGURE 14.52 Cutaway of an oil filter showing oil filter bypass and antidrainback valves. (*Courtesy of Tim Gilles*)

Variations in Filters

Oil filters are identified by a number that is printed on the metal shell of the oil filter and on the filter box. Usually printed on the box will be an application chart that tells which cars a filter will fit. A cross reference is often included that tells which other manufacturers' filters interchange with a particular filter.

Be sure to follow the filter manufacturer's catalog recommendations when selecting an oil filter. There are metric and U.S. threads found in a mix in both import and domestic filters, so a filter might fit on the mounting base and yet not have the correct thread. A loose thread fit could result in serious engine damage if the filter becomes loose. A tight thread fit can result in a stripped thread. Some filters have antidrainback valves and bypass valves; others do not.

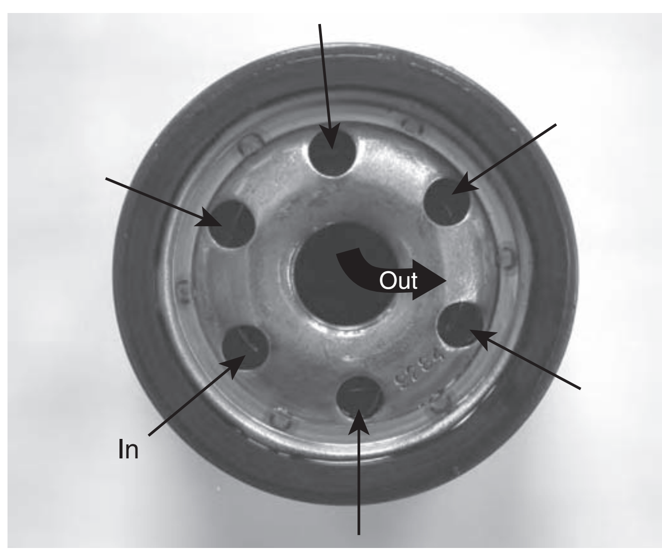


FIGURE 14.53 Oil flows into the filter through the small holes and out through the large center one.

VINTAGE ENGINES

Bypass Filters. Supplemental add-on filters and oil filters used on heavy trucks and vintage passenger vehicles are sometimes of the **bypass** or partial-flow **oil filter** design (**Figure 14.54**). A bypass filter traps very fine materials and allows very little oil to flow through it. It only filters about 10% of the oil at one time. Oil is picked up at any pressurized point and allowed to "leak" through the parallel path provided by the filter on its way back to the oil pan. Little, if any, pressure drop occurs from this leak because the amount of flow is so little.

Bypass filter elements are made of such materials as cotton fiber, shredded paper, stacked high-density filter papers, and wood chips, which can remove particles down to 1 micron in size (one thirty-nine millionth of an inch). They are called *depth-type* filters. These filters are capable of removing sludge and were used in older vehicles that used straight mineral (SA) oil (which produced sludge rapidly). Today's oils do not allow the formation of sludge unless detergent/dispersants have been depleted.

CHANGING THE OIL FILTER

The sheet metal shell on an oil filter is very thin. It can easily become collapsed with improper handling, making it difficult to remove. Many technicians prefer to use a professional quality *oil filter wrench* with a pivoting handle (**Figure 14.55**). This tool allows for easy positioning at the *base* of the filter. The sheet metal filter case is supported at the base by the heavy mounting plate (see Figure 14.48), so it will not collapse. There are also specialized oil filter wrenches available to fit the many different filter applications.

There is a rubber O-ring on the bottom of the filter that seals it against the engine block. Inspect it to see that it is in place on the filter and is undamaged (**Figure 14.56**).

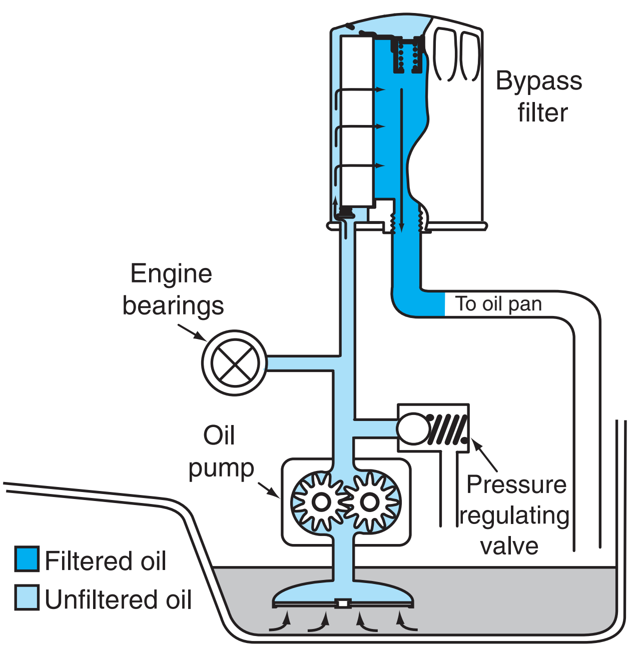


FIGURE 14.54 Heavy-duty filtering systems use a bypass filter that filters only a small amount of oil at any one time.

FIGURE 14.55 An oil filter wrench should be placed as close to the filter base as possible. (*Courtesy of Tim Gilles*)

FIGURE 14.56 The O-ring gasket is out of its groove on the base of this oil filter. (*Courtesy of Tim Gilles*)

NOTE

Check to see that the old filter O-ring is not stuck on the engine block. If the new filter O-ring is installed against the old O-ring, it is possible that oil pressure can blow through this weakened area, resulting in a serious oil leak and possible catastrophic engine damage.

The Automotive Filter Manufacturer's Council recommends that the filter's O-ring be lubricated with oil before installing the filter. It recommends against using grease.

Most filters have instructions printed on the outside stating the amount that the filter should be tightened. An example of such instructions is: "tighten the filter ¾ turn after the gasket contacts the block." If the filter cannot be tightened a sufficient amount with bare hands, a filter wrench can be used. Overtightening a filter will make future removal difficult.

NOTE

When refilling the crankcase with oil, an extra amount of oil equivalent to the oil filter's capacity must be added. Service information sometimes specifies an amount that includes the filter capacity. Some technicians fill the filter with oil before installation to prevent the engine from running "dry." This is especially recommended on engines with turbochargers.

CRANKCASE VENTILATION

The PCV was the first emission control system installed on all new cars since the early 1960s. The PCV system prevents the emission of hydrocarbons in blowby gases by scavenging them from the crankcase and reintroducing them into the combustion chambers. A *PCV valve* modulates a small amount of air leakage into the intake manifold that pulls the blowby gases from the crankcase (**Figure 14.57**). Besides eliminating one source of air pollution, the PCV system has two main benefits:

- It reduces sludge by removing moisture from the crankcase.
- Oil leakage caused by excessive crankcase pressure is reduced.

NOTE

Some people mistakenly call this system a PVC system. PVC stands for polyvinyl chloride, a common plastic used for wire insulation and plastic pipe.

The PCV system works best at idle and part throttle. Because it operates on intake manifold vacuum, the PCV valve does not function as well under a load, when there is less intake manifold vacuum. Therefore, it opens up further to allow

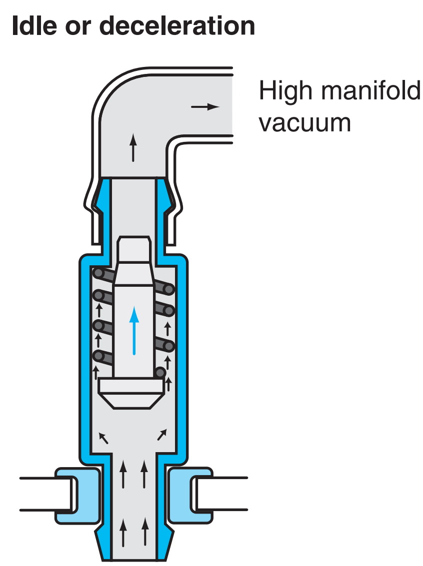


FIGURE 14.57 A PCV valve allows a small amount of intake manifold vacuum to leak to the crankcase.

VINTAGE ENGINES

Road Draft Tubes. Engines produced in the 1950s and earlier were equipped with a road draft tube to help purge the crankcase of crankcase pressure caused by blowby (**Figure 14.58**). These systems did not function when the vehicle was at rest. They depended on the forward motion of the vehicle to move air beneath the road draft tube to create a vacuum that would pull vapors from the crankcase into the surrounding air. Since the early 1960s, cars have had positive crankcase ventilation systems instead of road draft tubes. PCV systems are purported to have resulted in a 25% decrease in emissions from automobiles. Engines with PCV systems are much cleaner internally and acids are not formed in stagnant air like with a road draft tube.

more blowby to pass through to the intake manifold (**Figure 14.59**). Many people believe that blowby is higher when engine rpm is higher, but there is actually more blowby at idle. At higher speeds, compression rings seal better, resulting in less blowby.

On open PCV systems used before 1965, excess blowby could escape through a breather into the outside air. PCV systems today are *closed PCV systems* (**Figure 14.60**). Atmospheric pressure must enter the crankcase for the ventilation system to operate. Filtered intake air is supplied through a hose from the air cleaner. Fresh air in the hose, which is at atmospheric pressure, flows toward the negative pressure created by the PCV valve, which is an engineered vacuum leak. The fresh-air hose also provides an escape route for excessive crankcase pressure when blowby is more than the PCV valve can handle or the PCV valve is plugged. Excess pressure escapes through the

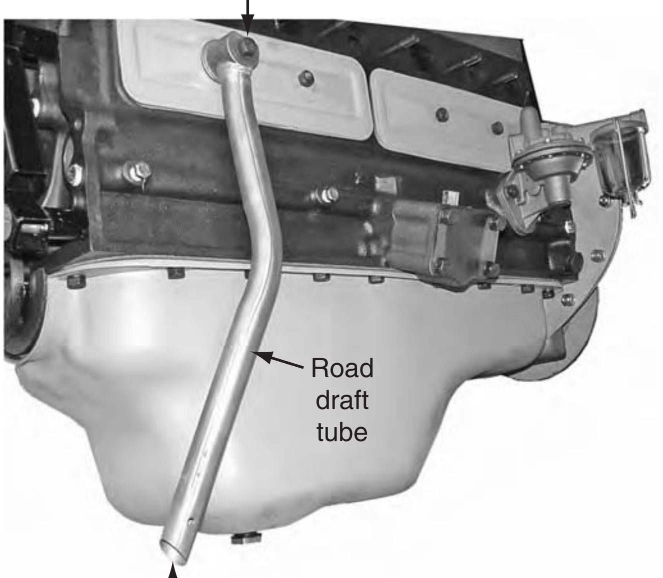


FIGURE 14.58 A road draft tube was used on vintage engines prior to positive crankcase ventilation. (*Courtesy of Tim Gilles*)

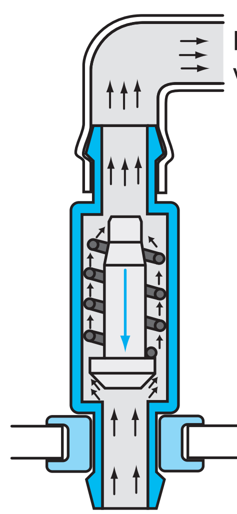


FIGURE 14.59 When the engine is under load, the spring moves the PCV valve to allow more airflow.

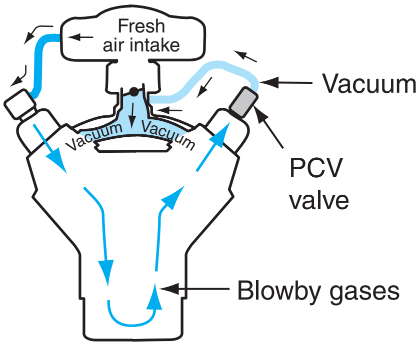


FIGURE 14.60 A closed crankcase ventilation system.

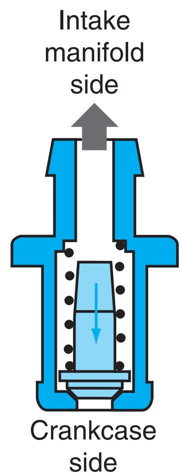


FIGURE 14.61 When the engine is off, or if there is an explosion in the intake manifold, the PCV valve is closed to the crankcase.

hose into the air cleaner, where it will be drawn once again into the intake system with incoming fresh air.

NOTE

A few PCV systems do not use PCV valves. Some use a metered orifice, and others use a breather hose from the crankcase to the air cleaner.

The orifice in the crankcase ventilation system, which is usually part of the PCV valve, is a specific size to match engine displacement. Therefore, it is very important that the correct valve be used. Performance problems, as well as oil leaks, can be traced to the installation of a PCV valve of incorrect size.

NOTE

Blowby is measured in cubic feet per minute (cfm). Normal blowby cfm can be estimated by dividing the maximum horsepower that the engine can develop by 50. For instance, a 250-horsepower engine would be expected to have 5 cfm of blowby. Engines built with closer top ring gap clearances tend to have less blowby and, therefore, make more horsepower.

When the engine is turned off, or if there is an intake manifold pop-back, the PCV valve is pushed against its seat by the spring, closing it off (**Figure 14.61**). If the valve was not against its seat during a pop-back, the flames from the explosion would be able to enter the crankcase.

FIGURE 14.62 Racing engines usually have multiple breathers in the valve covers to allow excess crankcase pressure to escape. (*Courtesy of Tim Gilles*)

Make sure that the hose running to the air cleaner is not kinked or its filter plugged. During a heavy load, this hose must allow excess pressure to escape from the crankcase. Racing engines must get rid of extra crankcase pressure, so they often use multiple breathers on each valve cover (**Figure 14.62**).

To test a PCV valve:

- Pull the valve from its mounting.
- With the engine running, cover the end of the valve with your thumb or finger (**Figure 14.63**).

FIGURE 14.63 Checking a PCV valve; the engine's idle should drop at least 50 rpm when the valve is plugged. Disable computer idle control on late-model cars when performing this test.

Engine rpm should drop 50 to 80 rpm, because the slight air leak that the PCV valve causes has been closed off. Late-model vehicles will need to have computer idle control disabled before running this test.

- With the engine running and the PCV valve installed, vacuum should be present at the rocker cover oil filler opening.
- With the engine turned off, the PCV valve can be removed and shaken. It should rattle.

Key Terms

antidrainback valve
API
boundary lubrication
bypass oil filter
dry start
full-flow oil filter
polymers
SAE
viscosity
viscosity index

Study Questions

1. Under normal conditions, when is the only time that an oil film does not keep engine parts separated?
2. What does SAE stand for?
3. When an oil is tested at 0°F (–18°C), what letter will appear in the viscosity listing on the oil container?
4. What is the name of the part of the oil additive package that swells, allowing oil to maintain its viscosity as it heats up?
5. What causes oil oxidation?
6. What is the best API service classification for automotive engine oil?
7. If sludge forms in a late-model engine, what additive is probably depleted?
8. What oil filter part would allow oil to get to the bearings if the filter is plugged?
9. When removing an oil filter, position an oil filter wrench at the _____ end of the filter.
   a. inner
   b. outer
10. What part of the engine usually drives the oil pump?
11. The lubrication system should be able to produce a minimum of _____ psi for each 1000 rpm.
12. When priming the oil pump, the pump should be spun in the same direction that the _____ normally rotates.
13. What could be indicated by low oil pressure at idle?
14. List three types of oil pumps.
15. A _____ displacement pump has a fixed output per revolution.

ASE-Style Review Questions

1. Technician A says that too much oil pressure can cause excessive oil consumption. Technician B says that viscosity goes up (oil becomes thicker) with lower temperatures. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. Technician A says that a full-flow oil filter will bypass some of the oil under cold running conditions. Technician B says that a full-flow oil filter can bypass some of the oil during high-speed operation. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. Technician A says that an oil filter used in a bypass system can filter out smaller particles from the oil than a full-flow system. Technician B says that a full-flow filter that is mounted in a horizontal or inverted position requires an antidrainback valve. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. Technician A says that oil pressure that fluctuates from high to low can be caused by a sticking oil pump pressure relief valve. Technician B says that a stuck-closed pressure relief valve will result in high oil pressure at idle (at normal operating temperature). Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. Technician A says that full-flow oil filters have a minimum resistance to oil flow compared to bypass filters and are not designed to filter out sludge. Technician B says that bypass oil filters are used in heavy-duty applications, primarily to provide filtration in addition to a full-flow filter. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. Technician A says that when oil oxidizes it becomes heavier and forms varnish deposits. Technician B says that in-town driving is easier on the engine than driving on the freeway. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that an SAE 40 oil has a lower viscosity than an SAE 20W-50 at engine operating temperature. Technician B says that a 10W-40 multiviscosity oil reaches bearings faster when the engine is first started than an SAE 30 single viscosity oil. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says that detergents and dispersants keep small particles suspended in the oil so that the filter can filter them out. Technician B says that detergents clean the surfaces within the engine. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that when the oil is cold and thick, it can bypass the oil filter. Technician B says that when the oil filter is dirty and restricted, oil can bypass the filter. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Technician A says that the “W” in SAE 10W-40 stands for “weight.” Technician B says that SA, or “nondetergent,” oil should not be used in late-model automobiles. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 15

Cooling System

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Analyze wear and damage to cooling system parts.
- Explain cooling system theory.
- Select and perform the most appropriate repairs to the cooling system.

Introduction

The cooling system is a very important support system to an engine. Failure anywhere in the system will cause severe engine damage. A vehicle owner should be reminded that periodic maintenance of the cooling system is vital to the dependable, long-term operation of a rebuilt engine. Many aspects of the cooling system are not well understood. Too often when engines are repaired this important system is neglected, resulting in a very expensive failure. It makes no sense to rebuild an engine unless the cooling system will also be as good as new. Failure of a hose, belt, or coolant pump can ruin a new engine in a short time.

Combustion temperatures sometimes reach as high as 4500°F (2482°C); average temperatures of combustion are close to 2000°F (1093°C). Aluminum pistons melt at about 1225°F (663°C), so this heat must be carried off rapidly to prevent engine damage (**Figure 15.1**). Most of this heat is not used to propel the piston and must be carried off by the cooling system (**Figure 15.2**).

TYPES OF COOLING SYSTEMS

Some smaller engines are only cooled by air, but most automotive cooling systems use liquid coolant to carry heat to the radiator and surrounding air. The engine block and cylinder head have cast-in water jackets surrounding its cylinders and combustion chambers (**Figure 15.3**).

Cooling System Parts

A liquid cooling system is made up of the following parts (**Figure 15.4**):

- The water pump, or coolant pump, circulates water throughout the system.
- The radiator conducts heat away from the coolant.
- Radiator hoses connect the parts of the cooling system.
- The fan pulls air through the radiator when the car is not moving fast enough to move the air.
- The thermostat controls the temperature of the coolant.

- Coolant is circulated to the heater in the passenger compartment.

Cooling System Circulation

Coolant exits from the bottom of the radiator after it is cooled. It is drawn into the coolant pump (commonly called a *water pump*) (**Figure 15.5**), which pumps it into the block and head where it picks up heat. The coolant is then returned to the top of the radiator where it is cooled again. Figure 15.4 shows a typical engine's coolant flow.

Coolant Pump

The coolant pump on the front of the engine is a centrifugal impeller-type pump. It is usually belt driven by the crankshaft, although some coolant pumps are driven by the back side of a timing belt (**Figure 15.6**) and a few engines use electric coolant pumps.

An *impeller* fits in the circular pump housing. As it turns, centrifugal force draws coolant into the pump inlet near the center of the pump (**Figure 15.7**). It exits from the outlet at the outside of the pump. Centrifugal pumps are *variable displacement*, which means their output changes with speed. The pump is sometimes called upon to circulate as much as 7500 gallons of coolant in 1 hour.

The pump shaft has a spring-loaded, permanent seal to prevent coolant leakage. **Figure 15.8** shows the relationship between the bearing and its spring-loaded *mechanical seal.*

The coolant pump housing is either aluminum or cast iron. Most pumps are aluminum, which is subject to erosion. As the aluminum erodes, the pump cavity becomes larger. This results in reduced pump efficiency, which can cause air pockets. Severe erosion can also result in serious internal or external leaks.

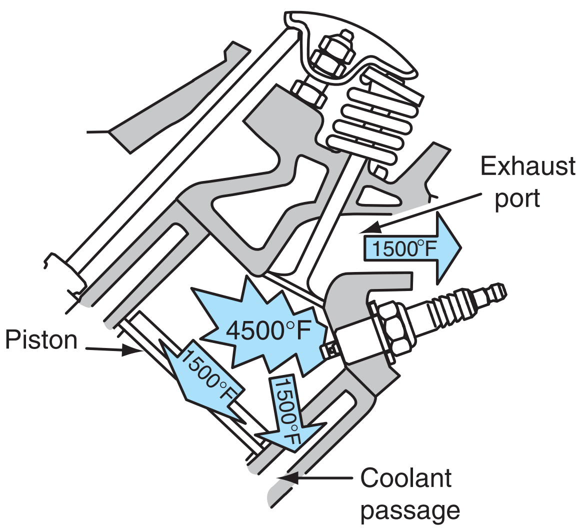


FIGURE 15.1 Engine heat is carried off by the cooling system.

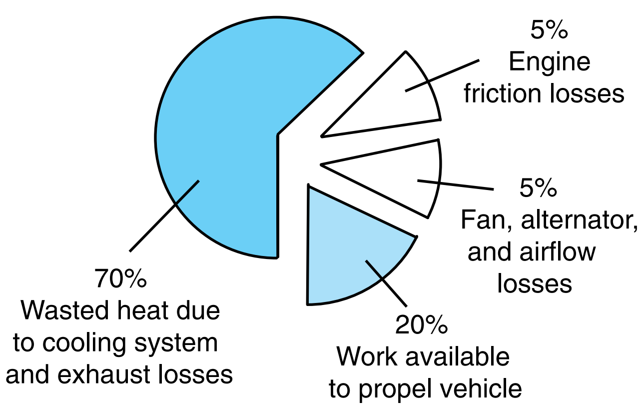


FIGURE 15.2 Seventy percent of an engine's heat energy is wasted.

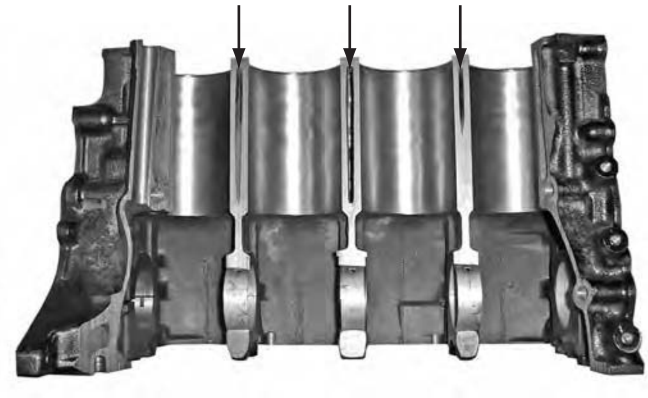


FIGURE 15.3 Coolant passages surround the cylinders. *(Courtesy of Tim Giles)*

Coolant Pump Failure

Coolant pumps can suffer a failure in the static seal, bearing, or impeller.

Seal Failure. Seal failure is very common. A seal can become red hot when an engine is run without coolant. Adding cold water to an overheated system shocks the hot seal, causing it to crack. Seal failure is often evident when coolant leaks from a coolant pump *vent hole* (**Figure 15.9**), sometimes called a *weep hole.*

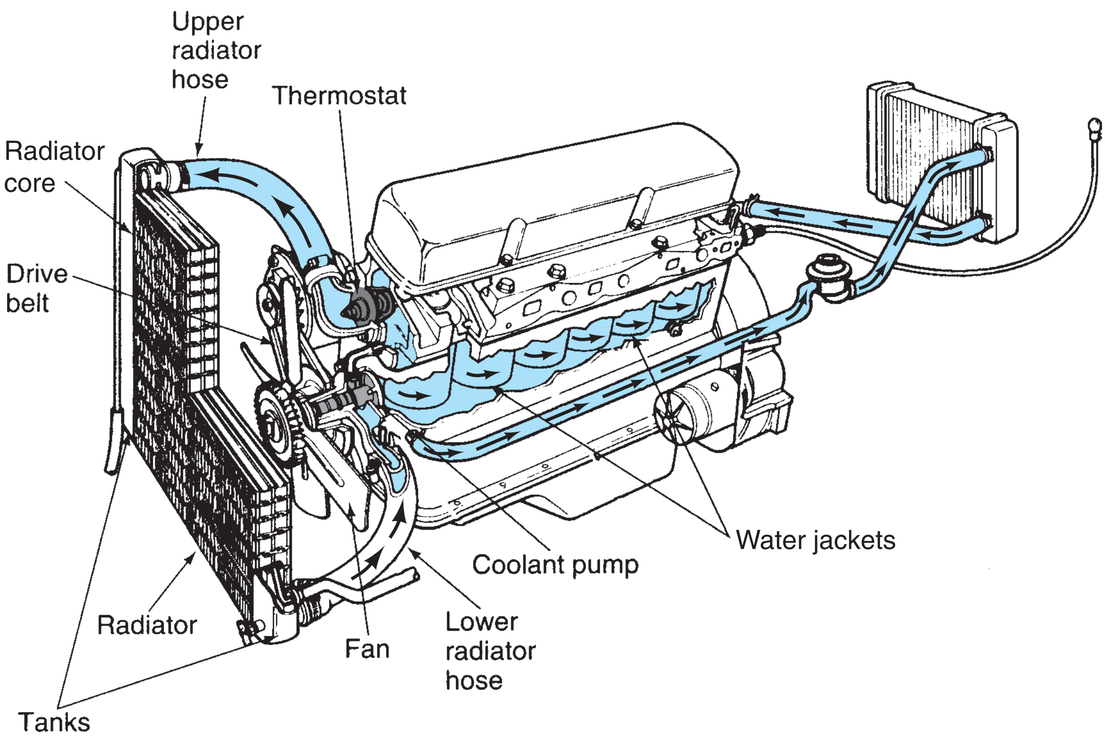


FIGURE 15.4 Parts of a liquid cooling system in a rear-wheel-drive vehicle.

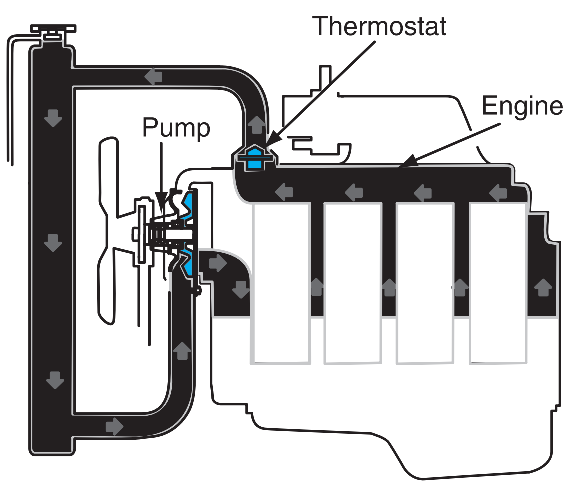


FIGURE 15.5 In a conventional flow system, coolant exits the bottom of the radiator and is drawn into the coolant pump.

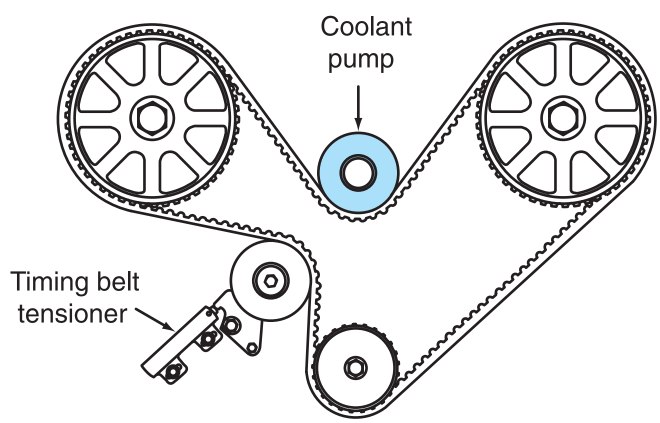


FIGURE 15.6 A coolant pump driven by the back side of a timing belt.

NOTE

Many newer pumps do not have vent holes.

Pump Bearing Failure. The pump bearing is permanently sealed and can be damaged by excessive belt tension. When a bearing fails, the static seal will also be damaged, which can result in a coolant leak.

- An out-of-balance fan assembly can lead to coolant pump shaft and bearing failure.
- Possible causes of pump bearing failure include a leaking fan clutch, a bent or broken fan, or an aluminum fan spacer that is cocked or cracked. Be sure to tighten the fan bolts evenly to avoid causing a cocked assembly.

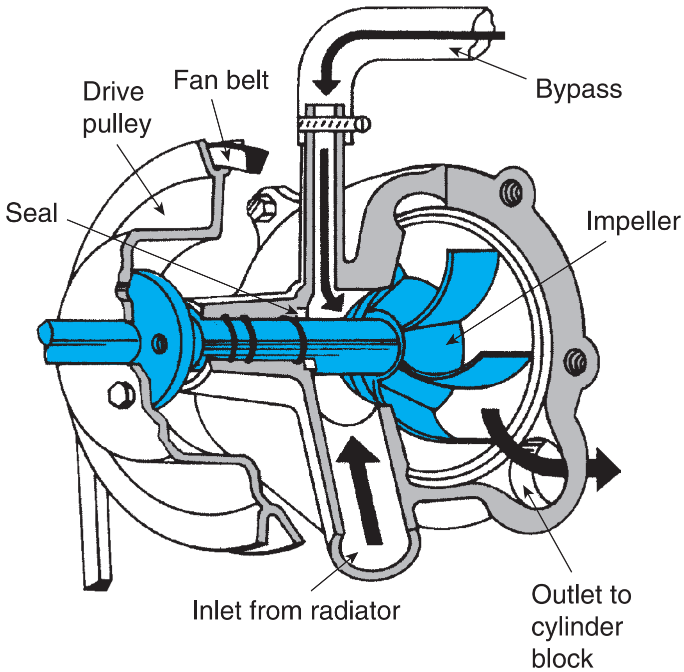


FIGURE 15.7 Parts of a coolant pump. *(Courtesy of Gates Corporation)*

Pump Impeller Failure. Pump impellers are either steel or plastic. Carefully inspect the impeller for erosion, looseness, or breakage. If pieces break off the impeller they will go into the block and, possibly, the radiator. It may be necessary to disassemble the radiator to be sure that all pieces are removed.

Pump Plate Leakage. Coolant pumps sometimes have a steel plate bolted to the back. This can also leak and should be resealed if a pump is reused.

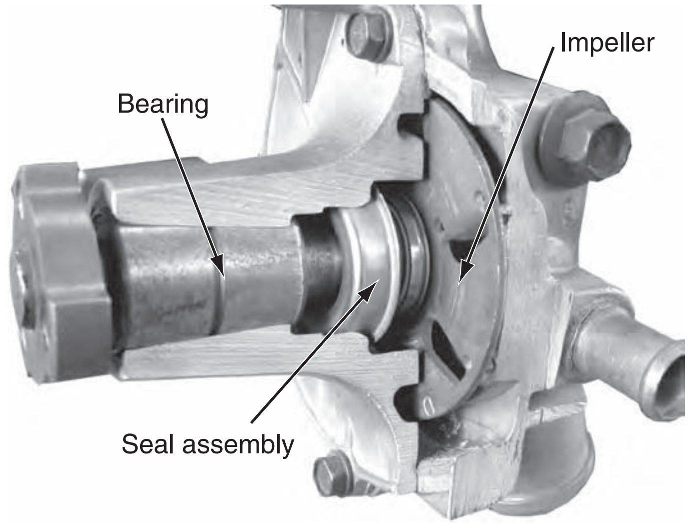


FIGURE 15.8 A cutaway coolant pump showing the relationship between the bearing and its spring-loaded mechanical seal.

ACCESSORY BELTS

Accessories are usually belt driven from the crankshaft pulley (**Figure 15.10**). The belt, pulleys, tensioner, bearings, and belt-driven accessories make up the *accessory belt drive system (ABDS)*. Pumps and air-conditioning compressors are driven either by a V-belt or a V-ribbed serpentine belt, which is more common on newer engines.

Belt Material

Accessory drive belts are very strong and flexible with *tensile cords* to provide strength. The

VINTAGE ENGINES

Older engines with cast iron heads sometimes had aluminum coolant pumps. In those days, rebuilt coolant pumps were common and iron pumps were more popular because, unlike aluminum, they were not affected by erosion.

VINTAGE ENGINES

On older coolant pumps, the plate gasket sometimes dries out and leaks. It is a good idea to remove the bolts in this kind of pump and cement both sides of the plate gasket before installing it.

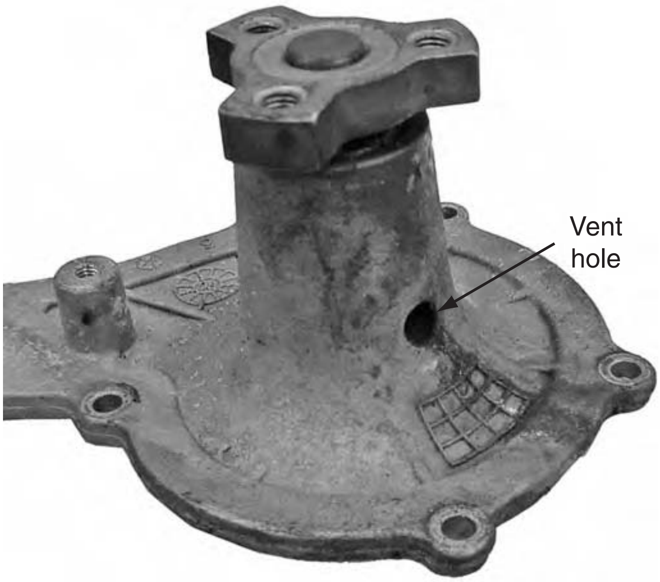


FIGURE 15.9 When leakage is evident at the vent weep hole, the pump seal has failed. *(Courtesy of Tim Gilles)*

overcord material on the top of the belt is made of oil-resistant artificial rubber. The undercord of the belt is the area beneath the tensile cords that supports the cord and transfers loads to the pulleys. Sometimes the undercords have a cord support platform with textile cords running perpendicular to the tensile cords. Tensile cords are used to prevent the belt from sagging in the middle, which results in uneven load distribution and early belt failure.

V-ribbed belts are ribbed on one side (**Figure 15.11**) and flat on the other. **Figure 15.12** compares the pulleys for V-belts and V-ribbed belts. The thinness of the belt makes it more flexible so it can bend around smaller pulleys and also be bent backward so both sides can be used to transmit power. Usually the ribbed side matches the pulley grooves of accessories and the flat side goes against a spring-loaded tensioning roller, but the flat side is also capable of transmitting power.

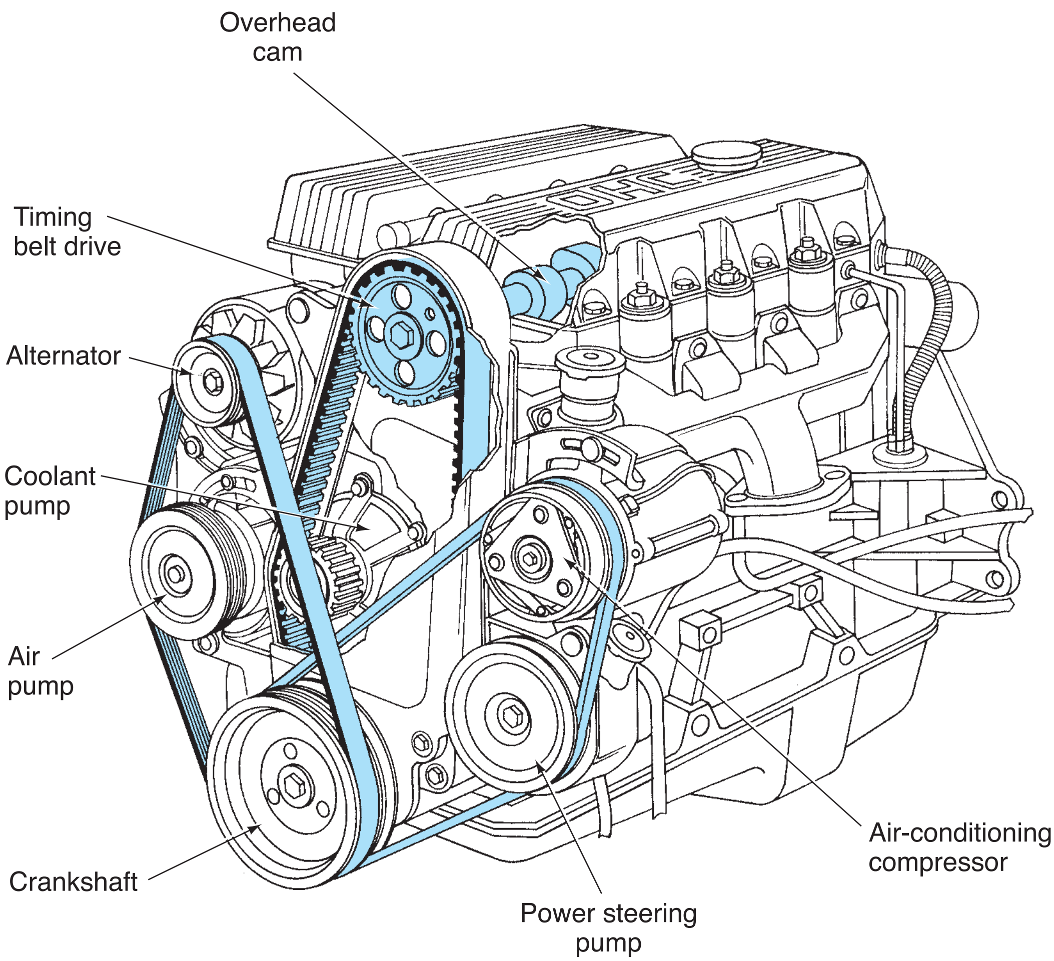


FIGURE 15.10 Belt-driven accessories and camshaft. *(Courtesy of Gates Corporation)*

VINTAGE ENGINES

Early vehicles used a flat drive belt. The V-belt was invented in 1917. It has more surface area in contact with the pulley groove than a flat belt of the same width would have. Today, most vehicles use serpentine V-ribbed belts.

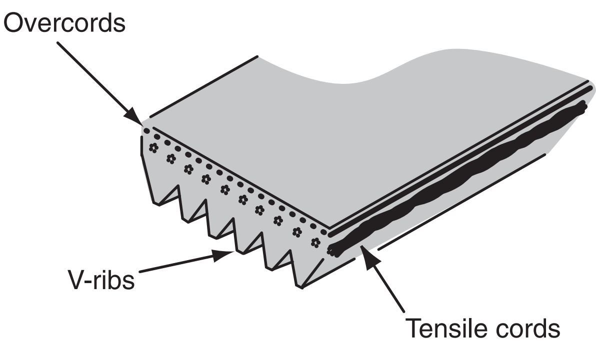


FIGURE 15.11 Construction of a V-ribbed belt.

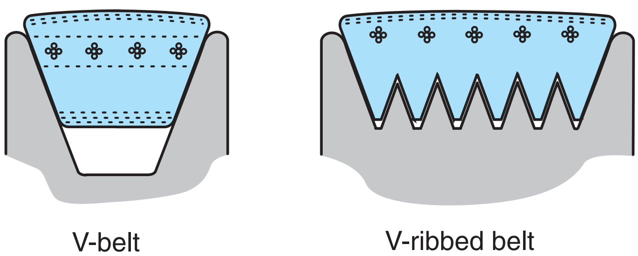


FIGURE 15.12 Comparison of a V-ribbed and a V-belt in their pulleys. Which belt has the most contact area?

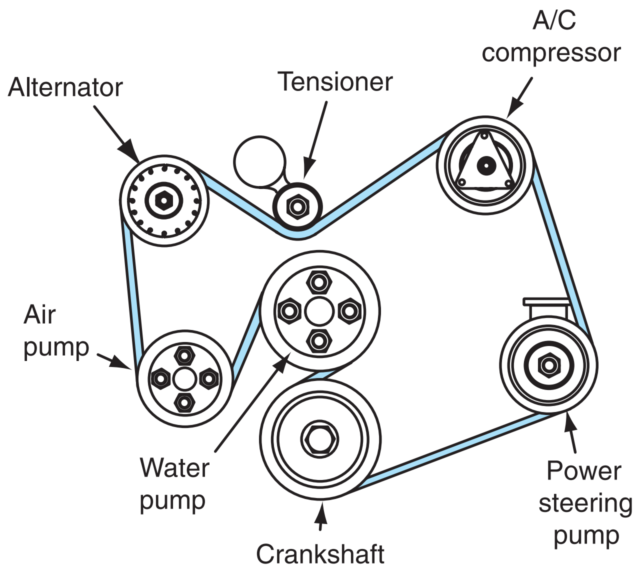


FIGURE 15.13 A serpentine V-ribbed belt drive.

V-ribbed belts are used in newer vehicles in a conventional manner or in a **serpentine** drive. Serpentine V-ribbed belts, which first appeared in the late 1970s, are used on many new engines today. One belt is used to operate all accessories (**Figure 15.13**). The belts are called serpentine because they follow a snakelike path, weaving around the various pulleys. Compared to V-belts, serpentine belts are easier to install, take up less space (**Figure 15.14**), transmit power more efficiently, and last longer.

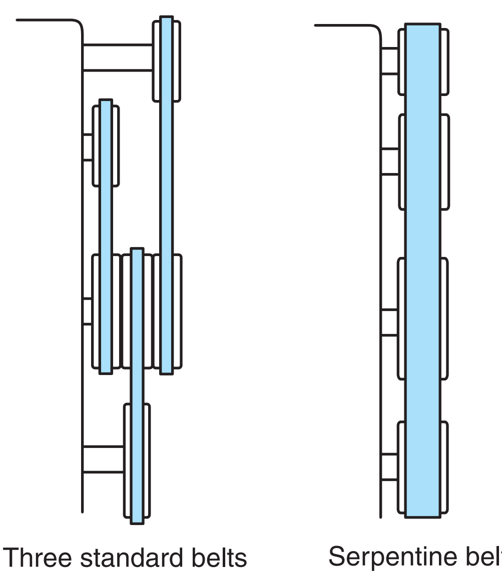


FIGURE 15.14 Serpentine belts save space.

Accessory Drive Belt Service

Accessory drive belts are very strong and dependable when they are replaced at reasonable intervals. A failed coolant pump drive belt can cause engine failure if the owner ignores the problem and continues to drive the vehicle until the engine severely overheats. One serpentine belt usually drives all of the accessories. The belts are relatively trouble-free, but if one fails, the cooling and electrical systems and power steering will all cease to operate. The engine will still run, but because the coolant pump is no longer being turned, driving the vehicle will result in serious engine damage.

CASE HISTORY

A motorist was traveling at 75 mph in moderate traffic in the fast lane on the freeway. Suddenly, the air-conditioning compressor clutch failed, causing the serpentine belt to be destroyed (Figure 15.15). The motorist was concerned for her safety and continued driving the vehicle until she could get off the freeway and locate a telephone. By the time she was able to leave the freeway, the engine was seriously damaged from overheating.

FIGURE 15.15 This serpentine belt was destroyed when the air-conditioning clutch failed. *(Courtesy of Tim Gilles)*

SAFETY NOTES

- Before replacing a belt, disconnect the electrical connection to the electric cooling fan to prevent it from unexpectedly turning on. Be mindful of the output terminal on the alternator, which will be hot when the battery is connected. Prying against the outside of the alternator can result in an accidental short circuit.
- Compare the old belt with the new one to be sure the new belt is the right size. A belt that is too long can rub on a radiator hose or fuel line after tension is adjusted. With a spring-loaded tensioner, too long a belt will result in insufficient tension.

Belt Inspection

A belt will sometimes appear to be good, even when it is about to fail. Check all drive belts for wear, cracks, or damage that would call for their replacement. Underside cracks on a serpentine belt are normal, but if there are more than three cracks in a 3-inch section of any individual rib, remaining belt life is less than 20% and the belt should be replaced along with the tensioner.

Belts made of EPDM, a synthetic rubber, suffer considerably less cracking.

Belt Replacement

Because belts are so important, it is advisable to change them periodically *before* they fail, regardless of appearance. Belt failures rise significantly after 4 years of use. Therefore, this is the minimum recommended interval for replacement, although belts made of EPDM sometimes have manufacturer suggested replacement intervals of 10 years or 150,000 miles.

Sometimes different width drive belts are used specifically within one vehicle manufacturer's product line. Always count the number of grooves on a pulley being replaced.

CASE HISTORY

A technician was replacing a defective air-conditioning compressor clutch with a new one. When the service advisor asked how the job was coming, the technician told him it would be finished in 1 hour. The customer was notified and arrived to

pick up his vehicle. While the technician was finishing the job, the service advisor completed the paperwork and the customer paid his bill. But when the technician attempted to install the V-ribbed belt, he found that it would not fit the new air-conditioning clutch pulley because it had five grooves, rather than six, like the original compressor clutch pulley. The job had to be put off until the next morning. The customer was from out of town and, without a car to drive, he had to get a motel for the night.

Belt Tension

A slipping belt can result in several problems, including severe engine damage. Most drive belts today are serpentine V-ribbed belts with automatic spring-loaded tensioners. If the tensioner does not apply sufficient tension to the belt it will slip, creating heat that migrates from the pulley into the shaft and bearing. If the bearing gets hot enough, the bearing cage can fail or the grease can boil out of the bearing, causing it to fail prematurely. Alternator bearings and coolant pump seals are especially sensitive to vibration and heat.

When the drive belt system includes an automatic tensioner, belt stretching will not normally cause low belt tension. Older engines sometimes experienced damage to accessory bearings and the upper front crankshaft main bearing when belts were *overtightened*. An automatic tensioner will not overtighten a belt unless the belt is too short.

When a belt slips on the pulley, it becomes glazed (shiny) on the bottom side. Glazing results as the belt ages from heat. A glazed belt must be replaced because it will not grip the pulley tightly, even if tension is adjusted at specification.

Spring-Loaded Tensioner Inspection

With the belt removed, spin the pulleys to see that they turn without resistance or roughness. Use a wrench to move the tensioner arm through its entire travel multiple times to verify that the arm moves smoothly without sticking. Inspect the outside of the tensioner for rust and grease. Rust migrating out from the inside indicates metal-to-metal wear and failure of the tensioner. Grease should not leak from the pulley bearing. If there is seepage, the bearing seal is damaged.

Check the tensioner arm for side-to-side looseness, which is indicative of a worn pivot bushing. Before removing the belt, run the engine while watching the belt as it rides on the flat idler pulley on the tensioner arm. The belt should remain centered on the pulley. If it is running off-center, a worn pivot bushing in the tensioner is a likely cause. Misalignment occurs as the tensioner arm moves away from its base. The bushing is internal and looseness is difficult to observe while the tensioner is installed on the engine. Because the tensioner moves out of alignment with the belt, look for side wear on the belt.

SHOP TIP

You can perform a spray bottle test with the engine idling. Wet the underside of the belt with water. The water acts as a lubricant; misalignment can be pinpointed if the belt stops chirping for a moment. If belt noise becomes louder, too little belt tension can be the cause.

Spring-Loaded Tensioner Internal Damper

Some tensioners have an internal damper that acts like a brake on the tensioner arm. The damper minimizes pulsations on the belt drive system that result when cylinder firing impulses are transmitted into the crankshaft drive pulley. If the damper becomes worn, the spring arm will bounce. This can cause the belt to hammer on the accessory drive pulleys, sometimes leading to part failure. A small amount of movement is normal as accessories are turned on and off, but if you can see the tensioner oscillating, a failed damper could be the cause and it should be replaced. According to Gates, tensioners that do not have a built-in damper may require more frequent replacement.

NOTE

Some tensioners are fastened against the engine block with left-hand fasteners.

Belt Alignment

Misalignment can cause rapid belt and pulley wear or thrown belts. According to Gates, belt temperature can rise by 30°F (–1°C) if the belt is misaligned by only a few degrees. This can cut belt life expectancy in half. There are two types of belt misalignment: parallel and angular. Pulleys can be parallel, although not in the same plane. Misalignment can also be the result of an improperly located accessory, tilted with its pulley at an angle different from the other pulleys (**Figure 15.16**). A misaligned V-ribbed belt can walk off the pulley or tear off a rib.

When pulleys are out of alignment, the belt will chirp. Noise is a result of vibration. In this case, the vibration results because the belt must continually slide into the groove as it moves against the pulley (**Figure 15.17**).

Short belt spans are less tolerant of misalignment. Noise will be more apparent when misalignment is between a flat pulley (backside pulley) and a nearby accessory.

NOTE

Wear on the side of the belt indicates misalignment.

A laser tool is handy for checking belt alignment (**Figure 15.18**). The tool is attached to one pulley. If the pulleys are in alignment, a laser beam shines precisely.

V-Ribbed Belt Replacement

Most V-ribbed belts have constantly spring-loaded tensioning idler pulleys. To release belt tension when removing or installing these belts, the smooth spring-loaded pulley is pulled away from the smooth back side of the belt (**Figure 15.19**).

A few vehicles use a "locked center" drive. With this design, belt tension is controlled in one of the following manners:

- Moving a tensioner pulley with an off-center bolt (**Figure 15.20**)
- Turning an adjustable jackscrew (**Figure 15.21**)
- Moving an accessory such as the alternator (**Figure 15.22**)

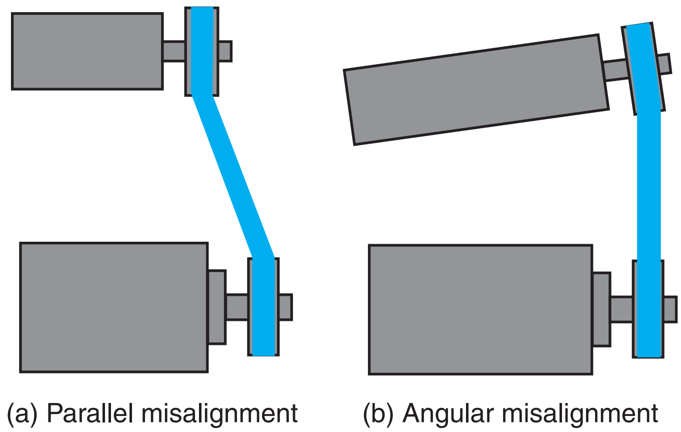


FIGURE 15.16 Pulleys can be parallel, but in different planes, or (b) an incorrectly located accessory can be tilted out of alignment.

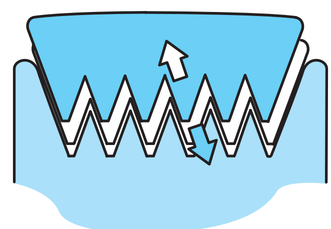


FIGURE 15.17 Noise happens when a misaligned belt vibrates in the pulley groove.

FIGURE 15.18 A laser tool used to verify belt alignment. *(Courtesy of Tim Gilles)*

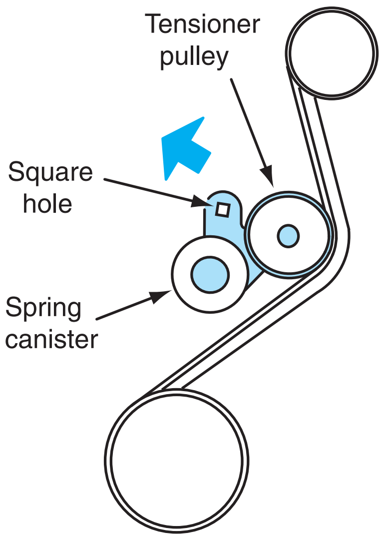


FIGURE 15.19 To install a V-ribbed belt with a spring-loaded belt tensioner, pull the pulley in the direction of the arrow to release belt tension.

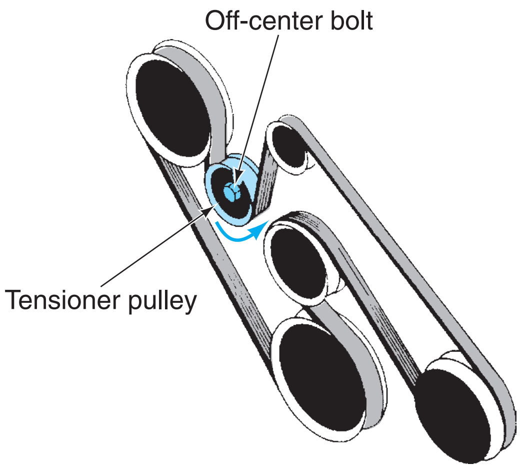


FIGURE 15.20 To loosen tension on this belt, turn the off-center bolt in the direction of the arrow. *(Courtesy of Gates Corporation)*

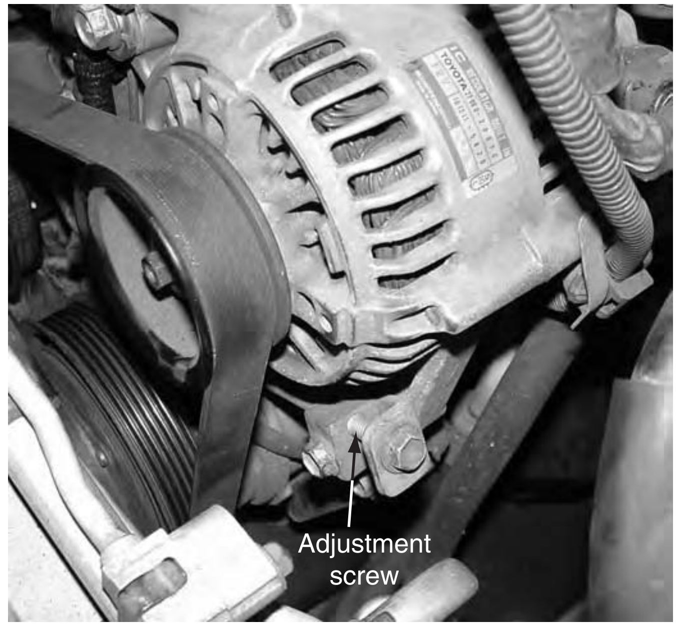


FIGURE 15.21 An adjustable jackscrew tensions this belt. *(Courtesy of Tim Gilles)*

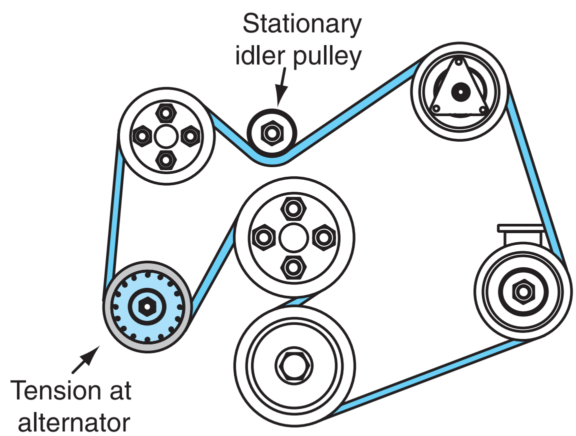


FIGURE 15.22 The alternator tensions this belt.

SHOP TIP

When replacing a belt tightened by a jackscrew, mark the location of the jackscrew threads with correction fluid before removing the old belt (**Figure 15.23**). If the new belt is the same brand as the old one, tightening to the correction fluid should provide an approximate belt tension before verifying with a belt tension gauge.

Most vehicles have an under-hood label showing a serpentine belt routing diagram, but sometimes there is none. In this case, make a sketch of how it is installed before removing the belt. Belt manufacturers produce catalogs with belt routing diagrams for the various makes of vehicles, and belt routing information is sometimes available in the owner's manual as well.

When the belt routing information is not available, the following tips might be useful:

- Remember that both sides of the belt can be used to drive accessories. The V-grooved side of the belt will mesh with pulley grooves. The flat side of the belt will go against a flat pulley.

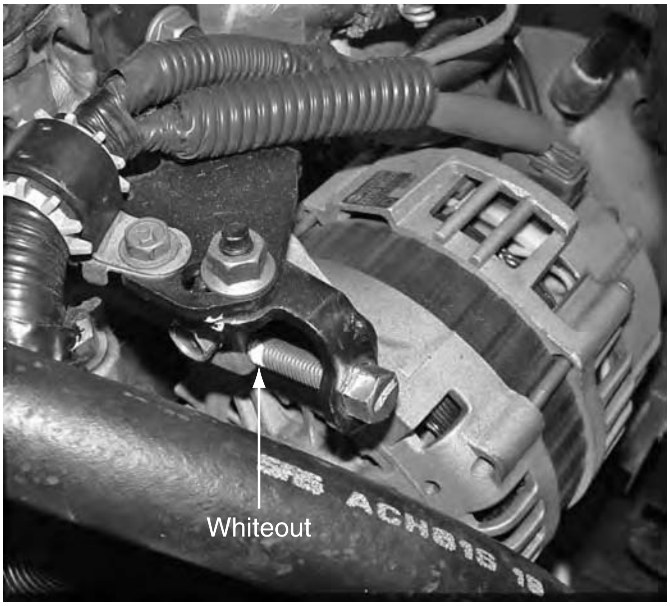


FIGURE 15.23 Before replacing a belt, mark the jackscrew with correction fluid. *(Courtesy of Tim Gilles)*

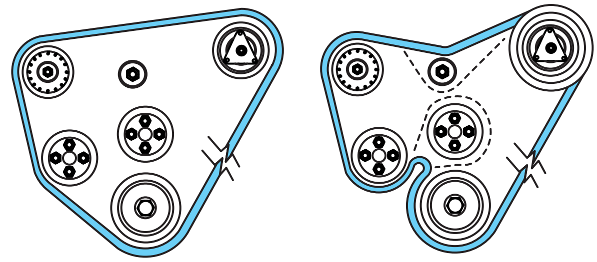


FIGURE 15.24 The belt is drawn in from the outside and looped around the smooth pulleys.

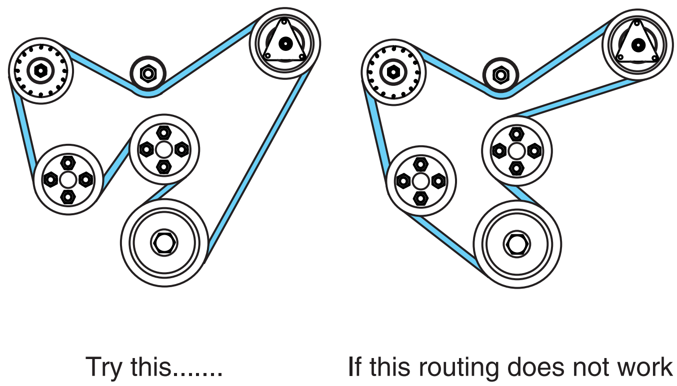


FIGURE 15.25 Different ways to position a serpentine belt.

- The belt is routed around the outside of the pulleys and is drawn in and looped around the smooth pulleys (**Figure 15.24**).
- Only one pulley can be threaded incorrectly. It is always near the center and is a smooth pulley.

SHOP TIP

If a belt seems too small to install, try installing it in a different order (**Figure 15.25**). For instance, if the belt will not go over the coolant pump pulley last, try installing it over the alternator pulley last.

SHOP TIP

When a belt is replaced, the old belt can be stored in the trunk for emergencies. If a belt fails, power to all accessories and the coolant pump will be lost.

Belt Tension

Belt tension is important for long belt life. Belts will stretch slightly in the first few minutes of operation and then remain constant in length. When no jackscrew adjustment is provided, there are several other ways that belts are tensioned:

- Some accessories are provided with a place to pry against (**Figure 15.26a**).
- Brackets sometimes have a hole that a prybar can be inserted into.
- Some manufacturers provide some provision for tightening, such as a ½" square hole in the mounting bracket for a ½" breaker bar to be inserted into (**Figure 15.26b**).

When there is no provision for tightening the belt, pry against a strong area of the accessory. Be sure that the outside of an alternator or power steering pump is not accidentally damaged. Do not pry on the power steering reservoir or any other delicate part. Power steering reservoirs are made of sheet metal. Prying against unreinforced sheet metal can result in a dent, which can cause a leak or damage to internal components of the pump.

VINTAGE ENGINES

Before serpentine V-ribbed belts, engines used V-belts; sometimes there were as many as four different belts to drive the various vehicle accessories. When a V-belt is overtightened, parts can be overloaded.

- Too much belt tension can cause failure of the coolant pump bearing, the alternator, or the front main bearing (**Figure 15.27**).
- Belts that are too tight can result in coolant pump and alternator bearing noise.
- Loose belts can cause overheating and abnormal combustion, noise, or a dead battery.

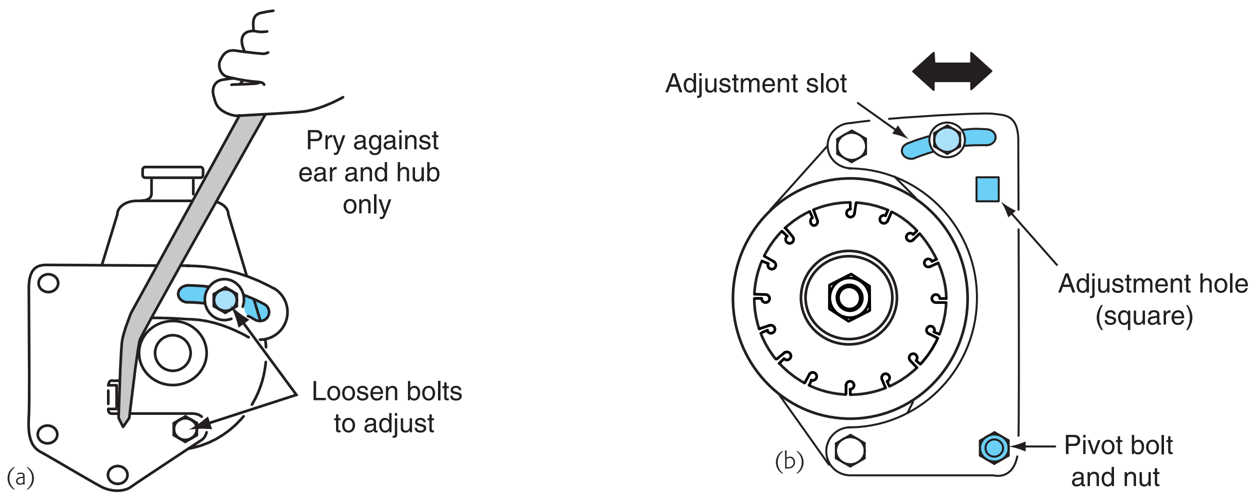


FIGURE 15.26 (a) When tightening the power steering belt, pry only in the designated areas. (b) Use a breaker bar or ratchet in the square hole to tighten the belt.

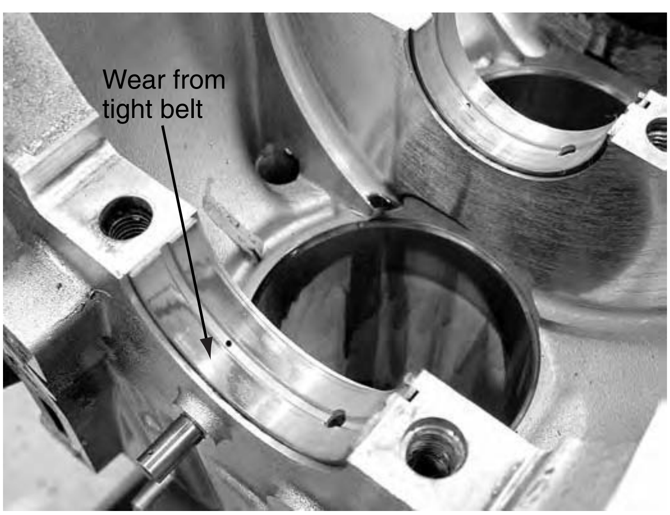


FIGURE 15.27 This front upper main bearing shows wear caused by a V-belt that was too tight. *(Courtesy of Tim Gilles)*

SHOP TIP

A new V-belt will stretch slightly during the first few minutes of operation. Therefore, set the tension about 15 pounds higher than the recommended specification. After running the engine for about 15 or 20 minutes, recheck and adjust tension using a belt tension gauge (**Figure 15.28**).

Most V-ribbed belts use a spring-loaded tensioner and do not require adjustment.

V-Ribbed Tension with Fixed Adjustment

V-ribbed belts usually require more tension than V-belts. Maximum tension should be limited

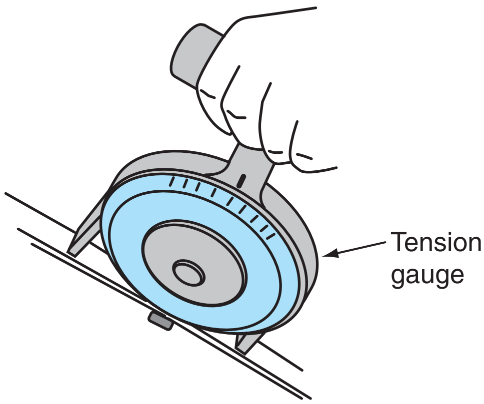


FIGURE 15.28 A belt tension gauge used on V-belts.

to 30 pounds per rib, checked at a splice-free area at the belt.

- Use a *click-type tension gauge* for V-ribbed and timing belts (**Figure 15.29**).
- After a new belt is installed, run the engine. Then loosen the tensioner bolt and retighten it.

After some initial tension is lost, V-ribbed belts will maintain 20 pounds of tension per rib for a long time. Used belts should have 15–20 pounds of tension per rib.

Stretchy Belts

Some manufacturers are using new *stretchy belts* that do not require a belt tensioner. Stretchy belt tension can be compared to a rubber band that applies tension when stretched past its relaxed length. In early applications of this design, the stretchy belt is used to drive the air-conditioning compressor from the crankshaft pulley. A primary serpentine belt with a belt tensioner is still used to drive the power steering pump, alternator, and coolant pump.

A stretchy belt is similar in appearance to a serpentine belt, but its reinforcing cord is made of polyamid material, which is more elastic than the aramid or polyester cords used in traditional serpentine belts. The backing material of a stretchy belt is also more elastic. A stretchy belt is designed to maintain adequate tension for 150,000 miles (240,000 kilometers). A stretchy belt is not to be reused and whenever it is removed it must be replaced with a new belt.

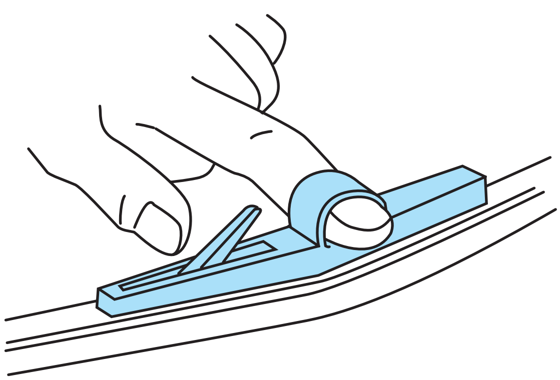


FIGURE 15.29 A click-type belt tension gauge is used for measuring tension on V-ribbed and timing belts.

THERMOSTAT

A thermostat is installed at the coolant outlet in the block or intake manifold to cause the engine to warm up quickly. When it is closed, it prevents circulation of coolant between the block and the radiator. When the coolant reaches a high enough temperature the thermostat opens.

Thermostats are made of brass or stainless steel; stainless steel is the more premium of the two materials. The two types of wax pellet thermostats commonly used in pressurized cooling systems are the balanced sleeve and the positive piston actuator, or reverse poppet. Both types use an expansive wax compound that expands at a predictable rate to open the valve in the thermostat. **Figure 15.30** is a thermostat cutaway to show the chamber where the wax is located. The operation of a positive piston actuator thermostat is shown in **Figure 15.31**. Other special thermostats are also available.

FIGURE 15.30 A thermostat cutaway. *(Courtesy of Tim Gilles)*

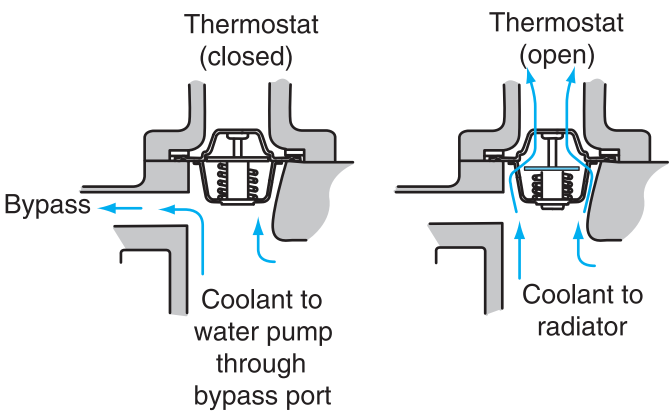


FIGURE 15.31 Operation of a "positive actuator" thermostat.

Be sure to compare the replacement thermostat with the original to be sure it will fit. When installing a thermostat, be sure it is firmly seated in its bore before you tighten the coolant outlet housing. **Figure 15.32** shows a coolant outlet housing that was cracked when the thermostat was not seated in its bore. Install the thermostat in the engine with its temperature bulb facing into the block (**Figure 15.33**).

Thermostat Operating Temperature

A thermostat is rated according to the engine operating temperature that it is supposed to maintain. The temperature of the thermostat is stamped on the bottom of the bulb in either Celsius or Fahrenheit (**Figure 15.34**). Thermostats sometimes have an air passage covered by a pin or a check valve

FIGURE 15.32 This coolant outlet housing was cracked when it was tightened while the thermostat was out of position in its bore. *(Courtesy of Tim Gilles)*

FIGURE 15.33 The thermostat is installed with its temperature bulb facing into the block.

(**Figure 15.35**). This feature allows air to escape as the cooling system is filled with new coolant. During engine operation it allows slight circulation of the coolant so the temperature sensor on the thermostat can more accurately sense the temperature of the coolant in the block.

In a warm engine, the thermostat will open partially and maintain the position necessary to keep engine temperature constant. Should the cooling requirements increase in hot weather or under a sustained load, the thermostat will open all the way.

NOTE

Installing a thermostat with a higher opening temperature will *not* result in quicker engine warm-up, because the thermostat on all engines remains closed until its predetermined opening point.

FIGURE 15.34 The operating temperature of the thermostat is stamped on the bottom in Fahrenheit (left), or in Celsius (right). *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Most late-model thermostats are rated 195°F (91°C). An occasional practice in older vehicles was to leave a thermostat out of an engine. This resulted in accelerated cylinder wall wear over time. Also, engine efficiency was reduced during cold operation, so fuel economy suffered. Sometimes leaving the thermostat out would lead to overheating by changing the coolant flow to the back of the block.

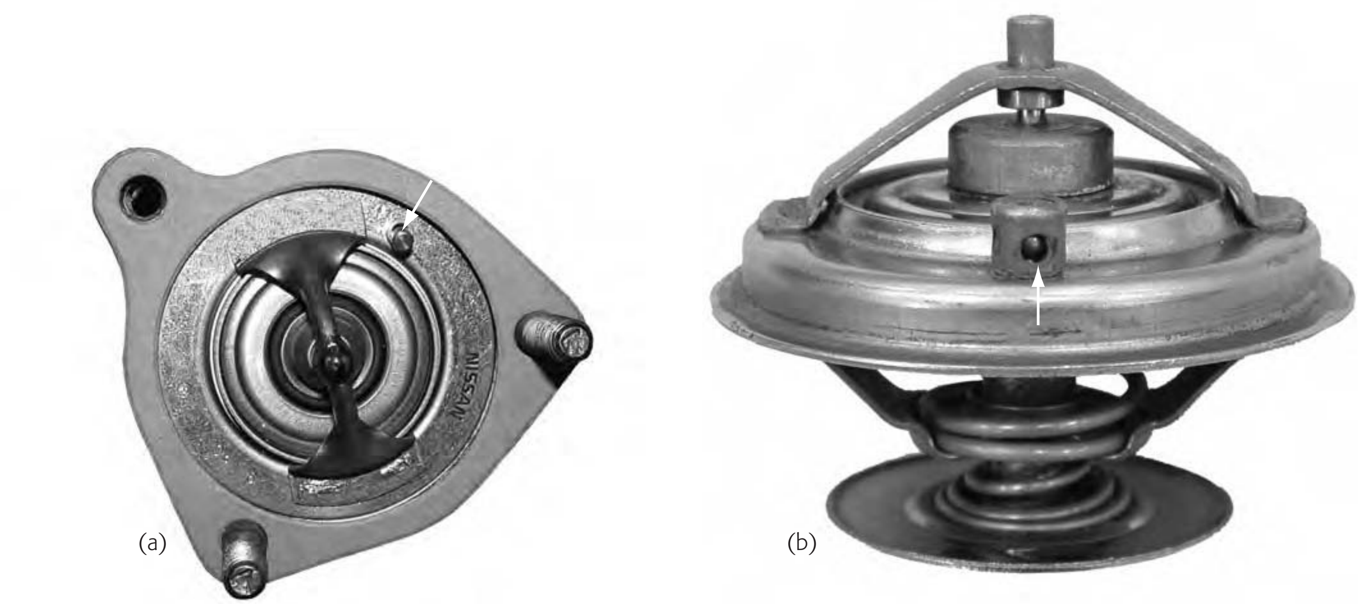


FIGURE 15.35 (a) A jiggle pin near the top of this thermostat helps bleed trapped air when filling the cooling system. (b) A ball check valve to help bleed trapped air. *(Courtesy of Tim Gilles)*

Always follow the manufacturer's recommendations when selecting the thermostat for the engine.

NOTE

Using a lower temperature thermostat in hot weather will *not* result in a cooler running engine. When the weather is very hot, all thermostats will operate in the wide-open position all the time after engine warm-up.

Thermostat Testing

On older vehicles, thermostat replacement was relatively easy, but thermostats on some late-model engines can be difficult to remove. On OBD II-equipped vehicles, a scan tool can be used to verify thermostat operation by reading coolant temperature. On older vehicles, a digital pyrometer can be used. Expect normal coolant operating temperature to be about 20°F (–7°C) higher than the rated temperature of the thermostat.

Thermostats are normally replaced on a maintenance basis without testing. But when replacing a thermostat suspected of being defective, its operation can be verified. After removing it from the engine, lower it into hot water and note the temperature when it begins to open (**Figure 15.36**).

THERMOSTAT BYPASS

The cooling system includes a **thermostat bypass** (**Figure 15.37**) that allows coolant to be pumped throughout the block when the thermostat is closed.

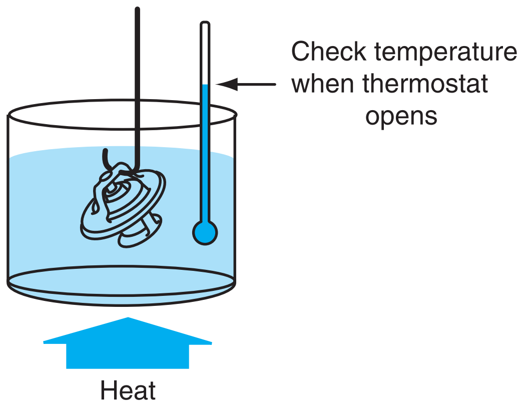


FIGURE 15.36 Thermostats are normally replaced on a maintenance basis without testing them, but the operation of a thermostat suspected of being defective can be verified using hot water.

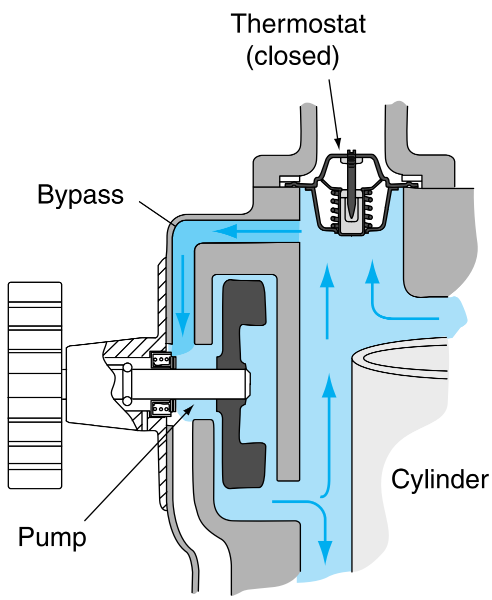


FIGURE 15.37 The cooling system includes a bypass that functions when the thermostat is closed.

Without the bypass, coolant temperature would be inconsistent and the thermostat would not be able to accurately sense when to open and close. Some bypasses are internal; others use a hose that is subjected to extreme heat and pressure. *Bypass hoses* are usually curved, molded hoses (**Figure 15.38**).

SHOP TIP

Bypass hoses are difficult to replace on some engines without removing the coolant pump. It is advisable to replace a bypass hose whenever the engine is disassembled or the coolant pump is removed.

FIGURE 15.38 A thermostat bypass hose. *(Courtesy of Tim Gilles)*

CAUTION

Do not try to use an unmolded heater hose as a bypass hose. It can fold over when bent, restricting water flow.

Reverse Flow Cooling Systems

Some engines have reverse flow cooling systems with their thermostats located at the top of the lower radiator hose at the inlet to the coolant pump (**Figure 15.39**). The purpose of this is to minimize "thermal cycling." Engines using reverse flow systems are made of aluminum, which can experience thermal shock from the entry of excessively cold coolant.

In a reverse flow system, the thermostat opens and closes more quickly. It begins to open in response to increased temperature of the coolant flowing through the coolant pump. The colder coolant entering the engine from the radiator closes the thermostat and the engine warms up more gradually. The temperature of the heater is more consistent and the temperature gauge does not fluctuate.

RADIATORS

Radiators are designed with either of two flow patterns: downflow or crossflow (**Figure 15.40**). Both designs work equally well. Today's vehicles

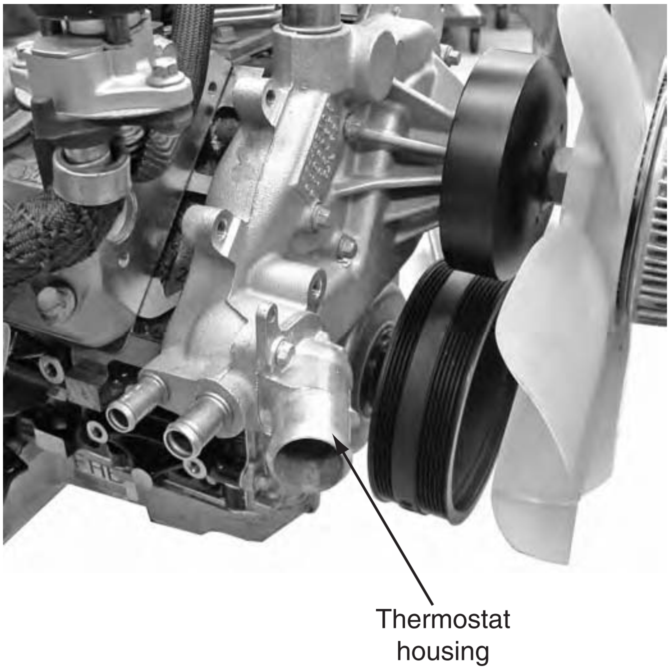


FIGURE 15.39 A reverse-flow system thermostat is located at the top of the *lower* radiator hose. *(Courtesy of Tim Gilles)*

use aluminum radiators with upper and lower radiator tanks made of plastic. The section of the radiator between the upper and lower tanks is called the core (**Figure 15.41**). Most cores are built in the serpentine fin design. The fins are wavy to create a

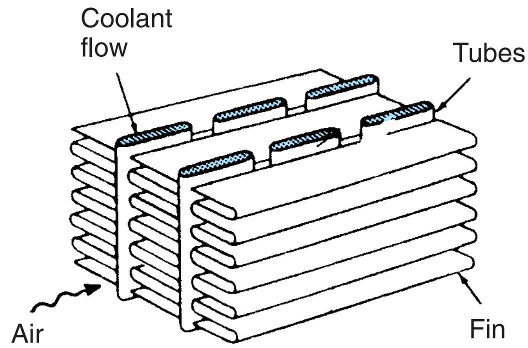


FIGURE 15.41 Parts of a radiator core.

maximum surface area. Heat is conducted away from the coolant tubes as air flows across the fins. **Figure 15.42** shows a radiator cutaway.

Radiator Inspection

Inspect the radiator for leaks, flaking, crushed or bent fins, or damage to the filler neck seat. Look for obstructions to airflow such as bugs and so forth, which can be washed out with water from the engine side of the radiator. Inspect the overflow hose and passage also. Be careful when moving or storing a radiator during an engine rebuild. **Figure 15.43** shows a radiator with fins that were bent by careless handling. These can often be straightened.

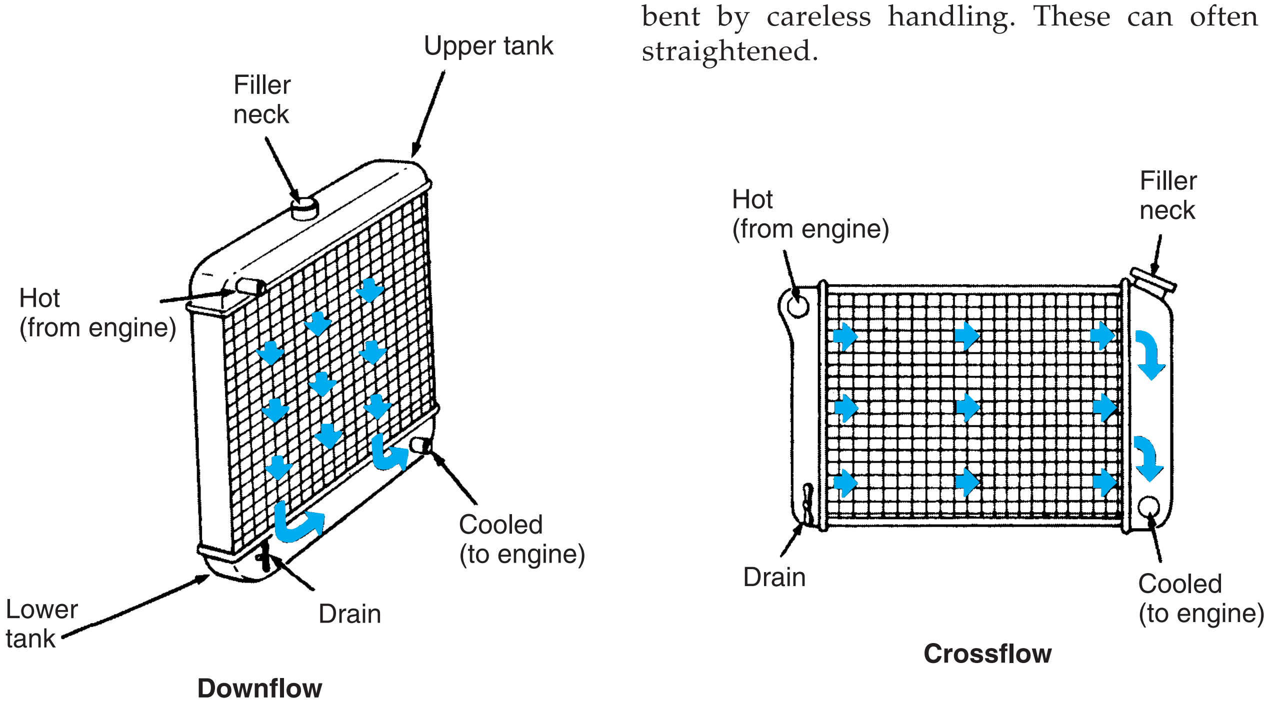


FIGURE 15.40 Coolant flow in downflow and crossflow radiators.

VINTAGE ENGINES

Radiator cores in vintage cars were made of copper and brass. The upper and lower radiator tanks were constructed of thin brass and the core was made of copper. The filler neck and all of the radiator parts were soldered together. When you inspect a copper/brass radiator, cooling fin metal should be firm and should not flake off when rubbed. If the cooling fin metal rots, a new radiator core will be needed. The fins should be firmly attached to the tubes. When a radiator with a copper core has fins in good condition, the radiator can be disassembled and cleaned by a radiator shop. In a process called "rodding out the radiator," rods are forced through the tubes of the radiator to clean it out. Then the top and bottom tank are soldered back on the radiator core prior to painting it.

A restricted radiator will result in engine overheating at highway speeds, and the restricted circulation can result in coolant being pumped out the radiator overflow.

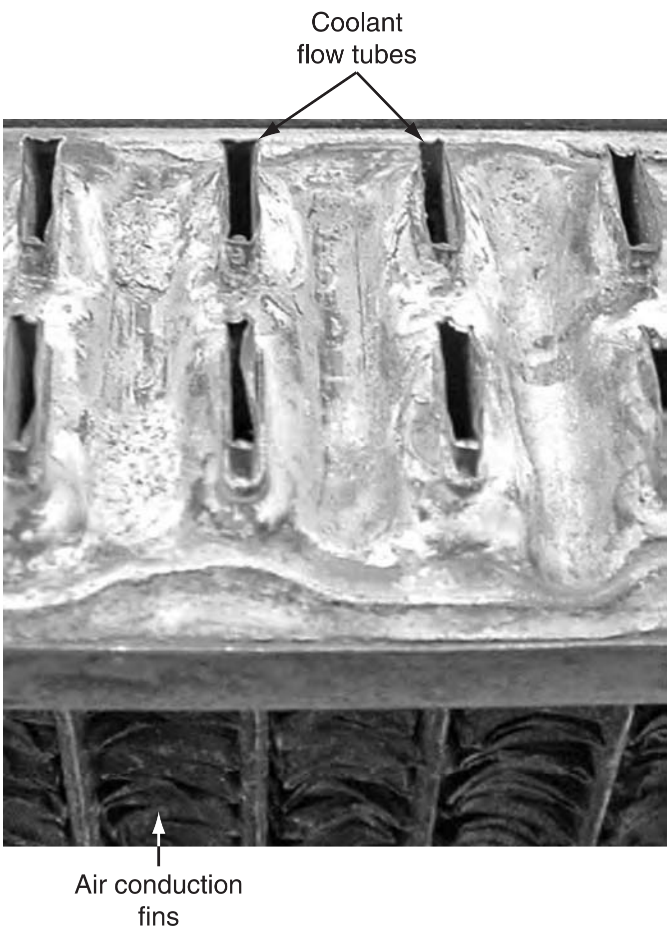


FIGURE 15.42 A cutaway radiator core. *(Courtesy of Tim Gilles)*

Radiators can be damaged by contact with a fan blade, which can occur when a fan clutch or coolant pump bearing fails. Damage can also occur when a broken motor mount allows the engine to move excessively.

Vacuum brazed aluminum core/plastic tank radiators have a good life expectancy and have proven to be durable. Although these radiators are not as tolerant of poor quality coolant, neglected

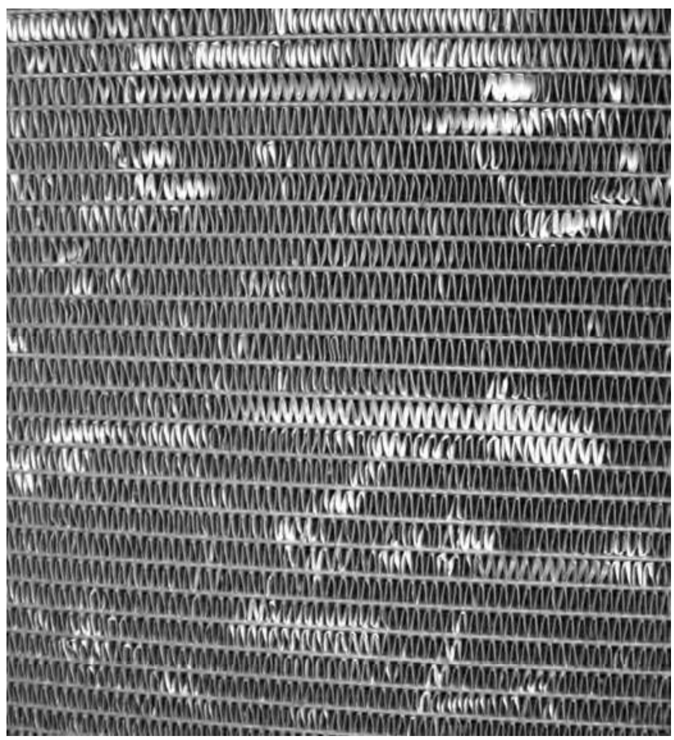


FIGURE 15.43 These radiator fins, bent during careless handling, should be straightened to allow airflow. *(Courtesy of Tim Gilles)*

maintenance, and low coolant level as are copper/brass radiators, they are relatively inexpensive to replace. Aluminum radiator cores also conduct heat better than copper ones. Although copper is a better conductor of heat, aluminum radiators are made with larger tubes and have more internal and external surface area. They also have no soldered joints.

Transmission Heat Exchanger (Oil Cooler)

In a vehicle with an automatic transmission, one of the radiator tanks usually includes a heat exchanger, often called an *oil cooler* (**Figure 15.44**).

NOTE

When a heat exchanger develops a leak, transmission fluid (approximately 35 psi) can enter the radiator (approximately 15–17 psi) during engine operation. When the engine is shut off, the pressurized coolant migrates to the transmission, where it can cause transmission failure.

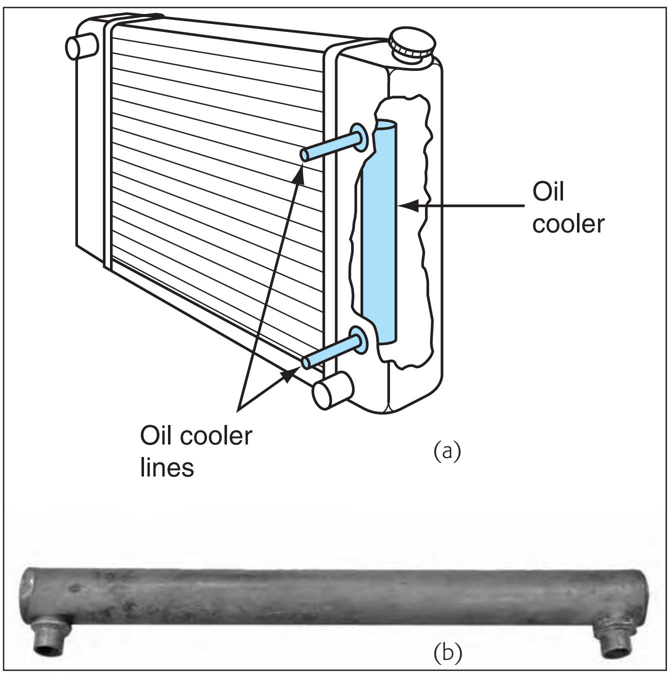


FIGURE 15.44 (a) An automatic transmission cooler is located in the radiator. (b) A transmission oil cooler. *(* [b] *Courtesy of Tim Gilles)*

SHOP TIP

If an automatic transmission fails, pieces of transmission parts can plug the transmission oil cooler in the radiator. This can result in crankshaft thrust bearing failure. Use a rubber-tipped blowgun to blow air through the cooler line to verify that it is not restricted. If needed, a transmission shop can test the flow rate.

Heater Core

The heater core, usually located inside the passenger compartment, is a small heat exchanger through which engine coolant circulates (**Figure 15.45**). A blower motor passes air across the fins of the heater core, transferring heat from the engine to the passenger compartment. Engine coolant is supplied to and from the heater core by two heater hoses. One hose carries coolant leaving the engine. A return hose carries the coolant back to the engine for reheating. If both heater hoses are removed during service or repair, mark one of them so that they can be returned to their proper positions. Newer vehicles have coolant flowing through the heater core at all times. Doors to the ducts around the heater core are opened and closed to control cabin heat.

A heater core can leak or become plugged. It must be removed for repair or replacement in the event of a leak. This is sometimes a big job, requiring the removal of many parts under the dash.

NOTE

A symptom of a leaking heater core is when the windshield becomes more fogged when the defroster is turned on.

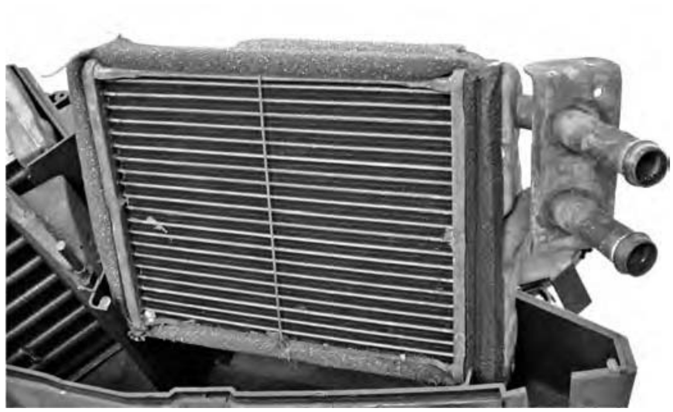


FIGURE 15.45 A heater core. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Older vehicles had a heater control valve installed in the hose controlling the flow of coolant to the heater core. It allowed coolant to flow into the heater core when the heater dash controls were set for “HEAT.”

However, with combination heater/air-conditioning systems momentary fogging of the windshield is a common occurrence when the heater is first turned on, even when the heater core is good. Operate the air conditioning with the heater control in the defrost position to dry the inside of the windshield.

One cause of heater core failure is when a ground side-controlled heater motor with a plastic fan has a bad electrical ground. Plastic fans make lots of static electricity. Some technicians think that grounding the heater core or radiator is a good idea. However, when the normal ground path is compromised, this encourages electron flow through the coolant from the heater core to the engine. Aluminum heater cores are especially susceptible to repeat failures due to this. When this happens, protect against static electricity by providing a redundant ground between the blower and the heater core.

Newer heater cores are aluminum and older ones are copper/brass. Aluminum is better for conducting heat, but it is more susceptible to corrosion damage. Today’s coolants are formulated to protect aluminum.

Hoses

Hoses consist of an inner rubber tube, reinforcement, and the outer rubber cover all bonded together with adhesives. Radiator hoses are designed to have a burst strength of between five and six times the working pressure of the cooling system. There are three kinds of hoses: straight, molded, and universal. Long radiator and heater hoses are usually molded hoses, preformed with the required bends. Bypass hoses often come in various lengths and are molded to the correct curve. They must usually be cut to length to reduce the inventory that a parts supplier must have on hand.

The upper radiator hose (engine outlet end) suffers the most abuse, because very hot water leaves the engine and travels through the hose before it is cooled by the radiator.

NOTE

Defective hoses do not always outwardly appear so. Deterioration on the inside of the hose can cause small particles to flake off and fall into the coolant (**Figure 15.46**).

CAUTION

Any questionable hose should be replaced. If a hose fails, an entire engine overhaul can be ruined.

FIGURE 15.46 A hose that is defective on the inside. Pieces of deteriorating hose can plug a radiator, hold a thermostat open, or plug a coolant passage. *(Courtesy of Gates Corporation)*

VINTAGE ENGINES

Universal hose, sometimes used as an aftermarket replacement on older engines, can be clamped on one end and then twisted until it assumes the desired bend. It is reinforced with wire to prevent collapse. Its disadvantage is that it resists the flow of water, so it hampers pump efficiency. Lower formed radiator hoses sometimes had a wire coil inside as well.

NOTE

Metal wire hose is part of the lining of the hose only. These hoses do not seal as well on the plastic water outlets on newer vehicles.

Rebuilt engine warranties do not cover overheating. Many rebuilders use temperature indicator labels (**Figure 15.47a**) or heat tabs (**Figure 15.47b**) to help determine their warranty obligations in case a rebuilt engine has been overheated. A *heat tab* is epoxied to a cylinder head, often to a core plug where it will be close to the coolant (**Figure 15.48**). The center of the tab will melt at 255°F (124°C). Do not locate the heat tab too close to an exhaust manifold or turbocharger. For more information on rebuilt engine warranties, see Chapter 17.

Hose Clamps

There are several styles of hose clamps (**Figure 15.49**). The worm gear clamp shown in the lower left corner of the photo is easiest to use and is popular with service technicians. Be sure to place the clamp as close to the ridge on the tube as possible to prevent the possibility of corrosion (**Figure 15.50**).

COOLING SYSTEM PRESSURE CAP

A pressure cap seals the opening on top of the radiator or coolant reservoir. It pressurizes the coolant and keeps it from surging out as it is circulated through the radiator.

Cooling systems are pressurized for two reasons:

- Coolant pump efficiency is increased.
- Putting pressure on the coolant raises the boiling point of the liquid in the cooling system.

When the cooling system is not under pressure, the coolant pump does not always remain full of coolant. *Aeration* is the result, which causes a loss of pump efficiency of about 15% and allows cavitation, which results in coolant boiling within the pump.

Normal engine operating temperatures are between 180°F and 212°F (82°C and 100°C). The typical coolant/water mixture boils at somewhere

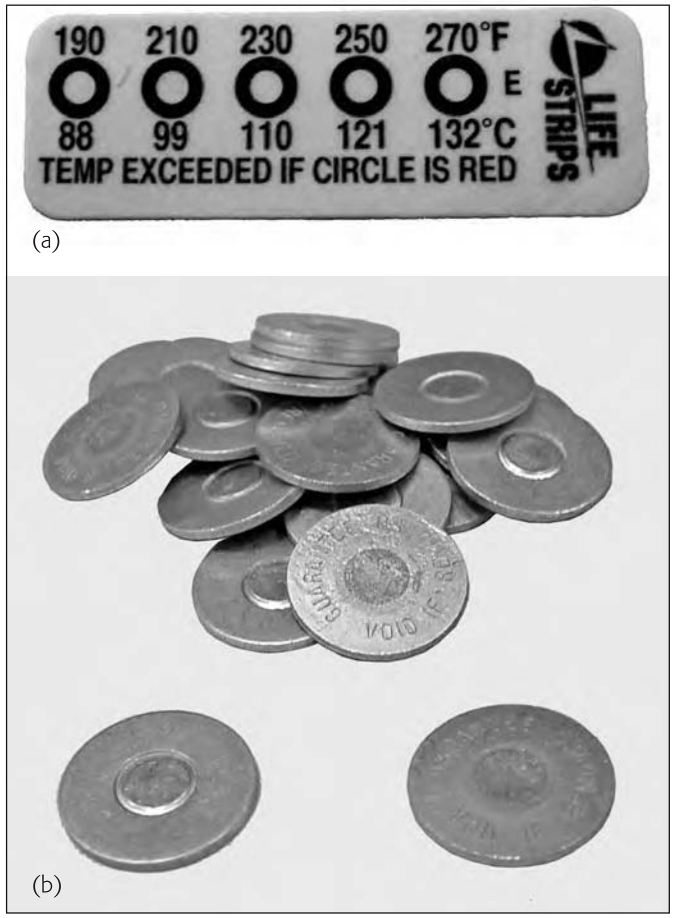


FIGURE 15.47 (a) A temperature-indicating strip shows when an engine has been overheated. (b) Heat tabs are installed by rebuilders to protect them from warranty claims caused by cooling system problems that are not the fault of the rebuilder. *(Courtesy of Tim Gilles)*

FIGURE 15.48 A heat tab epoxied to a cylinder head core plug. *(Courtesy of Tim Gilles)*

between 220° and 230°F (104°C and 110°C) without pressure. When the cooling system is overworked, temperatures can rise as high as 270°F (132°C) without the coolant boiling. Pure water boils at 212°F (100°C) at sea level, but its boiling point is less than that at higher altitudes because atmospheric pressure on the coolant is less.

NOTE

Each pound of pressure on the coolant raises its boiling point by about 3°F (–16°C).

A 15-pound cap will raise the boiling point of the water by about 45°F to 257°F (7°C to 125°C).

212°F (boiling point of water at sea level)

+ 45°F (3° ×15 lb)

257°F

Also, if coolant is mixed with water, the boiling point will be higher.

Type of Pressure Caps

There are two types of pressure caps; one fits on a radiator and the other fits on a plastic coolant reservoir. Each cap has a pressure valve and a vacuum valve. As coolant temperature increases, the coolant expands, creating pressure in the cooling system. The pressure valve is a relief valve that maintains system pressure below a specified point by allowing expanding coolant to move out of the radiator. When a hot engine is shut off, coolant temperature slowly drops. The vacuum valve allows coolant to return to the radiator.

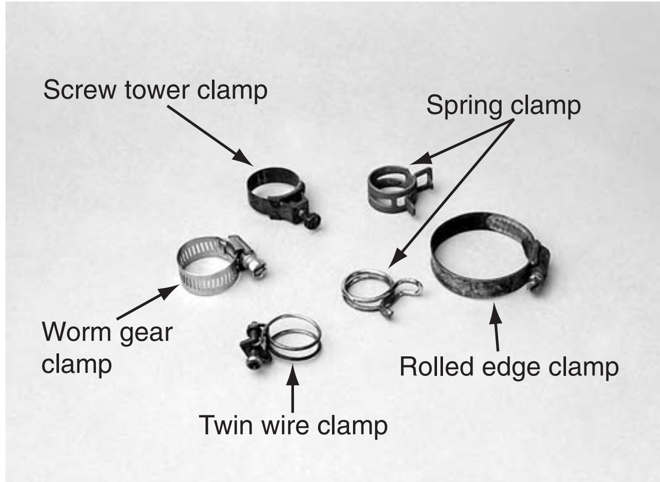


FIGURE 15.49 Different types of hose clamps. *(Courtesy of Tim Gilles)*

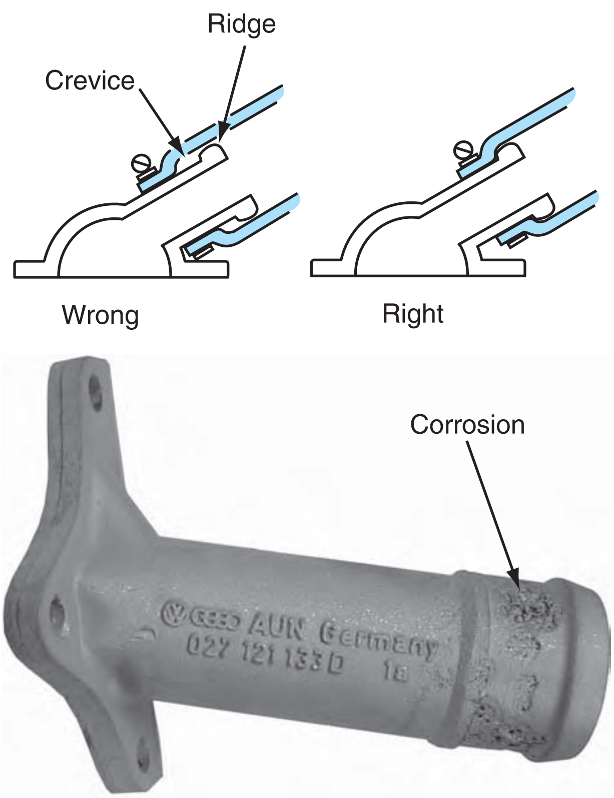


FIGURE 15.50 Failure to position the hose clamp near the ridge on the outlet housing leads to corrosion. *(Bottom: Courtesy of Tim Gilles)*

Radiator Cap Sealing Surfaces

A typical radiator cap has three sealing surfaces (**Figure 15.51**). The coolant recovery seal is the one that closes off the top of the radiator filler neck. The other two sealing surfaces are the cap's two valves: a pressure valve and a vacuum valve. These two valves are also used on caps that seal a coolant reservoir.

Pressure Valve. Most pressure caps pressurize the system from 13 to 17 pounds (metric caps range from 0.9 to 1.17 BAR) A large spring in the cap forces a rubber *pressure seal* against the seat in the *radiator filler neck* (**Figure 15.52**). The pressure valve maintains pressure on the coolant even when the engine is shut off as long as the coolant remains hot. With repeated cycling between open and closed, the pressure valve rubber seal is exposed to very hot coolant and can become worn or damaged (**Figure 15.53**).

SAFETY NOTE

Use caution when opening a hot radiator. Always squeeze the top hose first to make sure that the cooling system is not under pressure (**Figure 15.54**). If coolant is heated to 240°F (116°C) and the radiator cap is removed, the coolant temperature will be well above its unpressurized boiling point. It will boil violently and someone could be badly scalded by the exploding coolant!

Vacuum Valve. The vacuum valve (**Figure 15.55**) protects the radiator as the temperature of the coolant drops. As the hot liquid shrinks to occupy less space, this drops the pressure within the radiator and the spring-loaded vacuum valve opens. Excess coolant (which went into the recovery tank during warm-up) is drawn through the vacuum valve back into the radiator.

Some vacuum valves are spring-loaded and some are loose in the cap:

- A *constant pressure* cap has a spring-loaded vacuum valve. It allows the system to begin building pressure as soon as the coolant starts to expand.
- An *atmospheric pressure* cap has no spring on the vacuum valve. It does not build up pressure until the system gets hot. Many manufacturers recommend replacing an atmospheric cap with one with a spring to prevent coolant gelling.

Coolant Reservoir Cap

Coolant reservoir caps (**Figure 15.56**) work in much the same way as radiator caps. The pressure

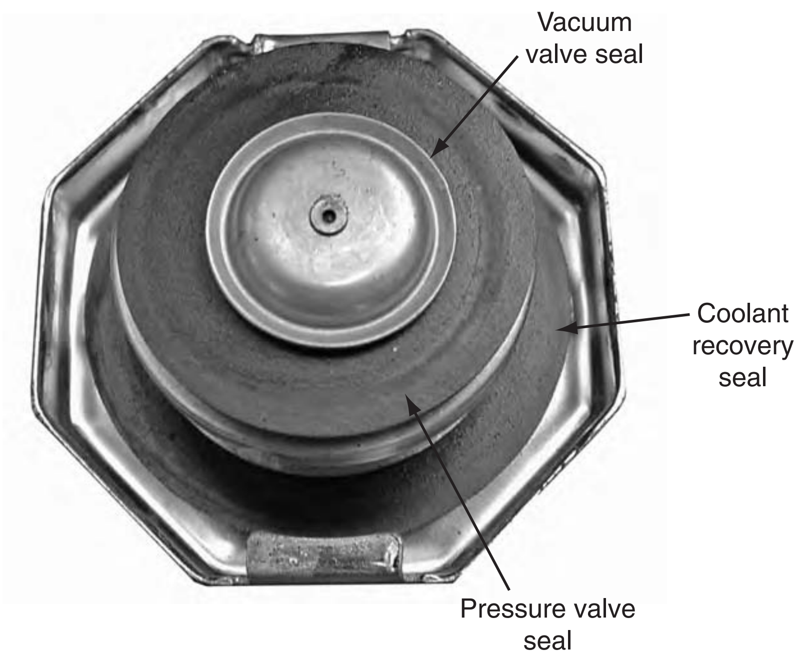


FIGURE 15.51 A radiator cap used with a coolant recovery reservoir has three sealing surfaces. *(Courtesy of Tim Gilles)*

valve, however, is contained internally within the cap and its seal does not move against a seat. Expanding coolant moves into the reservoir without passing a rubber sealing surface. The vacuum valve is similar in appearance to a radiator cap vacuum valve (**Figure 15.57**).

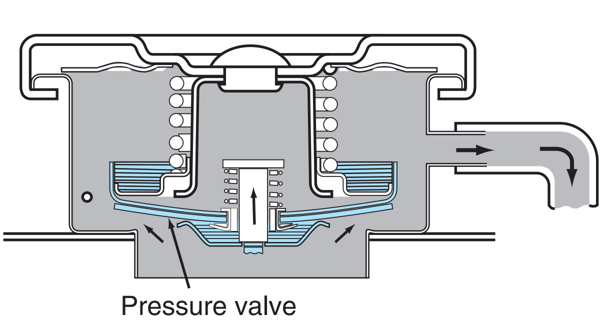


FIGURE 15.52 Pressure valve operation.

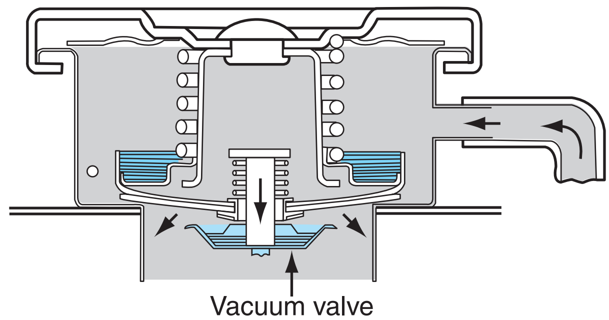


FIGURE 15.55 Vacuum valve operation.

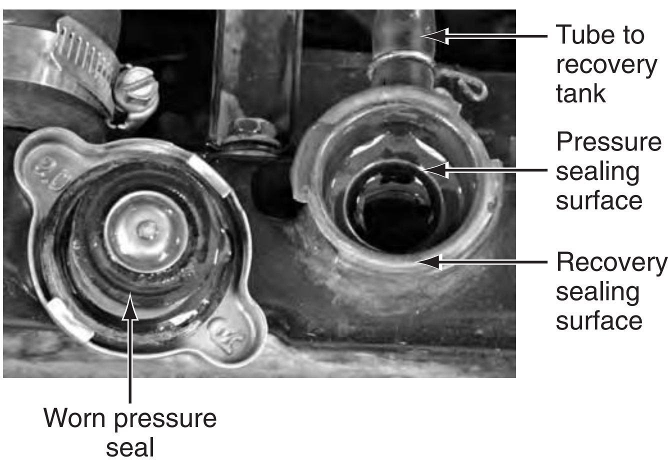


FIGURE 15.53 This radiator cap has a worn sealing surface. Important parts of the radiator filler neck are also shown. *(Courtesy of Tim Gilles)*

FIGURE 15.56 A coolant reservoir cap. *(Courtesy of Tim Gilles)*

FIGURE 15.54 Always squeeze the top hose before removing a radiator cap. *(Courtesy of Tim Gilles)*

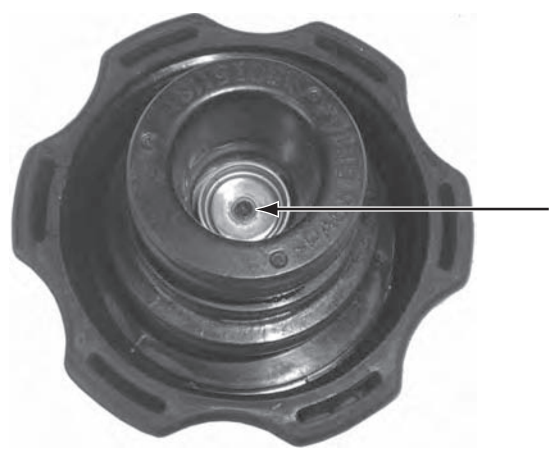


FIGURE 15.57 The vacuum valve in a coolant reservoir cap. *(Courtesy of Tim Gilles)*

NOTE

Some vehicles with lifetime coolant have suffered serious engine damage when the coolant turned to sticky gel. The cause has been traced to air in the system. A bad radiator cap seal can be one of the causes of air entering the system. Leakage at either of the other two sealing points can also be a cause.

Coolant Recovery System

Coolant recovery systems have been included on most new cars since 1969. **Figure 15.58** shows a typical system. Coolant expands by over one-tenth of its original volume as it reaches engine operating temperature. Expanding coolant goes into the recovery tank instead of onto the ground. When the coolant temperature drops, the vacuum valve opens, drawing coolant back into the system from the recovery tank. Because air never enters the cooling system, a properly operating recovery tank system increases overall cooling efficiency by 10%.

The top radiator seal prevents steam from escaping when the cap is turned a one-half turn to the pressure release position. It also seals when the coolant temperature drops in the radiator, causing coolant to be drawn in from the coolant recovery tank. A recovery tank also helps decrease corrosion resulting from air entering the cooling system.

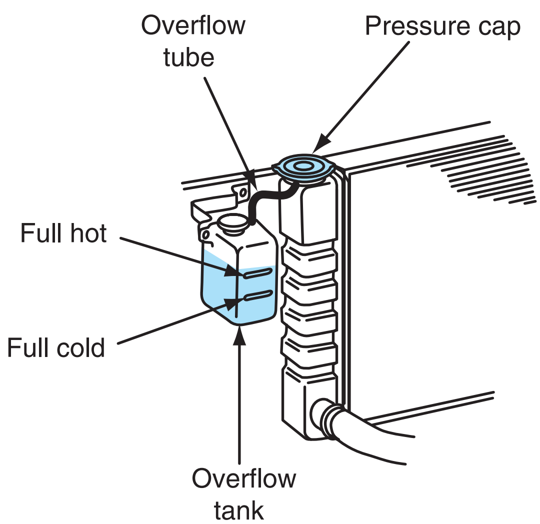


FIGURE 15.58 A closed coolant overflow system.

Pressure Testing

A pressure cap is tested using a pressure tester (**Figure 15.59**). A radiator cap tester does not test the top seal in the radiator cap. If the top seal is bad

FIGURE 15.59 Pressure testing a radiator cap. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

A coolant recovery system is a good feature to add to an older collector car. Add-on kits are available in parts stores. When the coolant level in a copper/brass radiator is allowed to drop below the level of the tops of the cooling tubes, solder bloom corrosion can occur. This corrosion is lead oxide that forms when oxygen in the air reacts with the solder at the top of the tubes.

(**Figure 15.60**), air can enter the cooling system. This can result in coolant failure (covered later).

- First, visually inspect the sealing surfaces and the vacuum valve.
- Moisten the sealing surface with water or coolant to help it seal during testing.
- There are many different adapters available to accommodate all of the different radiator cap sizes and styles. Install the correct radiator cap on the adapter and attach the pressure tester to its other end.
- Pump the handle until the gauge reaches its highest point. The needle should reach a high point and remain constant for at least 1 minute. The pressure rating of the cap is stamped or printed on the top of the radiator cap (**Figure 15.61**). This is the point where the pressure cap should relieve pressure. Pressure is listed in pounds (**Figure 15.61a**) or in barometric pressure (**Figure 15.61b**).
- Before removing the cap, release pressure from the tester. Some testers allow the release of pressure by pushing the tester hose sideways where it is joined to the cap.

Cooling leak inspection using a pressure tester is covered in Chapter 3.

SAFETY NOTE

Do not run the engine with the pressure tester in place. Pressure can climb to an unsafe level.

FIGURE 15.60 This defective top seal will prevent correct operation of the coolant recovery system, allowing air to enter the radiator. *(Courtesy of Tim Gilles)*

FIGURE 15.61 (a) A radiator cap with a pressure rating in pounds. (b) A radiator cap with a metric pressure rating in BAR or kilopascals. *(Courtesy of Tim Gilles)*

RADIATOR FAN

The fan's purpose is to draw air through the radiator when the vehicle is not moving fast enough to provide enough air circulation. It is really only necessary at idle and low speeds.

Belt-Driven Fans

Belt-driven fans are usually mounted on the front of the coolant pump, which is driven by a belt that rides in a pulley groove on the crankshaft. They are found on most rear-wheel-drive vehicles. Fans powered by electric motors and controlled by engine temperature are found on most front-wheel-drive vehicles (**Figure 15.62**).

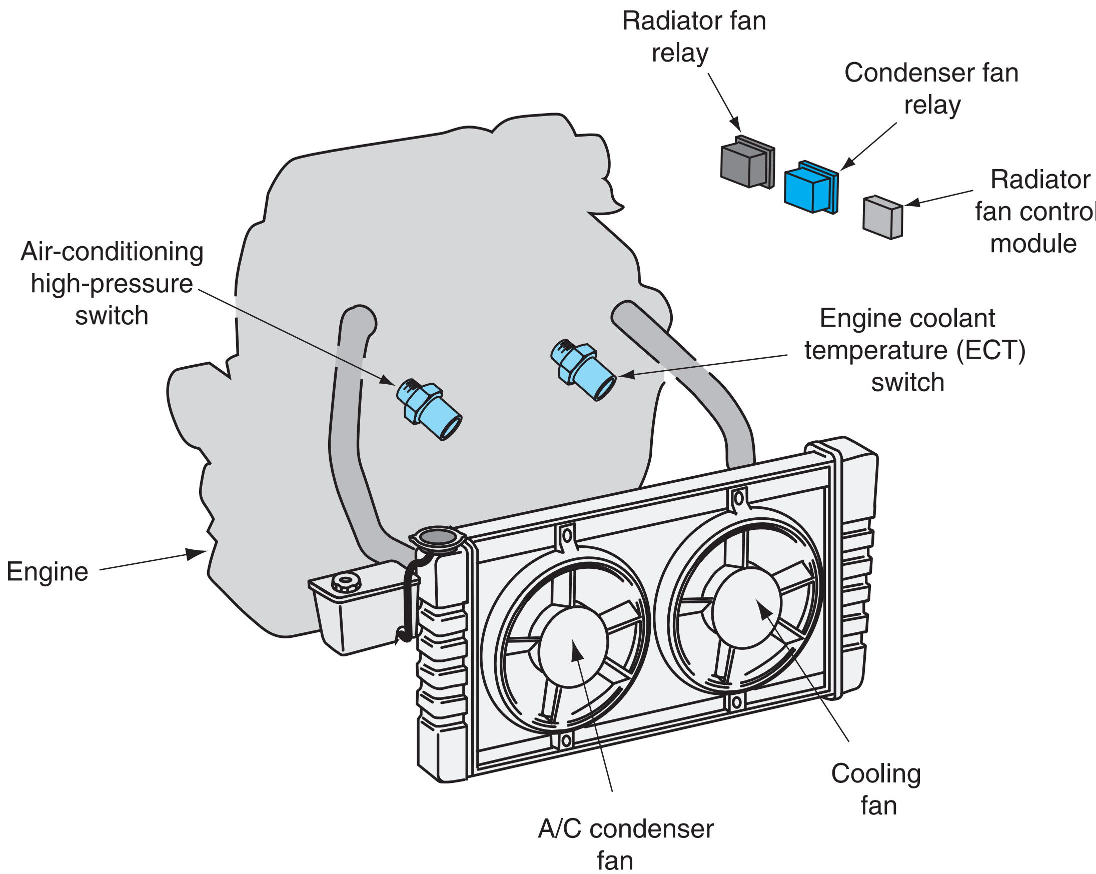


FIGURE 16.62 An electric cooling fan system.

Electric Fan

Most late-model vehicles have electric fans. The fan motor is switched on and off as the engine temperature rises and falls. The fan might also be switched on to cool the air-conditioning condenser. The fan can also operate after the engine is shut off. A timer controls this function so that the battery will not run dead. Aftermarket add-on fan kits are also available. These fans can often be heard running in parked vehicles to cool off the radiator after the engine has stopped.

The disadvantage of a belt-driven fan is that at higher speeds, when the fan is no longer required, it can rob the engine of horsepower. Manufacturers have developed several ways to minimize this. Electric fans are turned on and off in response to a signal from a coolant temperature switch threaded into the radiator, coolant outlet housing, or a coolant jacket in the engine block or head (see Figure 15.62). When the engine temperature goes above a predetermined temperature (usually about 230°F [110°C]), the fan comes on to provide extra cooling.

In addition to being a safety hazard, a broken fan blade can cut a power steering or radiator hose, a brake line, or other parts. Any time a fan blade loses a piece, the fan will become unbalanced. This can cause coolant pump failure.

VINTAGE ENGINES

Flex-fan blades were used on many older vehicles; they have a high angle at low speeds. At high speeds the blades flatten out, reducing the horsepower required to turn them.

Fan Clutch

To improve engine efficiency, many rear-wheel-drive vehicles have fan clutches to reduce the horsepower demands required by a traditional fan (**Figure 15.63**) Fan clutches can be either temperature-regulated or speed-sensitive (viscous).

Temperature-Controlled Fan Clutch. The temperature-controlled (thermal) fan clutch, generally used with a heavy-duty fan blade, is the type most used in original equipment. It is usually controlled by a bimetal coil spring (**Figure 15.64**), a thermostatic coil consisting of two types of metal wound together. When the coil is heated it expands and when it cools it shrinks. The fan only works when the engine is hot. When the engine is cold, the fan freewheels.

- When the air coming through the radiator is hot, the bimetal spring causes an internal valve to open; silicone fluid from a reservoir fills the working chamber and engages the clutch.
- When the air coming through the radiator is cool enough, the silicone fluid is directed back to the cavity in the center of the clutch, and the clutch disengages.
- Thermal fan clutches also respond to engine rpm through slippage in the fluid chamber. Slippage occurs when ram air through the radiator from vehicle movement is sufficient for cooling.

FIGURE 15.63 A fan clutch. *(Courtesy of Tim Gilles)*

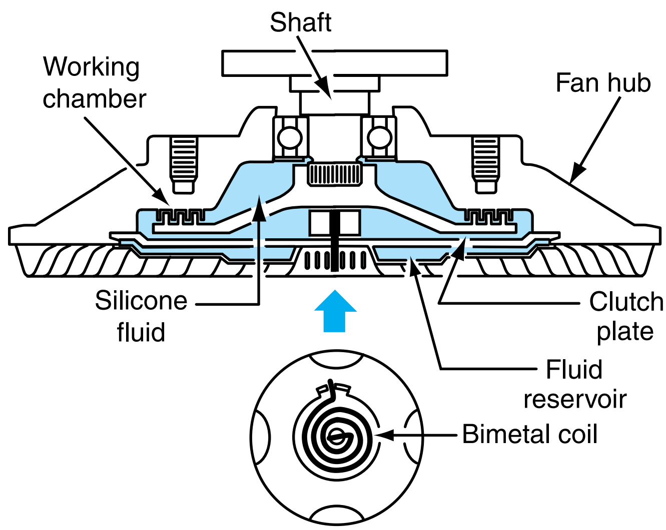


FIGURE 15.64 A cutaway of a fan clutch.

Speed-Sensitive Fan Clutch. A *speed-sensitive (viscous) fan clutch* slips when the resistance of air coming through the fan becomes higher. This fan is similar in operation to the flex fan in that it uses some horsepower at all times. A viscous fan clutch is not as efficient as a thermal fan clutch. A thermal fan clutch reacts not only to engine temperature, but also to rpm. So it would be the clutch of choice for high-performance or heavy-duty cooling applications.

Fan Clutch Inspection

Inspect the fan clutch for fluid leaks and to see if it is loose or frozen. There are several ways to test the temperature-controlled clutch.

- First, with the engine off, turn the fan by hand. There should be a slight resistance, but the fan should turn without the roughness that would indicate a bad bearing.
- Rock the fan up and down to see if it is too loose.
- If there is a buildup of greasy dirt in the bearing areas of the clutch, the silicone fluid has probably leaked out (**Figure 15.65**). If the bearing in the clutch fails, replace the clutch; otherwise, the resulting imbalance may ruin the coolant pump.

Engine Running Tests. Block off the radiator airflow and run the engine with the air conditioner operating to help warm the coolant.

- When the engine is cool, the fan will not pull much air.

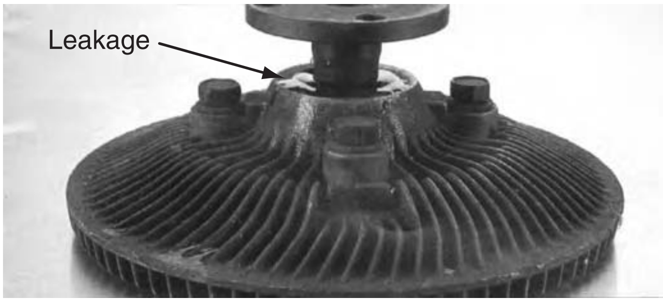


FIGURE 15.65 A leaking fan clutch. *(Courtesy of Federal-Mogul Corporation)*

- As the engine warms, there should be a noticeable increase in the noise level from the fan.
- If the fan clutch does not engage before the temperature gauge shows hot, it must be replaced.
- When a warm engine is shut off, the fan can continue to turn slightly, but it should not freewheel. If it turns more than four or five turns, it is probably defective.
- When the engine cools down after the radiator is unblocked, the fan should disengage.

SHOP TIP

A handy way to check fan clutch engagement is to write a number on the engine side of each fan blade with a marking crayon, and then point a timing light at the fan. If the drive pulleys are of equal size, the numbers will be stationary if the fan is locked up. If the clutch is slipping, the numbers will run backward.

NOTE

Many vehicles have two fans; one is to cool the air-conditioning condenser.

Electric Fan Testing. If the fan is not working, look for an obvious reason, such as a disconnected wire. Then check the fuse panel to see if the fuse is burned out. Next check the switch to see if it is operating properly, using the following procedure:

- When the engine is cold, disconnect the electrical connector to the coolant temperature switch. Use an ohmmeter to read across its two terminals. It should show an open (infinite) resistance. This switch is normally open. It closes in response to higher coolant temperatures.
- With the wires to the switch connected, run the engine until it is warm. The fan should come on, indicating a switch that is good.
- If the fan does not come on, disconnect the wires to the switch. With the ohmmeter, the switch should now show continuity (low resistance), indicating a closed switch. If not, replace the switch.

This will involve checking the coolant temperature sensor and any relays that apply. Refer to the appropriate service information.

SAFETY NOTE

Be sure to disconnect an electric fan motor whenever working near it.

There are many variations in electric cooling fan systems. Some vehicles bypass the coolant temperature switch whenever the air conditioning is turned on. This results in the cooling fan being on. Other vehicles require the air-conditioning system to achieve high side pressure of a certain amount before turning on the fan. Some systems continue to run the fan after the engine is off until the coolant temperature drops below approximately 210°F (99°C).

VINTAGE ENGINES

A speed-sensitive (viscous) fan clutch used with some older engines slips when the resistance of air coming through the fan becomes higher. This fan is similar in operation to the flex-fan in that it uses some horsepower at all times. A viscous fan clutch is not as efficient as a thermal fan clutch.

VINTAGE ENGINES

On older vehicles, the cooling system was often neglected, especially in frost-free areas of the country where people often used ordinary tap water to fill their radiators. The result was plugged radiators and thermostats (**Figure 15.66**), rusted radiator cap springs, rusted core plugs, plugged heater cores, rusted radiator hose reinforcement springs, metallic sediment in the coolant jackets (**Figure 15.67**), and a host of other problems. Most of these problems would have been avoided had the owner simply used a mixture of coolant and water instead of 100% tap water.

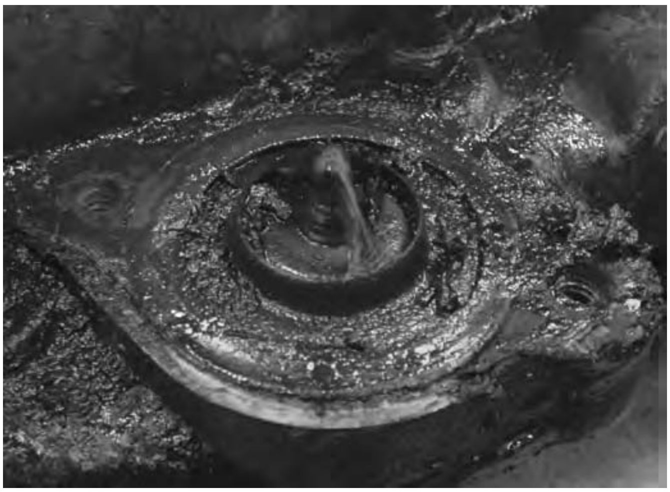


FIGURE 15.66 A thermostat on a vintage engine that is contaminated with rust cannot open and close properly. *(Courtesy of Tim Gilles)*

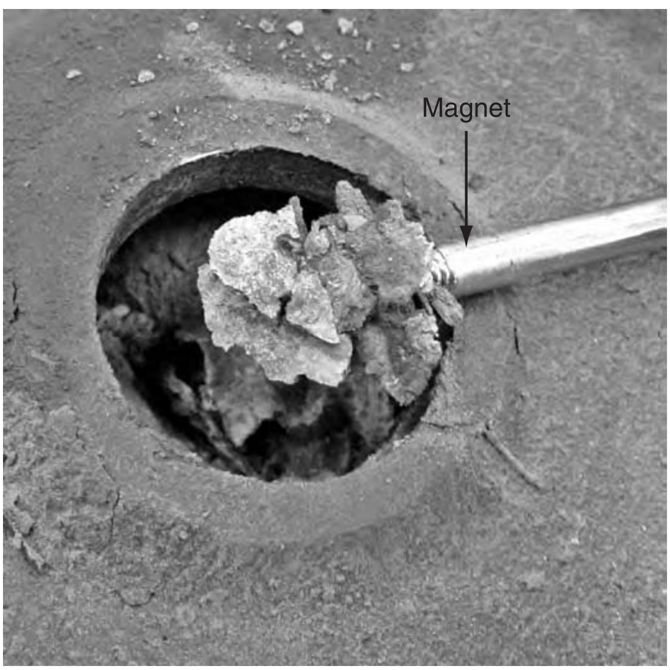


FIGURE 15.67 This sediment behind a core plug in the water jacket of a vintage iron block is magnetic. *(Courtesy of Tim Gilles)*

COOLANT

All automotive coolants are glycol based. The most common automotive coolants consist of a mixture of ethylene glycol with other additives and some water. Concentrated coolant is about 95% ethylene glycol, about 2.5% water, and the rest is additives. It is called permanent antifreeze/coolant because it does not evaporate.

NOTE

A common misconception is that the term *coolant* refers to a 50/50 mixture of antifreeze and water. The terms *coolant* and *antifreeze*, however, are used interchangeably by their manufacturers. In the industry, antifreeze/coolant is often simply called coolant.

The other glycol-based coolant is propylene glycol. The major difference between the two coolants is that propylene glycol is not as toxic.

Pure water has 1.4 times the heat-carrying ability of pure ethylene glycol, so water would be the best coolant to use if the only consideration in selection of a coolant were its ability to carry off heat. But water has other limitations. It forms rust on iron engine parts. Cylinder walls vibrate during combustion, breaking off the rust. The coolant carries the rust to other cooling system areas. Hard water forms mineral deposits and the resulting corrosion interferes with heat transfer, even before its results plug the radiator and fill the coolant jackets with sediment.

Coolant Boiling and Freezing Points

The freezing point for coolant is that point at which ice crystals begin to form. As coolant gets slushy, it will plug the radiator of a cold engine.

When slushy coolant trapped in the block gets hot, boilover can occur. The freezing point of pure water is higher than some winter temperatures, and its boiling point is lower than the coolant temperature at which a hot (but not overheated) engine can operate. Coolant has a higher boiling point than water, which is especially advantageous on today's hotter running vehicles with smaller cooling systems, multiple accessories, and air conditioning.

Water absorbs more heat than pure ethylene glycol coolant can absorb. Therefore, a coolant/water mixture is a better choice than concentrated coolant. Also, the freezing point of ethylene glycol concentrate is higher than if it is diluted with water. For use in motor vehicles, concentrated coolant is mixed with water until it is the correct mixture. **Figure 15.68** shows the effects of various coolant concentrations on boiling and freezing temperatures.

- Pure ethylene glycol freezes at 8°F (–13°C) and boils at 330°F (166°C). The factory radiator fill is usually about 50% water and 50% coolant, providing protection against freezing to –34°F (–37°C) and a boiling point of 265°F (129°C) when a 15 lb radiator cap is used.
- A 70% concentration is the maximum that should be used. The freezing point of a 70% concentration of ethylene glycol is –85°F (–65°C). Its boiling point is 11°F (–12°C) higher than would be provided by a 50⁄50 mixture.

Antifreeze/coolant is also available in a ready-to-use 50⁄50 mixture of antifreeze/coolant and purified water (**Figure 15.69**).

Coolant Color

When coolant is made, it is clear like water. During manufacture, it is dyed with one of several colors. Conventional *inorganic acid technology (IAT)*

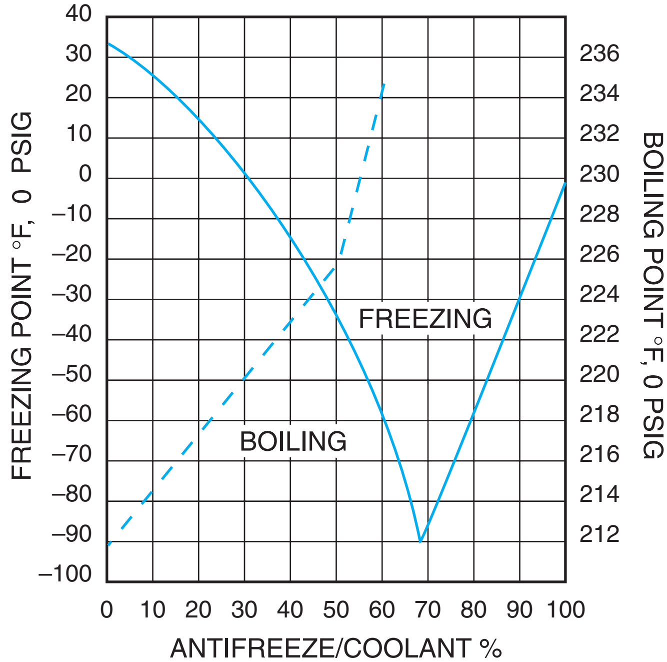


FIGURE 15.68 The ratio of ethylene glycol to water changes the coolant's freezing and boiling points.

FIGURE 15.69 Coolant is available in a 50% mixture of antifreeze/coolant and purified water. *(Courtesy of Tim Gilles)*

VINTAGE ENGINES

Some older automobiles did not have a temperature gauge. If the engine temperature reached a certain temperature, a switch in a sending unit closed and a high-temperature warning lamp on the instrument panel illuminated. The triggering temperature of the sending unit was usually well above water's boiling point (212°F [100°C] at sea level). With pure water, the warning light might never get a chance to work, because the water would have already boiled out before the switch reached a temperature high enough to close it.

coolant is usually green in color. Extended-life coolant is most often gold, orange, or red although it can also be various shades of green, pink, or blue.

NOTE

Color cannot be used to identify coolants. There are many different colors, but there is no guarantee that a certain color is a particular type of coolant.

Coolant Additive Package

There are many different types of ethylene glycol coolant using various additive packages. During the warranty period, it is especially important that the manufacturer's recommendations be followed when replacing coolant. After the warranty period is up, one of three coolants can be used to cover most vehicle makes. Those choices are discussed later.

Coolants have an additive package called a supplemental coolant additive (SCA). Conventional coolant has its own SCA package. Extended-life coolants use a different additive package that includes organic acids. These are called *organic acid technology (OAT)* coolants.

A variety of additives are included in automotive coolants, including inhibitors for aluminum protection, cavitation retarders, electrical galvanic activity preventers, antifoam additives, dyes, absorbers, and buffers.

A buffer is a liquid mixture of a weak acid and weak base. When additional acid or base is added to the solution, a buffer changes its pH level very little. A buffer, therefore, keeps pH at close to a constant value.

Cavitation happens in the cooling system when liquid forms air pockets as it boils due to a drop in pressure. When the bubbles collapse, they create potentially damaging shock waves in the coolant. Cavitation is covered in more detail later in this chapter.

An SCA package can include:

- **Borax** (sodium tetra borate), a buffer and neutralizer of acid.
- **Phosphate** (dipotassium phosphate). American and Japanese manufacturers use phosphate as a cavitation retarder and acid buffer. Phosphates protect cast iron but when used in very hard water (as found in Europe), scale forms.
- **Sodium molybdate**, an expensive corrosion inhibitor for heat-rejecting aluminum (when aluminum, such as in the coolant pump, is heating the coolant). Used as a cavitation retarder in nonphosphate coolants.
- **Sodium silicate** for aluminum protection.
- **Sodium nitrate**, which resists solder corrosion and pitting of aluminum radiators.
- **Triazoles**, chelants that grab and form a film over metal ions like brass and copper to prevent formation of a galvanic cell.
- **Sodium hydroxide**, used to keep the pH stable.
- **Phosphorescent dye**, which shows up under ultraviolet light. The colors vary and are for consumer identification only.
- **Benzoate**, which protects ferrous metals and high-lead solder. It is found in most coolants.
- **Water**, used to make the additives soluble.

Coolant Life

Like oil, coolant does not wear out, but the SCA package in conventional coolants requires replenishment on a regular basis, usually by exchanging the old coolant for new. Extended-life coolant has a long shelf life and it can remain in storage for many years without deteriorating. Conventional coolants with silicate additives have a shorter shelf life.

NOTE

One important consideration with long-life coolants is that they can turn to gel when air has entered the cooling system. To prevent this, be certain that the radiator cap is replaced on a regular basis and that all air is bled from the system during cooling system service or engine replacement. Thorough flushing must be done before adding new coolant.

Differences in Coolant

Coolants are not the same in European, Asian, and North American vehicles. There is some controversy regarding potential damage in using the wrong coolant in some manufacturers' vehicles.

- Most North American coolants contain phosphates and aluminum-protecting silicate additives.
- European coolants contain silicates but in lower concentrations than North American coolants.

- Japanese coolants do not contain silicates but use phosphates instead. Some say silicates are hard on coolant pump seals. Others say there is no evidence that silicates can harm today's carbide coolant pump seals.

Phosphate is often used as a corrosion inhibitor in North American and Asian coolants. The water in Europe is very hard. As phosphate softens water, it forms solids of calcium or magnesium salts. These can drop out of solution, blocking the cooling system. Using purified water would prevent this problem from occurring.

SHOP TIP

When community water has an abundance of minerals, distilled water should be used.

Electrolysis

Electrolysis, which can be of three types, is very destructive to the engine's cooling system. The first type, chemical electrolysis, results when coolant has become too acidic. Automotive cylinder heads on newer engines are most often made of aluminum and they are bolted to cylinder blocks made of cast iron. Chemical electrolysis occurs when two dissimilar metals in a liquid carry an electrical current. Just like in a battery, one of the metals acts like a positive plate and the other acts like a negative plate. During electrolysis, metal leaves one of the plates (the aluminum head) and is deposited on the other plate (the iron block). A corrosion inhibitor additive is required to protect the aluminum. To protect aluminum from corrosion, use a coolant that specifically states that it can be used with aluminum.

A second type of electrolysis can be caused by a faulty electrical ground circuit, which can result in extreme corrosion. Perform a voltage drop test on the engine's ground circuit during engine cranking. Perform a voltage drop test by connecting a voltmeter with the positive lead on the negative battery post and the negative lead on the starter housing at the engine block. **Figure 15.70** shows how a voltage drop test is conducted on the ground side of the electrical circuit. No voltage will be displayed on the meter during the ground check until the engine cranks and current is flowing in the circuit. Any voltage displayed on the meter during cranking is what is dropping across the circuit due to resistance.

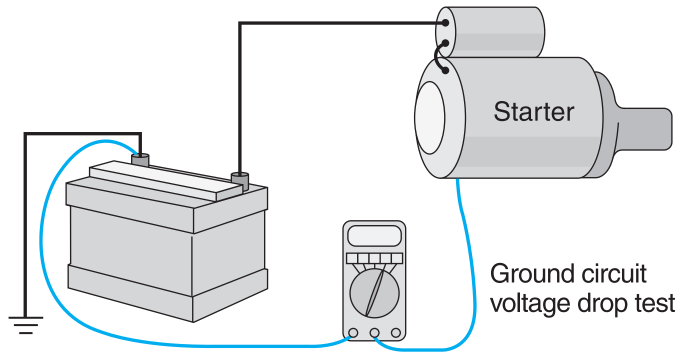


FIGURE 15.70 Excessive voltage drop in the ground circuit can cause electrolysis damage. Connect the meter as shown and read the voltage drop while cranking the engine.

A reading of 0.3 volt in the ground side is excessive. Less than 0.1 volt is desirable.

The third type of electrolysis results from static electricity. This is the condition that results in heater core failures, as described earlier.

COOLANT SERVICE

After it has been in use for a period of time, coolant loses some of its protective ability and can become corrosive from contaminants it has picked up.

Coolant Inspection

Inspect coolant while it is cold. Open the radiator cap and check inside the filler neck with your finger. Look for deposits of grease, dirt, or rust. Look for corrosion bloom, a white deposit that attaches to the tops of the tubes. Deposits like these indicate a need for a coolant change because the coolant additives have been depleted. If coolant appears to be rusty or contaminated, a radiator flush will be required.

Checking Coolant Conductivity

Electrolysis in the cooling system makes small holes in cooling system parts as metal transfers from one electrically charged part to another. Electrolysis can produce a voltage in the cooling system. The coolant's conductivity can be checked with a voltmeter (**Figure 15.71**).

- Ground the positive probe by attaching it to the radiator.
- Insert the negative probe in the coolant.
- A reading of 0.2 volt or less is good.

FIGURE 15.71 Checking the voltage level in the coolant. (*Courtesy of Tim Gilles*)

If the voltmeter reads 0.5 volt or more, the system should be flushed and refilled with new coolant to prevent corrosion of the metal parts in the system. Besides the internal problems this condition can cause, an inaccurate coolant temperature sensor reading can result when the cooling system charge is above 0.4 volt. The coolant solution should be close to 50% strength to provide adequate protection against electrolysis.

Coolant Change Interval

Most vehicle manufacturers recommend that coolant be changed *at least* every 3 years or 30,000 miles. Contaminants resulting from by-products of combustion can get into the coolant by leaking past a head gasket. Additives in the coolant package also become depleted and can be replenished by changing the coolant. Some coolant recycling machines clean old coolant before treating it with an SCA and returning it to use.

When mixing coolant and water, very hard water should not be used, especially with aluminum heads. Phosphate corrosion inhibitors can "drop out" of coolant with very hard water. Use distilled water instead.

Older vehicles require more frequent coolant changes. Inhibitors in the coolant wear out. Silicate additives that protect aluminum have a shorter life span than other additives because they are consumed as they react with the metals.

Draining Coolant

Most radiators have drain valves made of plastic. Loosen the drain plug and drain the coolant. If the coolant is to be used again, be sure to drain it into a clean pan.

When the radiator has no drain plug, it can be drained by removing the lower radiator hose. Twist the hose before trying to pull it off its connection, being careful not to damage the radiator. The hose connection is soldered to the lower tank on copper/brass radiators. This seal can break or the soft brass connection can be easily deformed.

Special tools are available for separating a stuck hose from its connection (**Figure 15.72**). If it does not separate easily it will be necessary to cut the hose (**Figure 15.73**). A special hose-cutting knife is available from tool manufacturers. Be especially careful not to cut through the thin plastic or brass on the inlet or outlet of a heater core.

Engines often have drain plugs on the side of the block. The plugs have tapered pipe thread and are sometimes rusted to the block, making them difficult to remove. If they are accessible and come out easily, remove them to drain the block. Use sealer

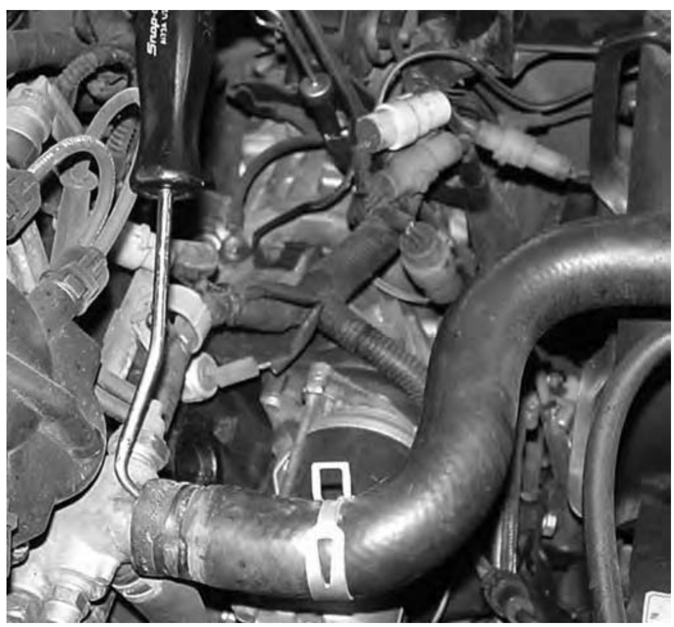


FIGURE 15.72 A special tool for loosening radiator hoses. Wet the tool first by dipping it in the radiator coolant. (*Courtesy of Tim Gilles*)

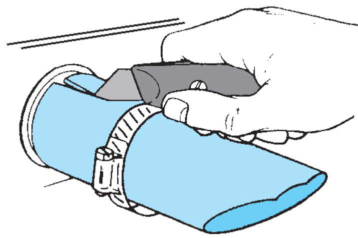


FIGURE 15.73 If a radiator hose will not come off without forcing it, cutting the hose might be necessary.

on them when reinstalling. Be careful not to overtighten pipe threads; they can wedge against the block and cause a crack.

Cooling System Flush

When coolant has not been professionally maintained, mineral deposits and dirt can build up in the water jackets (**Figure 15.74**). Without removing the radiator from the vehicle, the cooling system can be flushed, either with a cooling system flusher or by back flushing. A back flush is when water is run through the system backward from its normal direction of flow. A convenient way to back flush a cooling system is to install a "flushing-T" to the hose from the heater core to the engine (**Figure 15.75**). Following flushing, the T will remain in the hose with a threaded cap sealing its outlet. The T is installed into a relatively straight section of the hose that runs from the bulkhead (firewall) to the top of

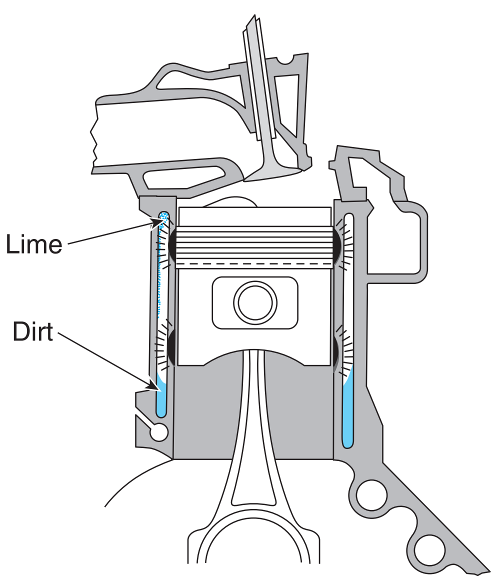


FIGURE 15.74 Tap water causes a buildup of dirt and minerals in the water jackets.

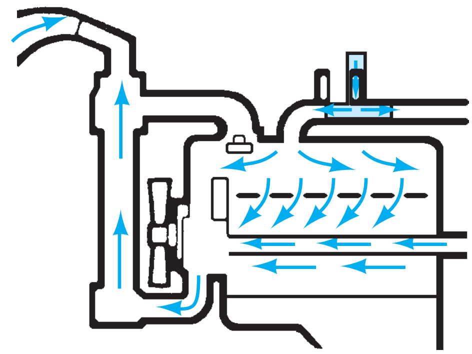


FIGURE 15.75 A plastic T installed in the upper heater hose.

the engine. Coolant that escapes from the top of the radiator should be captured and disposed of in an environmentally safe manner.

NOTE

Many communities have regulations governing the disposal of coolant. Be sure to follow regulations in your area. Ethylene glycol is biodegradable when new. But when it has been used, corrosion and heavy metals from within the engine and radiator can be present. In addition, coolant is poisonous to humans and animals.

Airlift Leak Check and Airlock Purge

A venturi system that uses compressed air to create a vacuum in the cooling system is an effective way to check for leaks and refill the cooling system (**Figure 15.76**). Using this tool ensures a cooling system that is purged of air. The procedure works best if the radiator is completely drained first. Insert the tool in the radiator filler neck or the reservoir tank using an adapter of the correct size, and then tighten it. With the refill hose valve closed, direct shop air into the tool's venturi assembly. As pressure drops in the radiator, the vacuum gauge on the top of the tool will begin to register and you will hear air hissing through the venturi body. Hoses sometimes collapse as the vacuum increases; this is normal. Allow vacuum to increase until the vacuum gauge reads 24–26". The entire airlift time will take less than 1 minute.

After the specified vacuum level has been achieved, check for leaks by waiting for 20 minutes to verify that system vacuum is maintained. If there are no leaks, insert the refill hose into a container of 50/50 coolant and slowly open the refill valve to fill the refill hose and purge it of air. Then close the valve. As the

FIGURE 15.76 A cooling system air lift. *(Courtesy of Tim Gilles)*

refill hose fills, the vacuum reading on the gauge will drop. Direct more shop air into the venturi assembly until system vacuum is once again 24–26".

With the cooling system under vacuum, open the refill valve so coolant can be drawn into the purged cooling system. The cooling system is full when the vacuum gauge drops to zero.

NOTE

Be sure there is more coolant in your coolant container than is needed to completely fill the cooling system. Otherwise, the coolant level in the container can drop below the hose inlet, defeating the purpose of the procedure by allowing air to enter the system.

Coolant Exchanger

A popular piece of shop equipment is a coolant exchanger. The machine is easy to use and when used correctly, little or no spillage of coolant occurs during a coolant exchange. The machine is also handy for draining and refilling coolant during an engine repair.

There are several manufacturers of coolant exchange machines. One of them is shown in **Figure 15.77a**. The following illustrates a typical coolant flush procedure. The upper radiator hose is disconnected and an adapter is attached with one end on the radiator and the other end to the upper hose (**Figure 15.77b**). Before removing a hose, the radiator level is lowered using the machine.

The machine has adapters for several sizes of radiator hose (**Figure 15.77c**) and hoses do not need to be cut. **Figure 15.77d** shows adapters installed in series with the upper radiator hose.

Many manufacturers recommend periodic replacement of the thermostat, which can be done as part of a flushing procedure. Thermostat removal and replacement is covered in another part of this chapter. When the thermostat is not being replaced, the engine is run during the coolant exchange and must be warmed up until the thermostat opens.

Premixed coolant is used, or coolant and distilled water are mixed in the correct proportion and quantity in one of this machine's two containers (**Figure 15.77e**). During the coolant exchange, one of the machine's containers collects the old coolant while new coolant is pumped into the cooling system from the other container. Following the exchange of coolant, the overflow reservoir is pumped out and cleaned, using some used coolant pumped from the exchanger. The reservoir is filled to the correct level with new coolant to complete the job. **Figure 15.77f** shows the different switch positions used during the flush procedure.

The coolant exchange process can also include a chemical flush when a radiator becomes partially plugged with soft sludge. Using a commercial chemical cleaner, the radiator can be flushed without removing it from the vehicle. With a hose running into the radiator, the engine runs at idle while the system is flushed. On some vehicles it is necessary to move the dashboard heater levers to the "heat" position to flush the heater core.

Some radiator cleaners are acids. Acids are effective for removing rust and scale, but they must be neutralized with a base following use, or damage to the cooling system can result.

SAFETY CAUTION

Be sure that you wear safety goggles when using the radiator flush chemical. It can cause blindness.

Run the vehicle for the required period. If the cleaning chemical requires a neutralizer, add it to the water remaining in the radiator after flushing is complete. The liquid remaining in the block will be 100% water.

When a radiator is restricted, it is removed from the vehicle. Aluminum radiators are replaced, but copper/brass radiators can be rodded out by a

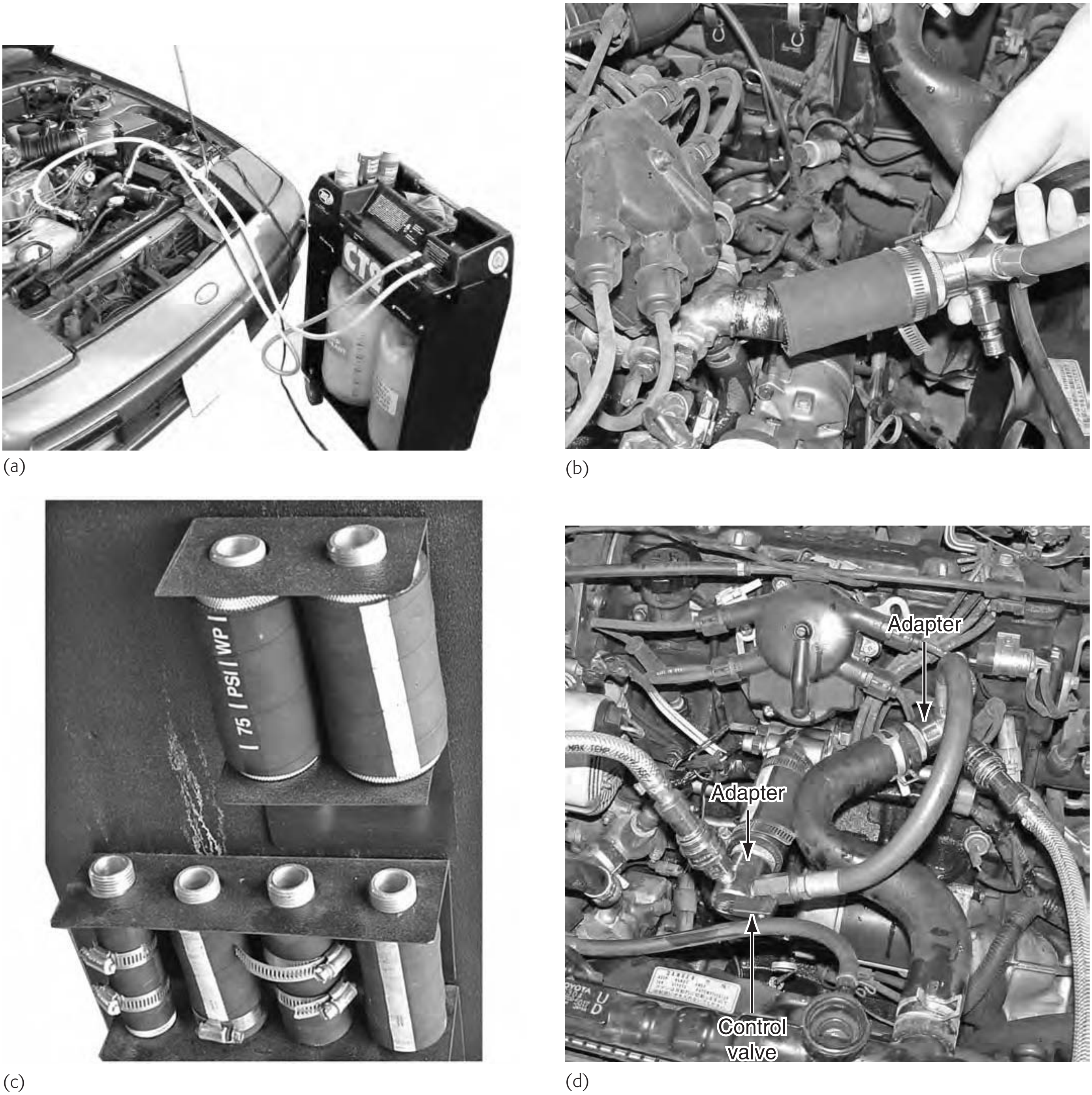


FIGURE 15.77 (a) A coolant exchanger. (b) Attaching one end of the adapter in place of the radiator hose. (c) Several sizes of adapters. (d) Both adapters installed in series with the upper radiator hose. *(Courtesy of Tim Gilles)*

radiator shop if the cooling fins have not been ruined by corrosion.

Aluminum Oxide Contamination

Aluminum oxide is very abrasive; it is what sandpaper is made of. It does not form unless the coolant has become too diluted with water. If there is aluminum oxide in the cooling system, it looks like black sand beads. When flushing a cooling system, heat the engine to operating temperature and re-flush at least three times, heating to full temperature each time. When the final flush has been completed, run the water through a coffee filter to see if any black sand particles remain.

(e) (f)

FIGURE 15.77 (continued) (e) One container collects old coolant and the other supplies new coolant. (f) The position of this switch determines whether old coolant or new coolant is pumped. *(Courtesy of Tim Gilles)*

Testing Coolant Condition and Strength

Different methods can be used to test coolant strength and condition, including chemically treated coolant test strips, specific gravity testing, and refractometer testing.

Coolant Test Strips

Coolant test strips (**Figure 15.78**), originally developed for the medical field, provide a popular way of testing coolant. A test strip typically includes three or more chemically treated pads attached to a long piece of thin plastic. Dipping the test strip into coolant in the radiator gives an indication of the condition and concentration of the coolant. The chemically treated pads change color to indicate pH, additive condition, and concentration/freeze point. Other test strips are available that can tell if different types of coolants have been mixed.

Test strips are relatively accurate, within 10 degrees of refractometer readings. Results vary with coolant temperature and should be done with the engine cold, which is a temperature of less than 120°F (49°C) (when it is safe to remove the radiator cap). Cold coolant provides consistent color readings. However, when a test strip is dipped into hot coolant the colored pads develop faster, resulting in a reading that is darker by about one color block

FIGURE 15.78 Different coolant test strips are used, depending on the type of coolant. *(Courtesy of Tim Gilles)*

than that of cold coolant. Instead of sampling from the radiator, you can test the concentration in the overflow tank. But this will not provide an accurate indicator if the coolant has been recently topped off or if the level is lower than normal.

To perform the test, dip the test strip into cool coolant for 1 second and shake it off. Then match the pads to the closest control colors on the bottle. Read the test strips in natural light. Typically, the end pad tells the freeze point and the highest pad indicates pH. Be sure to read the color of the pads within 1–3 minutes after dipping because the color can change as the pad dries. In colder weather (below 5°F [−15°C]), make a reading between 2 and 5 minutes. If the color of the strip falls between two of the control colors, select between the two.

Test strips have an expiration date, which is typically 1 year after manufacture for test strips in foil packages and 2 years for test strips in a bottle. Test strips are nontoxic and can be thrown away as normal waste. The colors of the pads can change due to long exposure to hot weather or sunlight, or leaving the lid off the bottle.

FIGURE 15.79 A coolant hydrometer measures the specific gravity of the coolant. *(Courtesy of Tim Gilles)*

Coolant Alkalinity (pH)

As coolant ages, acids form. Used coolant must continue to contain a sufficient amount of corrosion inhibitor to neutralize these acids. This neutralizing ability is called reserve alkalinity. Preserving an engine's cooling system depends on changing the coolant before its reserve alkalinity is depleted.

Conventional coolant has a higher pH than extended-life coolant. Its additives give it a pH level of about 10.5 when new. Used conventional coolant should test at a pH level of at least 9. Extended-life coolant, which is more acidic due to its organic acid package, should test at a pH level of at least 7.5. When the additives become depleted, the acid level rises (pH level drops) and corrosion begins. The first things to fail are usually the radiator and heater core because these are the thinnest cooling system parts.

Coolant Density Testers

Two types of testers can be used to measure a coolant's freeze point. Both determine the density of the coolant. The technician needs to know what kind of coolant is being tested. One cannot tell simply by the color if the coolant is the factory-recommended coolant or an aftermarket replacement like propylene glycol.

Hydrometer Testing

A *hydrometer* is one way to test coolant strength (**Figure 15.79**). It compares the weight of ethylene glycol to the weight of pure water. After checking instructions on the hydrometer, compress the rubber bulb and release it to draw some coolant into the tester. Then read the gauge.

Refractometer Testing

A *refractometer*, another tool used to measure coolant concentration (**Figure 15.80**), is an optical tester that measures how much light can be refracted (bent) by a liquid. Starting with a cool engine, use an eyedropper to remove coolant from the radiator. Place a drop or two of coolant on the viewing surface under the cover of the tester (**Figure 15.80a**). Close the cover and hold the tester up to a light source while looking into the eyepiece (**Figure 15.80b**). The freeze protection is viewed in degrees.

Coolant Concentration

Ethylene glycol coolant is mixed with purified water until its concentration is correct. Coolant in too high a concentration can be diluted with purified water. When coolant strength has become weak or additives are depleted, a coolant flush and change is recommended. A slightly weak concentration can be strengthened by draining off a quart of the coolant/water mixture and topping off with 100% coolant. After adding coolant, run the engine before rechecking the strength of the concentration.

(a) (b)

FIGURE 15.80 A refractometer. (a) Place a drop or two of coolant on the viewing surface. (b) Close the cover and hold the tester up to light. View the freeze protection in degrees. *(Courtesy of Tim Gilles)*

Before mixing water with coolant to achieve a concentration of approximately 50%, verify the cooling system capacity in the service information. Coolant is usually sold in gallon containers. If an engine has a cooling system capacity of 16 quarts, a 50% concentration would call for 2 gallons of coolant and 2 gallons of water. If a cooling system holds 13 quarts, 1½ gallons (6 quarts) will provide a mixture that fits into the 40/60 range. Unless the winter weather in the area is especially harsh, this will provide a good mixture. Keep in mind that maximum coolant concentration is 70% coolant and 30% water.

Which Coolant to Use?

Sodium silicate is an excellent aluminum protection additive. However, silicate additives can cause problems when used in too high a concentration. A majority of coolants contain this additive, although many contain a lesser percentage than conventional IAT coolant. Heavy-duty truck manufacturers and some automotive manufacturers specify the use of coolants without silicates. Be sure to use the coolant specified by the manufacturer.

When using conventional IAT high silicate coolant, 60% is a good maximum concentration because silicate solubility decreases as the ratio of coolant to water is increased. Silicates in a heavy concentration can gel on heat transfer surfaces, resulting in engine overheating and poor heater operation. Sand granules that are abrasive can also form, resulting in coolant pump leaks.

Coolant should be used before the shelf life date printed on the container expires. If coolant with silicate additives is stored for too long it can become like gel.

VINTAGE ENGINES

Older engines had cast iron cylinder heads and blocks. When a cooling system does not include parts made of aluminum, a good rule of thumb is to use a coolant *without* silicate additives.

The corrosion inhibitor used in DexCool® extended-life coolant is based on two organic acids. These replace the additives found in conventional coolants. Because there are no phosphates in the additive package, hard water deposits are virtually eliminated. One of the organic acid additives, 2-EHA, has been associated with softening of some plastic parts, including coolant gaskets and coolant pump impellers. Be sure to use DexCool in vehicles specified by the manufacturer.

HOAT Coolant

Hybrid organic acid technology (HOAT) coolant, usually known as G-05®, is a popular coolant used in a majority of new vehicles. It was the OE coolant originally supplied from the factory in Mercedes and Chrysler vehicles and is like OAT coolant except that it contains silicates, although at a lower level than conventional green IAT coolant. Like most other coolants (except for OAT), it also contains benzoate.

Following the warranty period, some repair shops recommend a thorough flush and refill with a coolant containing phosphates and/or silicates like the older IAT green coolant or G-05. These provide extended head gasket life and protect the coolant pump from cavitation damage.

NOTE

All manufacturers recommend that conventional and extended-life coolant not be mixed. If a vehicle is originally equipped with one type of coolant, it is prudent to continue to use that type of coolant.

There are many different coolants but you will probably be able to satisfy most coolant needs with three coolants, DexCool, G-05, or conventional green North American coolant.

SAFETY NOTES

- Ethylene glycol is a poison. Ingestion of 4 ounces is sufficient to kill a human being. Because it has a sweet taste, ethylene glycol is especially dangerous to animals. Dogs are occasionally poisoned by drained coolant carelessly left on the floor in a drain pan. Do not leave used coolant around the shop. Coolant is disposed of as hazardous waste.
- Be careful when handling extremely cold coolant. Ethylene glycol left in the trunk during cold weather can freeze-burn your skin.
- Although it is not flammable at room temperature, ethylene glycol will ignite in the presence of flame at about 474°F (246°C). Research by GM has shown that an explosion can actually occur if a mist of pressurized ethylene glycol coolant mixture is sprayed on an open flame.

Coolant Leakage into the Engine. Ethylene glycol coolant leaking into the crankcase can oxidize oil. The result is a varnish-like substance that can ruin valve guide seals and clog oil rings, although compression rings generally remain clean. There have been cases of engine seizure due to this varnish formation. The source of the leak must be found and repaired or the problem will recur. Internal coolant leakage can result from a leaking timing cover gasket, a defective head gasket, or by a crack in a head or block.

SHOP TIP

Flushing the engine can sometimes be effective if the engine is still in running condition. Ethylene glycol monobutyl ether, an engine flush marketed under different names, is mixed with lightweight engine oil and then flushed through the engine. The chemical, a common household cleaner, can be purchased through local laboratory supply houses. Union Carbide calls its product Butyl "Cellosolve®."

Thermoplastic Seizure. The mixture is thermoplastic: hard when cold, softening with heat. An engine with **thermoplastic seizure** is often hard to turn over when cold. The cooling system can be filled with hot water to help soften thermoplastic deposits, allowing the crankshaft to turn. If the crankshaft still cannot be easily turned:

- Remove all spark plugs and pour undiluted Butyl "Cellosolve" into the cylinders.
- Let the solvent saturate until the engine can be turned over.
- Complete the flushing procedure.

If the flushing procedure is not entirely effective, the engine must be totally disassembled and cleaned.

SAFETY NOTE

Butyl "Cellosolve" can penetrate the skin in harmful amounts. It can also damage paint. Wear eye protection and gloves, and use fender covers.

Bleeding Air from Coolant

Always recheck to see that the cooling system is full and all air has been purged before releasing the vehicle to a customer. Trapped air can cause coolant oxidation, cavitation, and engine overheating. Air pockets form when the cooling system is refilled after being empty. Some cooling systems are difficult to fill without trapping air. Due to aerodynamics, the radiators on many newer vehicles are lower than some other cooling system parts, causing trapped air that cannot be bled from the radiator filler opening as normal. Check the service literature for instructions on how to purge the system of trapped air. Some procedures call for removing the coolant temperature sensor or filling the system through the top radiator hose.

SHOP TIP

An airlift/airlock tool (covered earlier in this chapter) is an effective way to eliminate trapped air.

When bleeding trapped air, sometimes it is helpful to jack the front of the vehicle as high as a floor jack will go to position the radiator higher in its relation to the rest of the cooling system. Some engines have a bleed screw to allow air to be purged from a high spot in the cooling system (**Figure 15.81**). When a cooling system does not have a bleed screw, it can sometimes be bled of air by removing a heater hose at the system's highest point (**Figure 15.82**). Removing a heater hose bleeds air from the heater core, too.

Air can leak into the cooling system through a small leak in the lower (suction) radiator hose connections.

To test for leakage of air into the system:

- Replace the pressure cap with a nonpressure cap (or tape up the filler neck on the radiator with duct tape).
- Put a hose from the radiator overflow pipe into a jar of water, and watch for air bubbles.

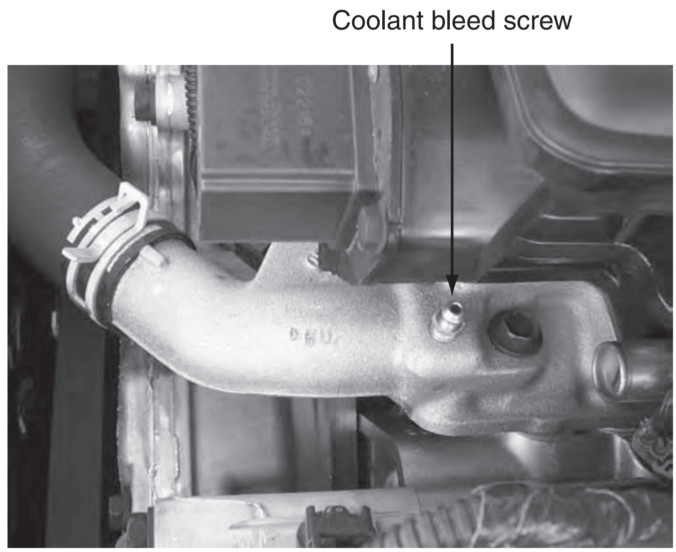


FIGURE 15.81 Some engines have a bleed screw for removing trapped air from the cooling system. *(Courtesy of Tim Gilles)*

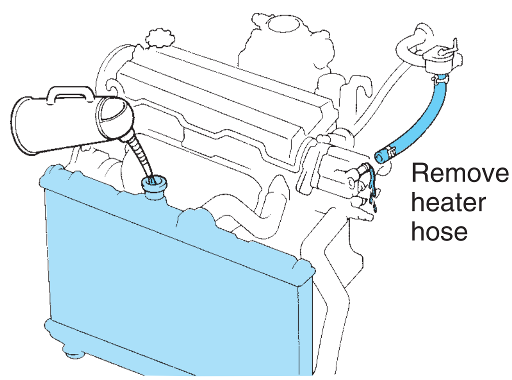


FIGURE 15.82 When refilling the system, bleed air off by removing a hose from the highest place in the system.

Cavitation

Cavitation is the formation of air bubbles in the coolant. The following are some of its causes:

- The coolant boiling
- Air in the coolant
- A suction restriction
- Overpumping
- Vibration of the cylinder walls during combustion

Cavitation can create up to 60,000 psi of pressure from the bubbles if they burst. As boiling coolant travels through the engine, the bubbles collapse and chip off metal. **Figure 15.83** shows cavitation erosion in a cutaway of an aluminum

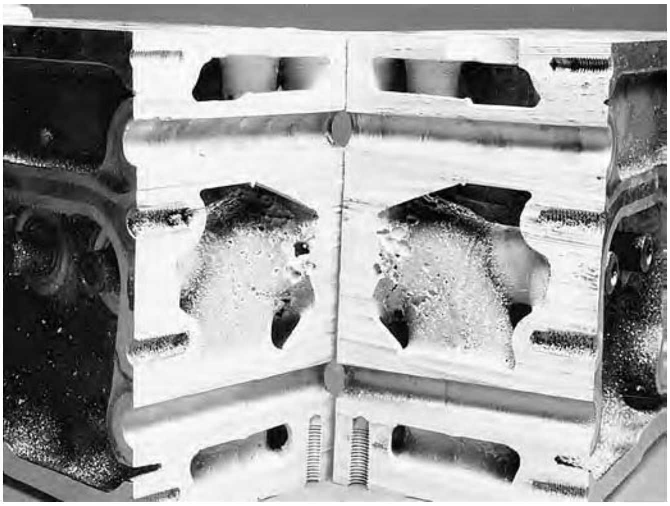


FIGURE 15.83 Cavitation erosion in an aluminum head. *(Courtesy of Prestone Products Corporation)*

cylinder head. The eroded aluminum flakes can plug the radiator.

If the coolant pump tries to move more water through the cooling system than is possible, a pressure drop at the suction side of the pump results in cavitation on the pump impeller. Good cooling system maintenance, including good antifreeze, a good pressure cap, and tight connections, can help prevent cavitation. Phosphate additives in the coolant control cavitation, but these are not available in parts of Europe. In fact, some European warranties may be voided by their use.

Key Terms

cavitation
thermoplastic seizure
thermostat bypass
serpentine

Study Questions

1. What can happen to the coolant pump if cold water is added to an overheated cooling system?
2. For each pound of pressure on the coolant, approximately how much will its boiling point increase? _____ °F
3. Automotive coolant is a combination of ethylene glycol and _____.
4. What is it called when an electrical current develops between two dissimilar types of metal in the cooling system?
5. _____ is the name of one type of coolant additive that protects aluminum.
6. What is the name of the small valve in the center of a radiator pressure cap?
7. Two names for the part of the radiator that automatic transmission fluid flows through are the transmission oil cooler and the heat _____.
8. _____ in the thermostat expands to cause it to open.
9. What passage allows coolant to circulate within the block when the thermostat is closed?
10. When the bottom of a radiator core feels considerably colder to the touch than its top, it is probably plugged.
    a. True
    b. False
11. When a radiator is disassembled and cleaned out, this is called _____ out.
12. When measuring the voltage of coolant, what is the limit before the system should be flushed out?
13. What is the name of the tool that compares the density of water to that of coolant?
14. Why is ethylene glycol coolant dangerous to animals?
15. Why is there a small hole in some thermostats?

ASE-Style Review Questions

1. Technician A says that the lower radiator hose fails most often. Technician B says that 100% coolant provides better cooling than a mixture of coolant and water. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. Technician A says that a fan is not necessary at freeway speeds. Technician B says that the fan is supposed to push air through the radiator. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. Technician A says that the pressure cap can raise the boiling temperature of the coolant. Technician B says that the small valve in the center of the radiator cap is the vacuum valve. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. Technician A says that installing a thermostat with a lower temperature rating will help an engine run cooler in hot weather. Technician B says that a stuck-closed thermostat can cause a computer-controlled fuel system to run rich when the engine is cold. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. Technician A says that a vehicle that overheats only on the freeway probably has a stuck-closed thermostat. Technician B says that the thermostat can be left out of the engine with no ill effects. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. Technician A says that in a conventional flow cooling system, coolant leaves the engine through the top radiator hose. Technician B says that if cold water is added to a hot cooling system, the coolant pump could start to leak. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. A transmission heat exchanger has failed. Technician A says that if the engine is running, oil will flow from the transmission to the radiator. Technician B says that when the engine is off, coolant will flow into the transmission. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Two technicians are attempting to locate a leak by using a pressure tester on the radiator. Technician A says to use a mirror and flashlight to locate a leak if the location cannot be seen. Technician B says to run the engine when performing the test. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that when replacing a thermostat the temperature sensing bulb faces out of the block. Technician B says that engines with

aluminum heads should use antifreeze with special (silicate) additives. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

10. Technician A says that older radiator cores are made of copper and brass. Technician B says that newer radiator cores are usually made of aluminum and have plastic tanks. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

SECTION 4

Engine Repair and Reassembly

Overview

This final section of the book includes repair methods, hardware, and the procedures for reassembling, starting, and breaking in a rebuilt engine. Chapter 16 includes fastener theory, broken fastener and thread repair, and flared line repairs. Also included are gaskets and seals. Chapter 17 deals with engine reassembly, installation, and break-in. Included are the final inspection before returning the vehicle to the customer and warranty coverage. Proper trade procedures are emphasized.

CHAPTER 16

Engine Hardware: Fasteners, Thread Repair, and Gaskets

Contents

Objectives

Upon completion of this chapter, you should be able to:

- List fasteners and the methods in which they are used for repair.
- Describe the various methods of thread repair.
- Perform repairs to flared lines.
- Explain the theory related to gaskets and seals.

Introduction

A good engine repair technician must know many things about fasteners (nuts and bolts), tightening procedures (torquing), different methods of repairing broken fasteners, and the uses of gaskets and sealers. This chapter deals with these parts and procedures.

CHARACTERISTICS OF FASTENERS

An externally threaded fastener used with a nut is called a *bolt*. When it is used without a nut in a threaded or blind hole to hold components together, it is known as a capscrew.

Several kinds of fasteners are used in automobiles. They are selected according to purpose and price. There are marks on the head of a bolt that identify its grade. Fasteners are made of different grades of metals, and some are hardened.

Hardening. To toughen, or temper, a metal, it is heated to a specific temperature and then quenched.

Softening. To soften, or anneal, a metal, it is heated and allowed to cool slowly.

BOLT STRETCH

When a bolt is correctly tensioned, it will be "spring-loaded" against the part. Bolts are purposely stretched like this to provide **clamping force** or "spring tension" to hold parts together (**Figure 16.1**). Head bolts must hold against the pressure of combustion that is trying to push the head away from the head gasket and block. The clamping pressure on the bolts is greater than the combustion pressure in the cylinder, so the head

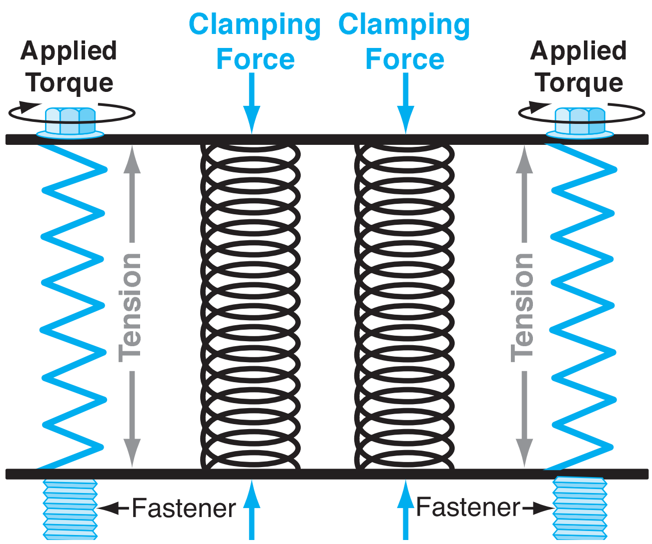


Figure 16.1 Fasteners are purposely stretched to provide continual clamping force.

Figure 16.2 When a bolt is overstretched, the screw thread distorts. A nut will not turn easily on the bolt in the stretched area. *(Courtesy of Tim Gilles)*

bolts never feel the stress as long as correct bolt torque is maintained.

Usually a bolt is stretched to 70% of its **elastic limit** when properly tightened to specification. The elastic limit of a fastener is reached when it will no longer return to its original shape when loosened. When a bolt has been overstretched **(Figure 16.2)**, a nut can turn easily down the bolt threads until it encounters the stretched area, where it will become hard to turn.

NOTE

A bolt can be overstretched because it is of too poor a grade of fastener for the torque being applied, or because a thread lubricant is used without a corresponding reduction in torque. Some technicians depend on "feel" when torquing. An experiment that tests a special tension gauge against a group of experienced technicians will show how inaccurate this method of torquing really is.

Figure 16.3 This indicator is used to measure connecting rod stretch before and after torquing. *(Courtesy of Tim Gilles)*

The tightening load on a fastener is known as *preload.* There are three ways of measuring the preload on a fastener. The most common is with a *torque wrench.* A torque angle gauge is another method. The most accurate method is to measure the actual amount of *bolt stretch*. This is not practical, however, unless both ends of the bolt are accessible for measurement with a micrometer or dial indicator before and after tightening. High-performance engine builders measure bolt stretch on connecting rod bolts using two procedures. Compression of the rod can change the outcome by a small amount.

SHOP TIP

Use a micrometer to measure the length of a rod bolt. Then install the rod cap, tighten the rod nut to its specified torque, and remeasure the length of the bolt. The specified amount of stretch for OEM rod bolts is around 0.006". Less stretch indicates too much thread friction. Too much stretch can be due to an overstretched bolt.

Racing engine builders measure bolt stretch using a special dial indicator **(Figure 16.3)**.

TORQUE AND FRICTION

Torque is the measurement of the twisting effort required to tighten a fastener.

NOTE

Torque changes with the use of lubricants. Heavy lubrication of threads can result in overstretched bolts.

Approximately 90% of the torque applied in tightening a dry, unplated fastener is used to overcome friction. About half of that 90% is lost to fric-

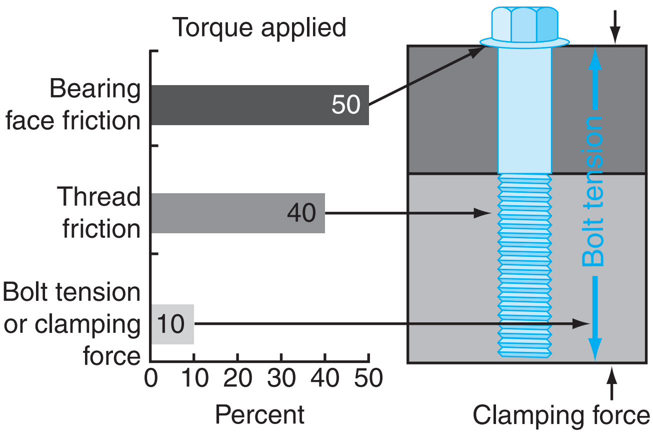


Figure 16.4 Friction can prevent correct clamping force.

tion between the head of the bolt and the work surface; the other half is lost between the threads. The final 10% provides the tension (clamping force) necessary to hold the assembly tight **(Figure 16.4)**.

Thread Lubricants

An antiseize compound should be used where a bolt might become difficult to remove after a period of time—for example, in an aluminum block, or on exhaust manifold bolts **(Figure 16.5)**. A chart in the appendix (at the back of the book) shows how much to reduce torque when thread lubricants are used.

Lubricants also introduce the possibility of a **hydrostatic lock**, where oil is trapped in a blind hole. When the bolt contacts the oil, it cannot compress it; therefore, the bolt cannot be properly tightened. A cracked part can result.

Fastener Grades

The heads of bolts have markings to identify their grades **(Figure 16.6)**. Metric bolts are numbered. The higher the number, the greater the strength of the bolt.

Figure 16.5 An antiseize compound is used where a bolt might be difficult to remove. (*Courtesy of Tim Gilles*)

- *Tensile strength* is the maximum stress a material can withstand without breaking.
- **Yield point** is the maximum stress a material can withstand and *still be able to return to its original form without damage.*
- *Ultimate strength* is about 10% higher than the yield point (for high-quality steel). That is the point at which the fastener breaks.

The International Standards Organization (ISO) defines fastener quality in terms of tensile strength and yield strength. This standard is used for metric fasteners and is anticipated to eventually replace all other grading standards. When interpreting an ISO fastener grade number:

- The first number is the tensile strength.
- The second number is the yield strength.

For example, a metric bolt marked 8.8 has a tensile strength of 800 MPa (115,000 psi) and a yield

VINTAGE ENGINES

On standard inch bolts, there are radial lines that indicate strength. Count the lines and add 2 to determine the strength of the bolt. These are known as SAE bolt grades and are evaluated by the American National Standards Institute (ANSI) standard, which is used to measure a fastener's tensile strength.

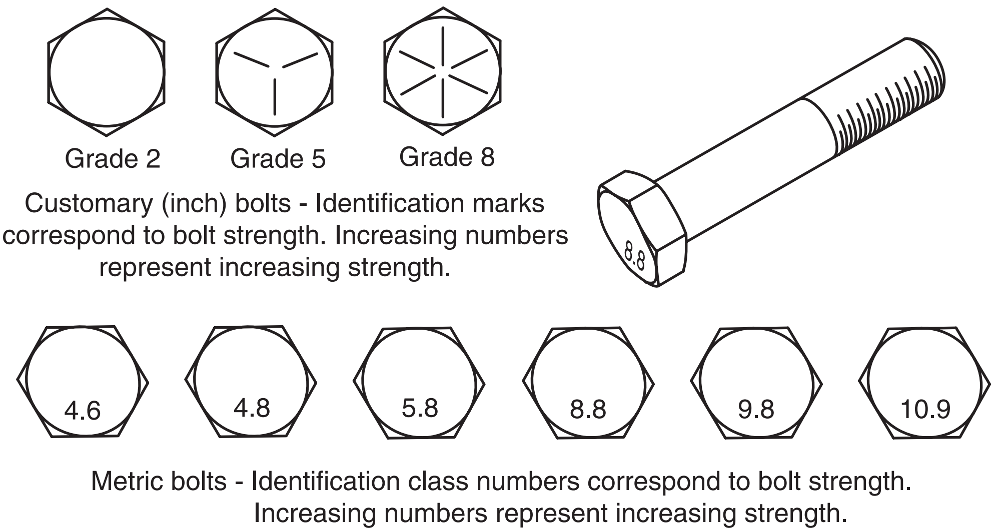


Figure 16.6 The top of the bolt head is stamped with a bolt grade marking.

strength of 80% of 800 MPa. A 10.9 bolt has a tensile strength of 1000 MPa (145,000 psi) and a yield strength of 90% of 1000 MPa. Markings are required only on bolts classed 8.8 or higher.

Metric fastener strength is called property class rather than grade (as with SAE fasteners). SAE grades and property classes are comparable:

In the appendix at the back of this text, there are charts describing the tensile strengths and the torque recommendations for various sizes and grades of fasteners. Remember that these torque recommendations are not for gasketed joints or for soft materials.

SAE Grade	Property Class
Grade 2	5.8
Grade 5	8.8
Grade 7	9.8
Grade 8	10.9

NOTE

The strongest bolts are not always the best choice. A high-grade fastener might be best for a front suspension bolt but may not be suitable for use in an engine. Using a higher grade of fastener allows a higher torque to be used. However, if torque is not increased, there is no increase in the clamp load, whether a higher bolt strength is used or not. Also, higher strength bolts have less resistance to fatigue than softer bolts if they are undertightened.

Using more torque can distort parts of the engine, like the cylinder bores or main bearing bores. Follow the OE manufacturer's torque and fastener recommendations. Automotive bolts are usually 8.8 (metric) or grade 5 or 6 (inch-standard). To determine the size of a fastener, measure the screw thread. Rolled screw threads are larger than the shank of the bolt (the area between the thread and the head of the bolt). The bolts shown in **Figure 16.7** do not have rolled threads. They are also rusted, which makes them unsuitable for reuse.

Figure 16.7 Rusted fasteners like these must be discarded. (*Courtesy of Tim Gilles*)

Torque Wrenches

The amount of torque applied to a fastener can be measured with a torque wrench. There are three styles of torque wrenches. The inexpensive beam wrench is very common. The "click" (spring) wrench is available with a ratchet (**Figure 16.8a**). It is the most versatile, because it can be used in hard-to-reach places in the engine compartment. The "click" can be felt, even if the gauge cannot be seen (**Figure 16.8b**).

NOTE

Reset this torque wrench to zero after each use; this will unload the spring and maintain its accuracy.

The dial torque wrench is the most accurate (**Figure 16.9**). Some are available with a light or a buzzer for use when the dial face cannot be seen. Torque wrenches used in automobile repair have $^1/_2$", $^3/_8$", or $^1/_4$" square drives.

To get an accurate reading with a torque wrench:

- Hold it at 90° to the fastener being tightened.

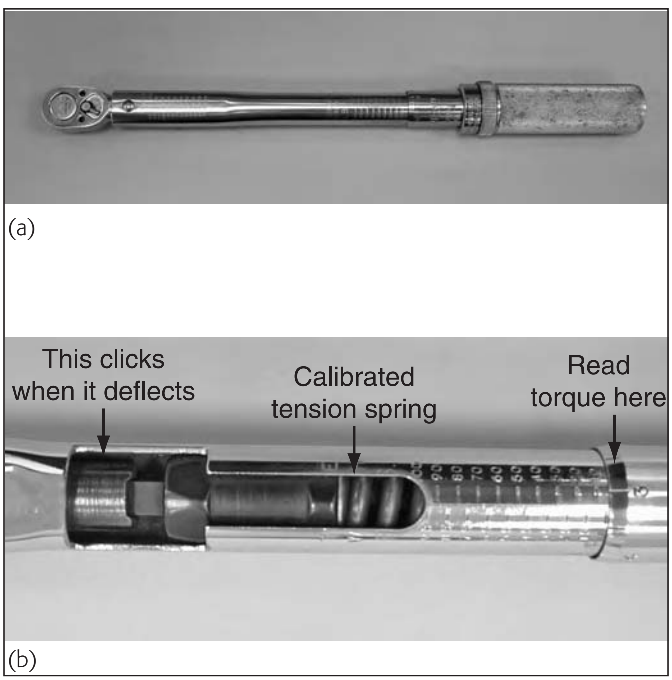


Figure 16.8 (a) A "click" torque wrench. (b) Cutaway of a "click" torque wrench. (*Courtesy of Tim Gilles*)

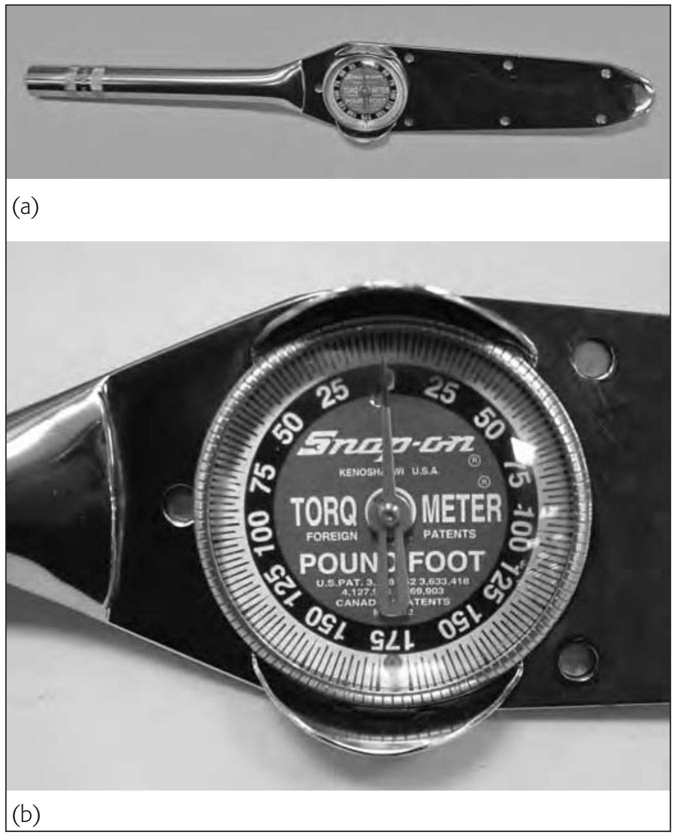


Figure 16.9 (a) A dial indicator torque wrench. (b) The dial can be rotated. (*Courtesy of Tim Gilles*)

- Select a torque wrench of the correct size. If 50 foot-pounds are required, use a 100 foot-pound torque wrench.
- If specific procedures are not described in service literature, torque in three or four steps:
  - Tighten first to about one-third of the torque specification.
  - Then tighten it two-thirds.
  - The third step should be to within 10 foot-pounds of the final specification. When the last step is within 10 foot-pounds, the final torque will be more accurate.
  - The final step is to double-check all torque readings.

NOTE

During the recheck, if a bolt still moves it should be removed to see if there is any water or oil in the hole. Liquid can cause initial resistance to torquing before it "bleeds" up the threads, causing the bolt to loosen.

Torque is measured in *foot-pounds* or inch-pounds. A common metric measurement of torque is the newton-meter. Torque specifications for metric cars are generally given in foot-pounds in English-language manuals.

NOTE

Mechanical torque wrenches are only accurate between 20% and 100% of full scale. A 125 foot-pound torque wrench can only be used above 25 foot-pounds. One inch-pound equals $^{1}/_{12}$ of 1 foot-pound. When you need to measure a smaller value, use an inch-pound torque wrench and multiply the torque figure by 12 **(Figure 16.10)**.

CASE HISTORY

An apprentice was replacing a valve cover gasket. He checked the torque specifications, which said "60," but he failed to notice a footnote next to the specification. Had he read the footnote at the bottom of the specification page, he would have learned that the specification was for inch-pounds, rather than foot-pounds. He did not break the fastener. But he broke off the valve cover screw mount on the cylinder head (Figure 16.11), resulting in a very costly repair.

Electronic Torque Wrench

Digital torque wrenches (**Figure 16.12**) are more expensive than mechanical torque wrenches but are

Figure 16.10 When using an inch-pound torque wrench, multiply the foot-pound specification by 12. (*Courtesy of Tim Gilles*)

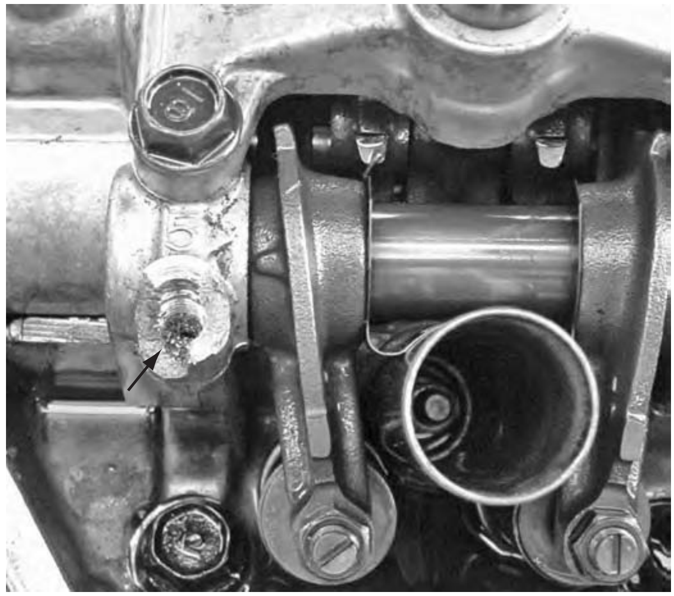


Figure 16.11 This cylinder head casting was damaged when the fastener was torqued to the wrong specification. (*Courtesy of Tim Gilles*)

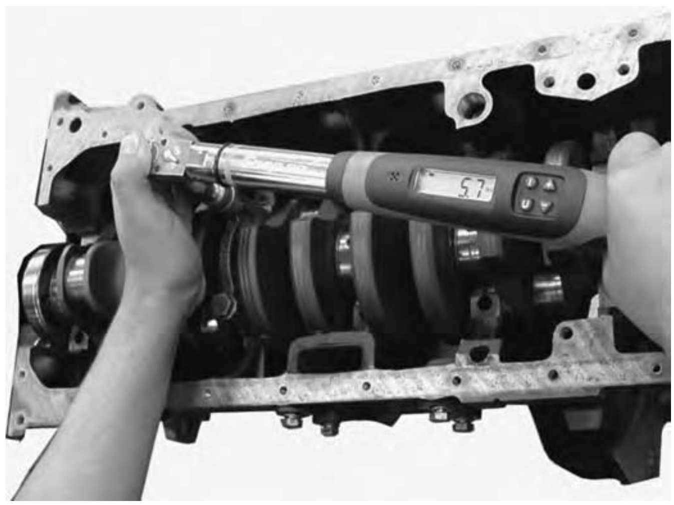


Figure 16.12 An electronic torque wrench. (*Courtesy of Tim Gilles*)

purported to be as accurate as dial torque wrenches. Additionally, they are convenient and can switch between metric and inch measurements with the touch of a button.

Torque by Degrees

On the factory assembly line, equipment tightens fasteners to stretch them a prescribed amount. Torque angle gauges that help keep track of how far a fastener is turned are available from tool manufacturers. They duplicate this "torque-turn" or "torque-angle"

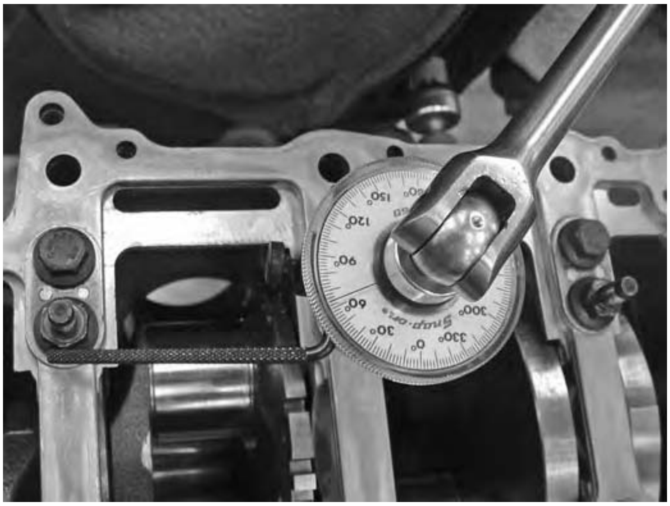


Figure 16.13 A torque angle gauge measures how far a fastener is turned, following a low initial tightening with a torque wrench. (*Courtesy of Tim Gilles*)

method of tightening when a torque-turn specification is available.

- First tighten the bolt to the specified torque using a torque wrench.
- Then turn it an additional 35° to 180°, depending on the specification **(Figure 16.13)**.

Tightening in this manner lessens the possibility that variations in friction will have an effect on torque readings.

Torque to Yield

A common misconception is that when a fastener is torqued to its yield point, it will no longer exert the necessary clamping force on the fastened joint. **Figure 16.14** shows the relationship between clamping force, bolt stretch, and yield point. Normal head bolt torque values have a calculated safety factor of about 25% less than the proof load of the bolt (the maximum amount a bolt can be torqued without becoming permanently stretched). So clamping force is only 75% of its potential for the bolt size. Further study of the chart in Figure 16.14 will show that a small amount of installation error in one or more of these head bolts can result in a wide variation in clamping force.

Because torque is a function of friction, head bolts torqued to the same specification can produce variables in clamping force of up to ±20%. Some of the bolts might be called on to do more than their share of the clamping, rather than

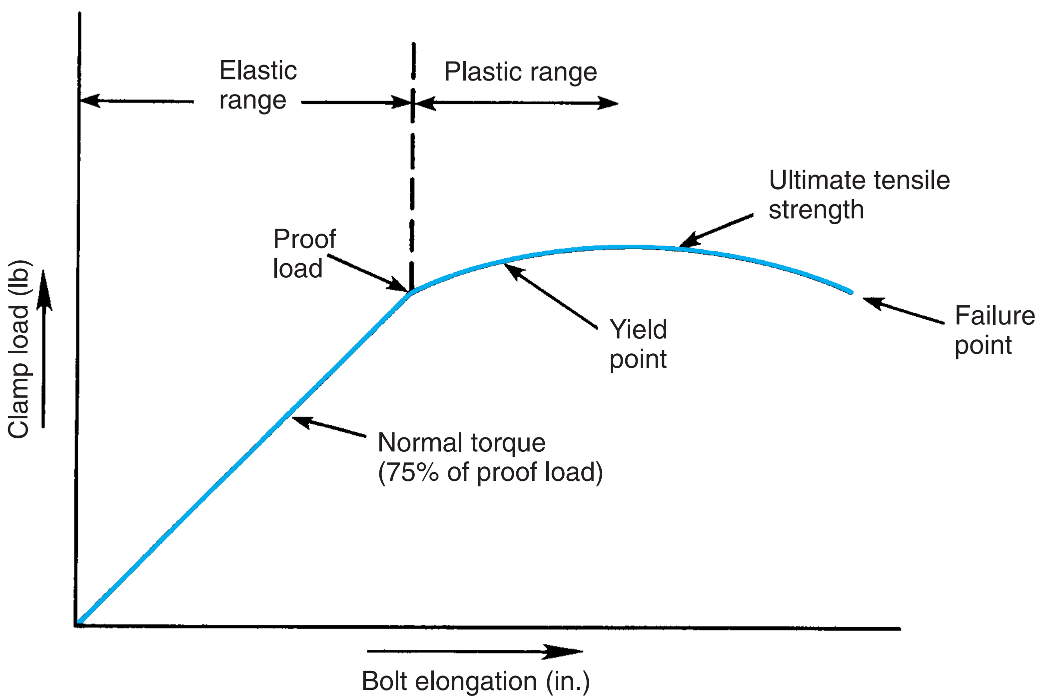


Figure 16.14 This chart shows the relationship between the correct clamp load and bolt failure.

sharing the load equally. The result can include distortion of engine cylinders. Some manufacturers have even used different amounts of torque on head bolts of the same engine in order to stress the block in a desired manner.

In some late-model engines, head bolts are purposely torqued to within 2% of their yield point. This method, known as *torque to yield*, provides a more consistent clamping force and the most fatigue resistant joint possible. Notice in Figure 16.14 that the bolt may be elongated considerably at its yield point before it reaches its failure point. Notice also that the clamp load through the entire yield section on the chart is more constant, especially when compared to the large changes that occur in clamping load when the bolts are torqued to different values that are within the elastic range of the fastener.

Whenever the head is removed, bolts that have been torqued beyond yield have already been stretched beyond their elastic limit and must be replaced. When their replacement is called for, gasket sets are sometimes supplied with a new set of head bolts.

Nuts

The grade of a nut must match the grade of its companion bolt. Manufacturers use several nut markings to denote grade identification **(Figure 16.15)**. Grade 8 nuts are always marked, but sometimes grade 5 nuts are not.

Should I Reuse a Nut?

A nut is manufactured to be slightly softer than the bolt so that its threads can flow to fit the threads of the bolt **(Figure 16.16)**. This thread distortion is permanent. Bolts are normally reused in the engine rebuilding process. Nuts, however, lose some effectiveness with repeated use. When a nut is reused, there is more friction between the threads and an accurate torque reading cannot be achieved.

A nut acts much like the coils of a spring when an assembly is tightened with each thread carrying progressively less load:

- The first thread of a coarse fastener (the one against the work being clamped) supports about 38% of the total load.
- The second supports about 25%.
- The third supports about 18%.

The first thread will be into the plastic range (yield), whereas the outer threads may not even be touching the bolt at all.

Locknuts, like the type used on some rocker arm studs, are deformed at the top **(Figure 16.17)**. These nuts lose some of their locking ability with repeated reuse. For the best clamping results, do not remove and replace them any more than is necessary. One locknut, the Marsden nut **(Figure 16.18)**, has a series of slots near the top and makes perimeter contact on a shoulder around its bottom.

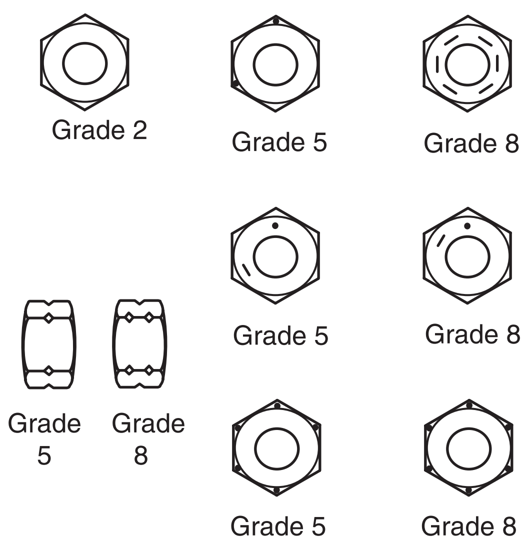


Figure 16.15 Nut grades are labeled in various ways.

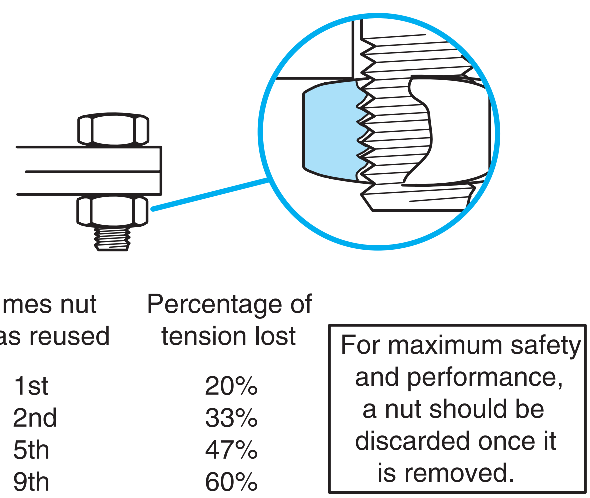


Figure 16.16 A nut conforms to the thread of a bolt, so it loses more holding ability each time it is reused.

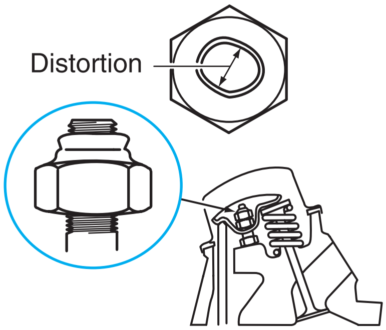


Figure 16.17 A typical locking nut used on rocker arm studs is distorted at the top.

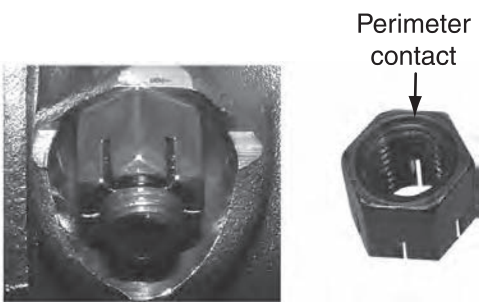


Figure 16.18 A Marsden nut. The bottom of the nut contacts on a shoulder around the perimeter of the nut.

Prevailing torque nuts have a plastic insert that will return to its original shape. The manufacturer claims it can be used up to four times before replacement.

Washers. Use of the proper washer is also necessary to achieve the correct load on a bolt. Use a through hardened heat treated flat washer. Case hardened washers are hard on the surface only; the core of the washer is soft and will compress, allowing the connection to lose clamping force.

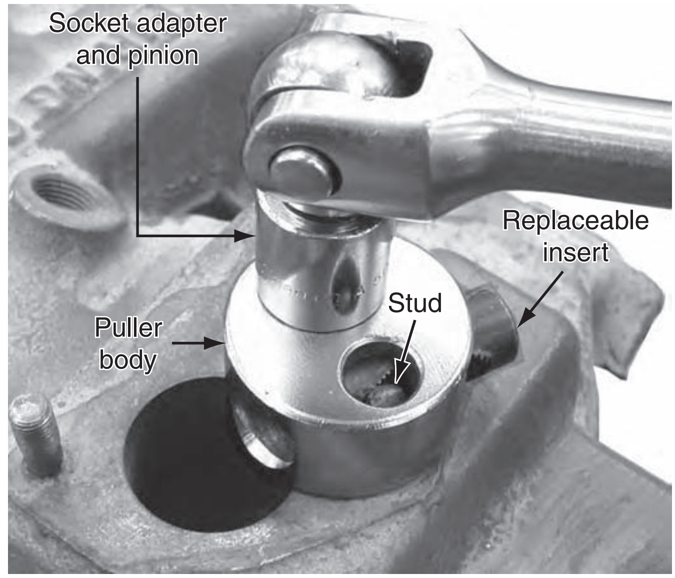


Figure 16.19 A stud puller. (*Courtesy of Tim Gilles*)

Figure 16.20 Remove the socket adapter and pinion from the tool body to change the size of the stud puller insert. (*Courtesy of Tim Gilles*)

Removing a Stud

Some studs have threads on both ends. They are often found on carburetor mounts and exhaust manifolds. To remove a stud, a special stud puller may be used. The stud puller shown in **Figure 16.19** has replaceable inserts for different diameter studs. The inserts have a rack gear on the back **(Figure 16.20)** that meshes with a pinion beneath the socket adapter. When a puller is not available, use two nuts with a lock washer between them. Turn the nut that is farthest from the end of the stud to remove the stud.

Bolt Failures

Fatigue breaks account for about three-quarters of fastener problems. A bolt becomes fatigued from working back and forth when it is too loose. This problem occurs when the assembly is not properly torqued to stretch the bolt.

Shear or torsion breaks result from the use of a poor grade of fastener, too much friction, or an improper thread fit. Technicians sometimes fail to clean bolt threads in the block thoroughly.

SHOP TIPS

- Bolt holes in the block must be chased with a tap (**Figure 16.21**).
- There are two kinds of tap wrenches (**Figure 16.22**). For speedy cleanup, one type has a $^{3}/_{8}$" drive female head and can be used with a ratchet or speed handle after removing the handle (**Figure 16.23**).
- Clamping force on the head bolts will not be accurate unless thorough cleaning is done to the bolt thread (**Figure 16.24a**) and the underside of the bolt head (**Figure 16.24b**).

Bolts can be broken when they are bottomed out. Normally, bolts should turn into the thread for four to six turns, or about $1^{1}/_{2}$ times the diameter of the screw thread. If a bolt is bottomed out, the sudden stop of the bolt is felt, instead of the "elastic" feeling of normal bolt stretch.

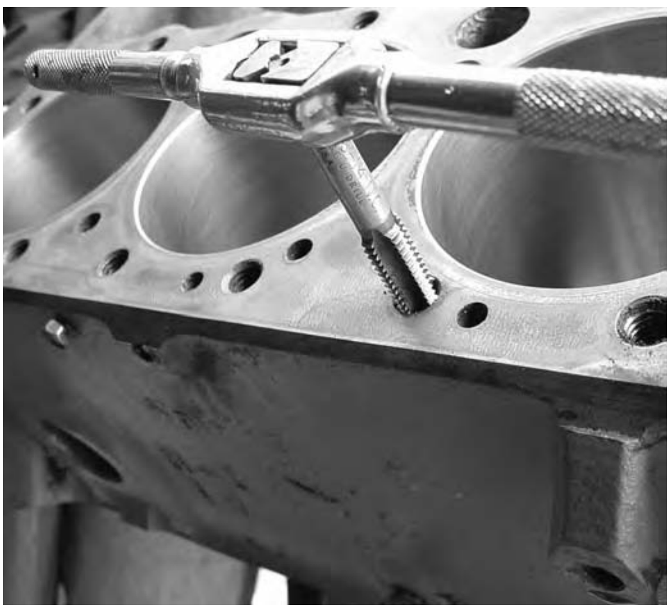


Figure 16.21 Bolt holes in the block must be chased with a tap to ensure correct clamping force after assembly.

Figure 16.22 Two kinds of tap wrenches. (*Courtesy of Tim Gilles*)

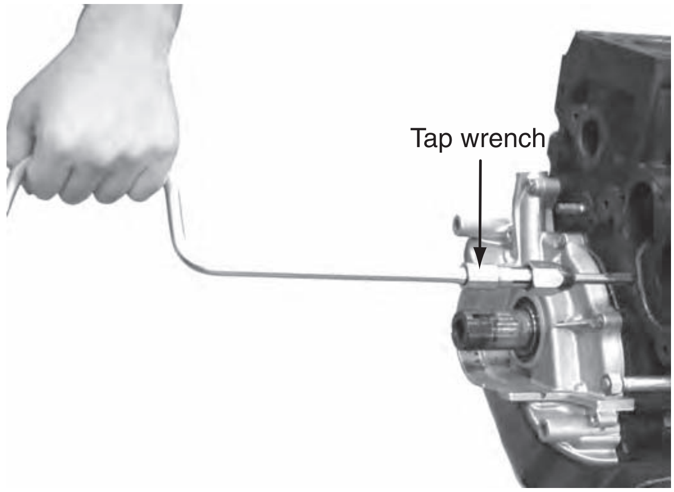


Figure 16.23 A tap wrench with its handle removed can be used with a speed handle for faster thread chasing. (*Courtesy of Tim Gilles*)

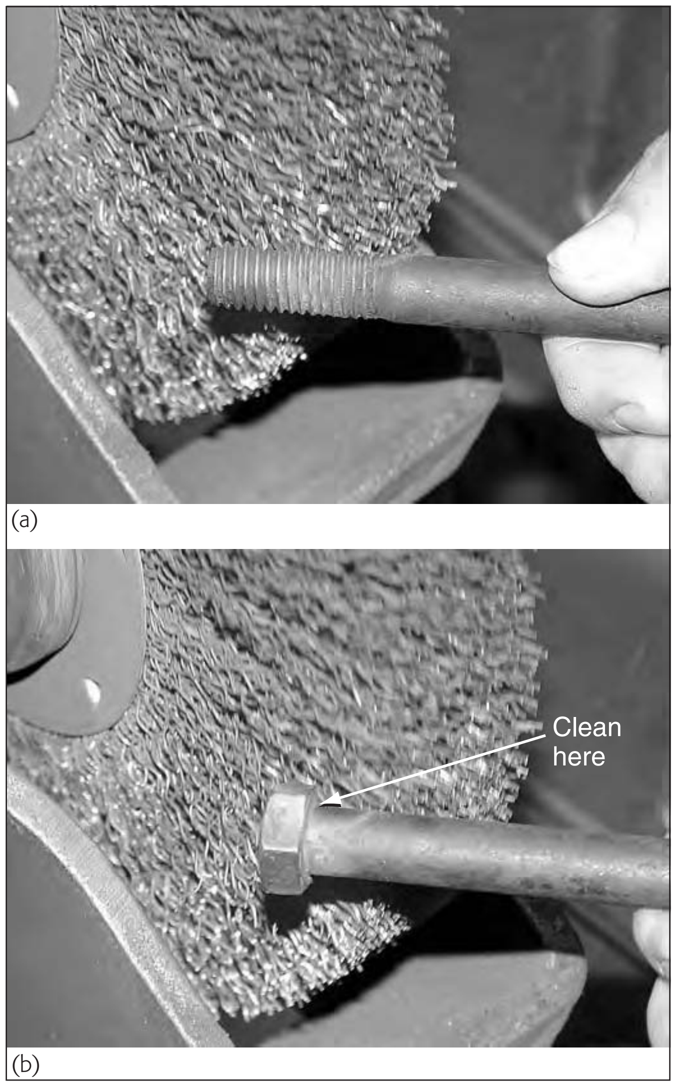


Figure 16.24 This is important! (a) Clean the bolt thread. (b) Clean under the bolt head. (*Courtesy of Tim Gilles*)

Crossed threads are usually the result of improper assembly procedures.

SHOP TIP

When two parts are fastened together, do not completely tighten *any* of the fasteners until *all* of them have been started into their threads. With all the bolts loose, a hole that does not line up can be aligned using a rolling head prybar (see Figure 17.74). This tool is also handy in aligning motor mounts and transmission crossmembers.

DRILL BITS

Drill bits are used to make or enlarge holes in metal and to help remove broken fasteners **(Figure 16.25)**. A drill bit has two flutes that provide a channel for the cutting chips to escape into during drilling. They also allow cutting fluid to reach the cutting edge of the drill.

The web that separates the flutes of the drill increases in size from the point to the shank. The web can be so large at its point that it will be necessary to drill a pilot hole with a smaller drill bit **(Figure 16.26)**. A center punch is used to locate the web (or point) of the drill. Only a small area of the *land* (the spiral area on the drill body) is equal to the diameter of the drill. The rest of the land is relieved (made smaller) to cut friction.

The tip of a drill bit must be sharp. Its angle will be flatter for hard metals, such as steel, and steeper for softer metals. A drill bit that is sharpened "off center" **(Figure 16.27a)** will drill a hole that is too large. Be careful to make the angles equal. A properly ground drill will give off even amounts of chips

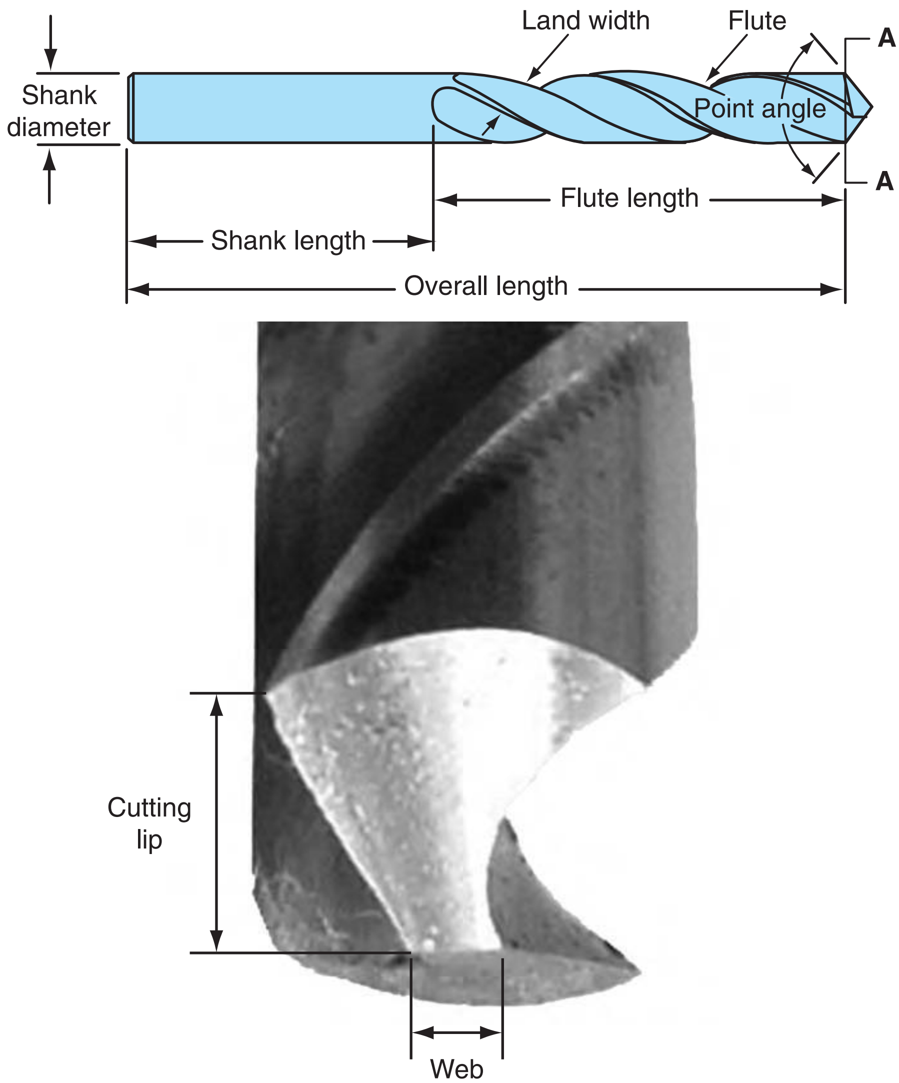


Figure 16.25 Parts of a drill bit.

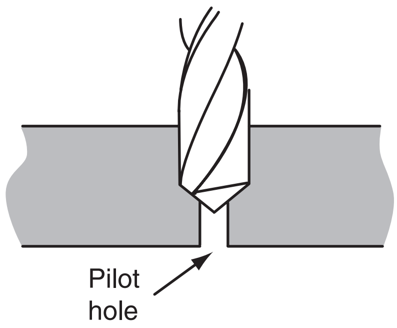


Figure 16.26 Before drilling with a large drill bit, drill a pilot hole.

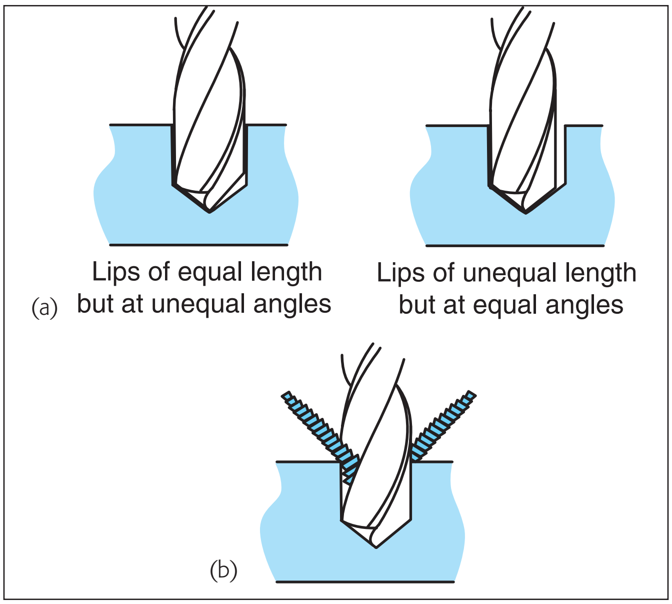


Figure 16.27 Importance of correct drill angles. (a) Unequal length sides on a drill bit results in an oversized hole. (b) A properly ground drill bit will chip equally from both flutes.

from both sides of the metal as it cuts **(Figure 16.27b)**. For iron and steel, the bit is cut to a 59° angle **(Figure 16.28)**. The back side of the cutting lip must slope off, as shown in **Figure 16.29**, to produce the chisel edge on the drill. Too little clearance causes the drill to rub instead of cut. Too much clearance causes the bit to cut too rapidly, which may cause it to break or chip.

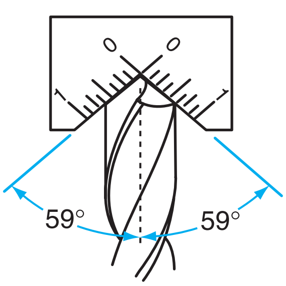


Figure 16.28 Drill bits for iron or steel are ground to a 59° point angle.

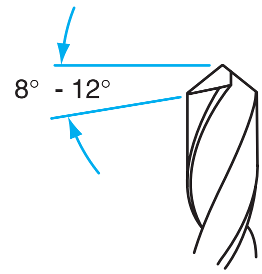


Figure 16.29 The cutting lip must slope off as shown here.

Hand Sharpening a Drill

Hand sharpening the drill bit requires some practice. Hold the drill against the wheel at a 59° angle, and rotate it in an arc movement **(Figure 16.30a)**. The angle and length of the lip can be checked with a gauge **(Figure 16.30b)**.

SHOP TIP

Be sure to quench the bit often to keep it cool. If it gets too hot, the temper can be drawn from it.

If much precision drilling is to be done, drilling handbooks are available from several manufacturers.

Drill Speed and Lubricants

To prevent drill bit wear, keep as close as possible to the recommended drilling speed. Bits are usually made of high-speed steel; they will be marked "HS" or "HSS" on their shanks. When ground, they give off a dull red spark. Cheaper drill bits (carbon steel) give off white sparks when ground. Use them at half the cutting speed of high-speed steel, because their resistance to heat is lower.

Approximate HS drill speeds for mild steel are:

- 1500 rpm for $^1/_4$"
- 1000 rpm for $^3/_8$"
- 750 rpm for $^1/_2$"

Drill aluminum with the same size drill bit at an rpm twice as fast. Soft cast iron is generally drilled at the speed required for mild steel.

- When drilling steel, use a cutting oil.
- Cast iron and aluminum can be cut dry. When tapping aluminum, however, cutting fluid is helpful.

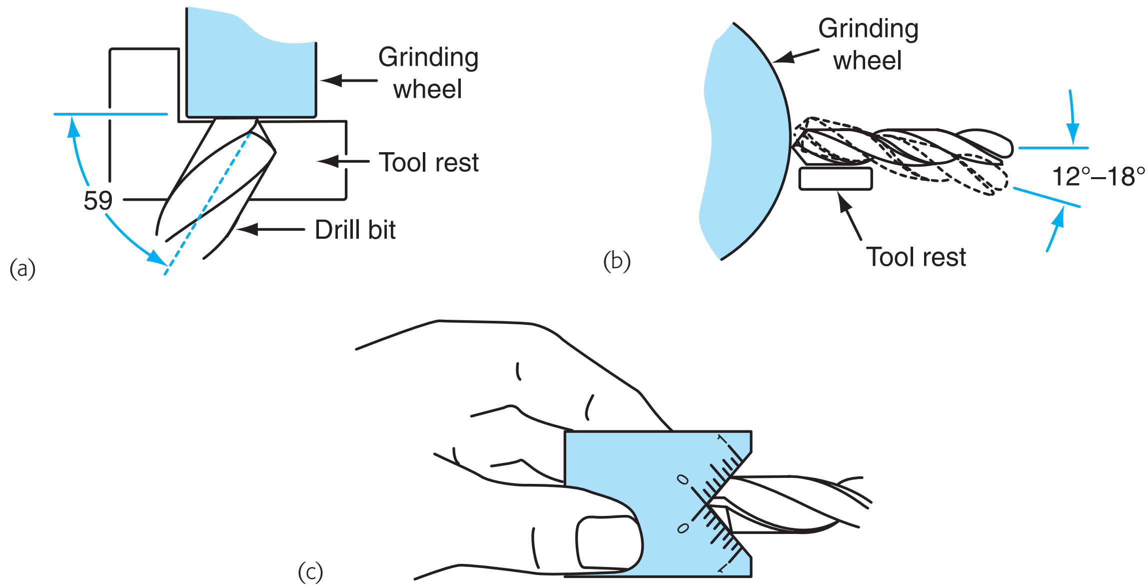


Figure 16.30 Sharpening a drill bit by hand. (a) Hold the drill on the work rest at about 59° to the wheel, and rotate the front of the drill upward. (b) Check the angle on a drill gauge.

Drill Size

Drills are sized in a number of different ways. Most technicians own a fractional set of drills called a drill index. Sizes in the drill index increase by increments of $^1/_{64}$". Decimal equivalents are also printed on the index.

Drills also come in letter and number sizes. Letter size drills increase in size from A (0.234") to Z (0.413"). They are larger than the largest number sized drill.

Drills sized by number range almost $^1/_4$", from 80 (0.0135") to 1 (0.228"). The most widely used number sized drills usually are numbers 1 to 60 (0.040"). Commonly used metric drills range from 0.20 mm to 16.00 mm in size.

Figure 16.31 A thread pitch gauge identifies a fastener's number of threads per inch or millimeter distance between the threads. (*Courtesy of Tim Gilles*)

TAPS, THREADS, AND DIES

A tap is used to cut threads in a previously drilled hole. Standard and metric both have coarse and fine threads for each diameter of fastener. To determine the screw thread of a hole, screw in the correct tap and then read the size on the tap. A special thread pitch gauge **(Figure 16.31)** can be used, but this method is not always dependable; some screws have different diameters but the same number of threads per inch or millimeter.

Standard threads come in both coarse and fine threads. The fine thread is called national fine; the coarse thread is national coarse. These are classified, respectively, as UNF and UNC. The *U* stands for "unified"; it means that the thread interchanges with British threads. A UNF thread callout for a $^3/_8$" diameter thread would be $^3/_8$" × 24. It would have 24 threads per inch. A UNC would be $^3/_8$" × 16. It would have 16 threads per inch.

Metric screw threads are coarse, medium, or fine. An 8 mm coarse tap would be marked 8 × 1.5; a medium thread pitch, 1.25; and a fine tap, 8 ×1.0. The last number in the callout represents the thread pitch in millimeters and can be compared to threads per inch in the Unified System. An M8 × 1.0 thread has an outside diameter of 8 mm and advances 1 mm during every 360° rotation of the thread. This means there is 1 mm between screw threads. Notice that the higher pitch number denotes the coarser thread.

Thread Fit

There are several thread classifications. Male and female threads can conform to each other in different ways, some tight and some loose:

- Class 1 threads are loosely fitting threads intended for ease of assembly or for use in a dirty environment.
- Class 2 threads are the most common. They are designed to maximize strength, considering typical machine shop capability and machine practice.
- Class 3 threads are used for close tolerance. They are used in all aviation.

Classes 1A, 2A, and 3A apply to external threads and Classes 1B, 2B, and 3B apply to internal threads.

Types of Taps

There are three types of taps available for any given thread size **(Figure 16.32)**.

- The tapered tap helps pilot the tap into the hole.
- The plug tap is a standard tap.

Figure 16.32 Three types of tap, all of the same pitch and diameter. (*Courtesy of Tim Gilles*)

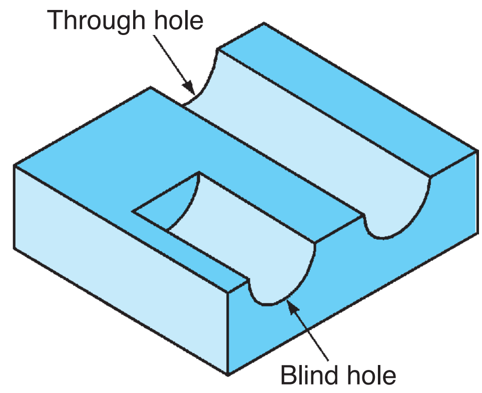


Figure 16.33 A blind hole does not go all the way through a part.

- A bottom tap makes threads almost all the way to the bottom of a blind hole, and it "chases" threads to clean them. A blind hole is one that has a bottom **(Figure 16.33)**.

SHOP TIP

Looking at the appearance of a tap can tell you if it is sharp. Shiny taps are sharper.

Pipe Threads

Pipe threads are used for heater outlets in the heads, block, and intake manifold as well as for oil gallery plugs and oil and coolant temperature sending units **(Figure 16.34)**. Pipe taps have tapered threads **(Figure 16.35)**, designed to wedge against each other. Therefore, when tapping a pipe thread do not continue turning the tap until it turns easily. Because the size of a pipe thread is determined by the inside diameter of the piece of pipe, a $^{1}/_{2}$" National Pipe Taper (NPT) tap will be quite a bit larger than $^{1}/_{2}$".

Figure 16.34 Pipe threads are found on threaded plugs, heater outlets, and oil and coolant temperature sending units. (*Courtesy of Tim Gilles*)

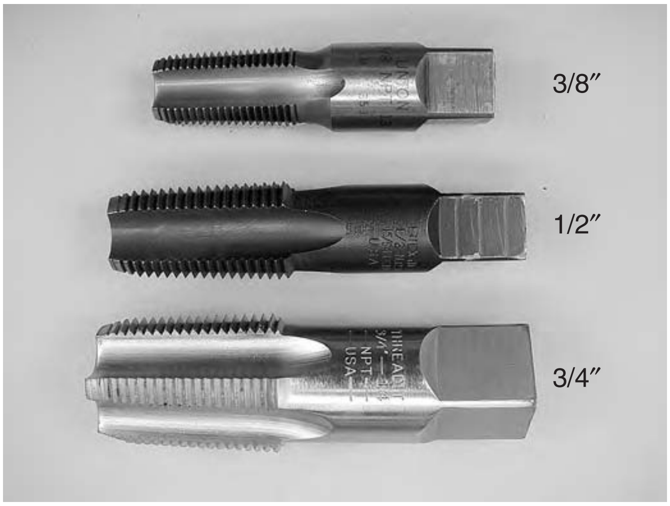


Figure 16.35 Pipe taps for NPT threads. (*Courtesy of Tim Gilles*)

CASE HISTORY

An apprentice was chasing the threads in a cylinder block after removing it from the hot tank. He tapped out all of the holes, including those for the oil gallery plugs. Oil gallery plugs have tapered pipe threads. The apprentice turned the tapered pipe tap through the entire length of the thread until it turned easily. When the new oil gallery plugs were installed, they could not be tightened and the block had to be repaired.

SHOP TIP

There are special inside pipe wrenches for removing pipe nipples from cylinder heads and manifolds **(Figure 16.36)**.

Figure 16.36 Inside pipe wrenches grip the I.D. of the pipe fitting. (*Courtesy of Tim Gilles*)

Determining Tap Drill Size

Before tapping a thread, a hole of the correct size must be drilled. A **tap drill** usually provides about 75% of a full thread. This allows some margin for error and keeps the tap from binding during the tapping operation. The tap drill chart **(Figure 16.37)** shows which drill to use. A $^3/_8 \times 24$

Size	Threads per inch			Outside Diameter Inches	Tap Drill Approx. 75% Full Thread	Decimal Equivalent of Tap Drill
	NC	NF	NS			
0	...	80	...	.0600	3/64	.0469
1	...	...	56	.0730	54	.0550
1	64	...	...	.0730	53	.0595
1	...	72	...	.0730	53	.0595
2	56	...	...	.0860	50	.0700
2	...	64	...	.0860	50	.0700
3	48	...	...	.0990	47	.0785
3	...	56	...	.0990	45	.0820
4	...	...	32	.1120	45	.0820
4	...	...	36	.1120	44	.0860
4	40	...	...	.1120	43	.0890
4	...	48	...	.1120	42	.0935
5	...	...	36	.1250	40	.0980
5	40	...	...	.1250	38	.1015
5	...	44	...	.1250	37	.1040
6	32	...	...	.1380	36	.1065
6	...	...	36	.1380	34	.1110
6	...	40	...	.1380	33	.1130
8	...	...	30	.1640	30	.1285
8	32	...	...	.1640	29	.1360
8	...	36	...	.1640	29	.1360
8	...	...	40	.1640	28	.1405
10	24	...	...	.1900	25	.1495
10	...	...	28	.1900	23	.1540
10	...	...	30	.1900	22	.1570
10	...	32	...	.1900	21	.1590
12	24	...	...	.2160	16	.1770
12	...	28	...	.2160	14	.1620
12	...	...	32	.2160	13	.1850
1/4	20	...	...	.2500	7	.2010
1/4	...	28	...	.2500	3	.2130
5/16	18	...	...	.3125	F	.2520
5/16	...	24	...	.3125	1	.2720
3/8	16	...	...	.3750	5/16	.3125
3/8	...	24	...	.3750	Q	.3320
7/16	14	...	...	.4375	U	.3660
7/16	...	20	...	.4375	25/64	.3906
1/2	13	...	...	.5000	27/64	.4219
1/2	...	20	...	.5000	29/64	.4531
9/16	12	...	...	.5625	31/64	.4844
9/16	...	18	...	.5625	33/64	.5156
5/8	11	...	...	.6250	17/32	.5312
5/8	...	18	...	.6250	37/64	.5781
3/4	10	...	...	.7500	21/32	.6562
3/4	...	16	...	.7500	11/16	.6875
7/8	9	...	...	.8750	49/64	.7656

Figure 16.37 A tap drill chart for inch-sized drills. A size conversion chart is located in the appendix in the back of the book.

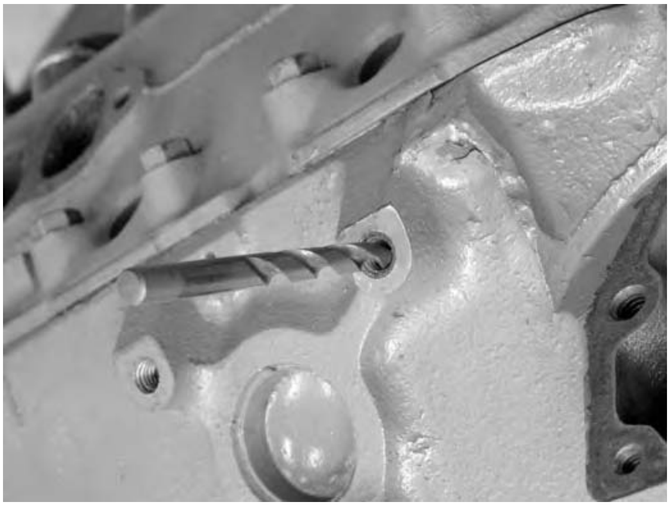


Figure 16.38 The largest drill that fits into a threaded hole of the same size can be used as a tap drill. (*Courtesy of Tim Gilles*)

(24 threads per inch) tap would require a Q (0.332") drill. From a fractional size drill index, select the next largest size available. In this case, the right choice is an $^{11}/_{32}$ (0.343"), which is only 0.011" larger than a letter Q drill (see appendix for size conversion). If a tap drill chart is not available, select the largest drill bit that will fit into a threaded hole the same size as the desired thread (**Figure 16.38**).

NOTE

Do not use a smaller drill; the tap could bind and break. A female screw thread that is only half of full depth has been shown to have so much strength that the bolt would strip before the thread would strip.

Tapping a Hole

When tapping a hole, it is a good practice to advance the tap and then back off about one-quarter turn to break off any metal chips that might accumulate. These chips could ruin the new thread. The chips can be felt breaking as the tap is backed off. The broken chips gather in the flutes of the tap (**Figure 16.39**). Thread lubricants are required when tapping steel and most nonferrous metals; cast iron can be tapped dry.

Be especially careful not to break a tap **(Figure 16.40)**. A tap is as hard as a drill bit, so it cannot be removed by conventional methods, which require drilling a hole in the broken part. A broken tap can sometimes be removed by driving it counterclockwise with a center punch to back it out of the hole in the same manner used to remove a broken bolt (**Figure 16.41**). A tap is brittle, so if it does not back out of the hole, try breaking it up with a sharp punch to remove it. Some machine shops have a mechanical tap extracting tool that fits into the flutes of a broken tap to remove it. If none of these methods work, take the part to a shop that has an **electrical discharge machine (EDM)** to remove it. This process can be costly, but it is capable of eroding hard parts, leaving the original screw thread.

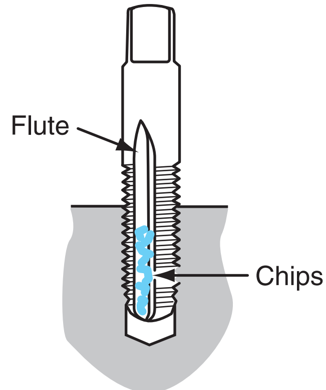


Figure 16.39 During cutting, chips gather in the flutes of the tap.

Figure 16.40 A broken tap is difficult or impossible to remove. It is hard and cannot be drilled. (*Courtesy of Tim Gilles*)

Electrical Discharge Machining (EDM). Broken taps and drill bits **(Figure 16.42)** can also be removed by EDM, known as spark erosion, which erodes the screw, leaving the surrounding area intact. This method, which is done in specialty machine shops, is

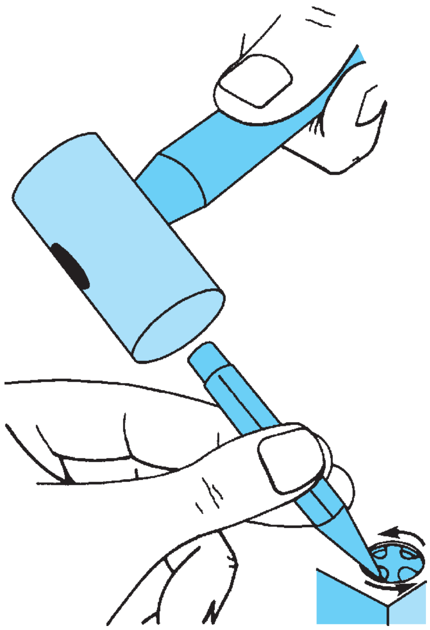


Figure 16.41 Try to remove a broken tap with a center punch or a chisel.

Figure 16.42 A broken drill bit or tap can be removed using an EDM. (*Courtesy of Tim Gilles*)

effective on metals; one piece is connected to positive and the other is connected to negative. An electrical spark is created between the broken piece and the electrode, which is held in a vibrating head. The temperature of the spark at the electrode is over 9032°F (5000°C), but erosion is done under a fluid bath and the parent part does not suffer from heat changes. The broken part is turned to dust, which is washed away.

Dies

Dies are used to make external threads on a round rod. A die is especially useful for "chasing" burred threads.

SHOP TIP

When shortening a bolt, first screw a die onto the bolt threads (**Figure 16.43**). After shortening and chamfering the bolt, removing the die will clean up the end of the thread. A die can also be used to determine the size of a screw thread.

REPAIRING BROKEN FASTENERS AND DAMAGED THREADS

Every technician has to remove a broken bolt occasionally. If a broken bolt has not "bottomed out" in the hole, it can sometimes be removed by driving it in a counterclockwise direction with a chisel, just as in removing a broken tap (see Figure 16.42). A bolt that has broken off above the surface may be removable with pliers or a stud extractor. A left-hand drill bit can be used with a reversible drill motor to remove a broken bolt that is not bottomed out.

SHOP TIP

Heat applied with a torch will often make removal of a broken stud or bolt easier. Applying wax to quench after heating lubricates the screw thread makes removal easier.

Figure 16.43 A die can be installed prior to shortening a fastener. When it is backed off the fastener, it will clean the end threads. (*Courtesy of Tim Gilles*)

Sometimes it is necessary to use a screw extractor set to remove a broken bolt **(Figure 16.44)**.

- First, make a center punch mark *precisely* in the center of the fastener **(Figure 16.45)**.
- Then drill a hole of a precise size into the broken fastener **(Figure 16.46)**. The drilled hole should go all the way through the bottom of the fastener.
- Drive the extractor into the hole with a brass hammer **(Figure 16.47)**.
- Then unscrew the broken fastener **(Figure 16.48)**. Use as large an extractor as possible, so that the walls of the drilled stud will become as thin and flexible as possible. The extractor set includes a nut that fits over the extractor. Slide the nut down the flutes. Then grip the nut with a pair of wrenches (to exert equal force) and turn the extractor counterclockwise.

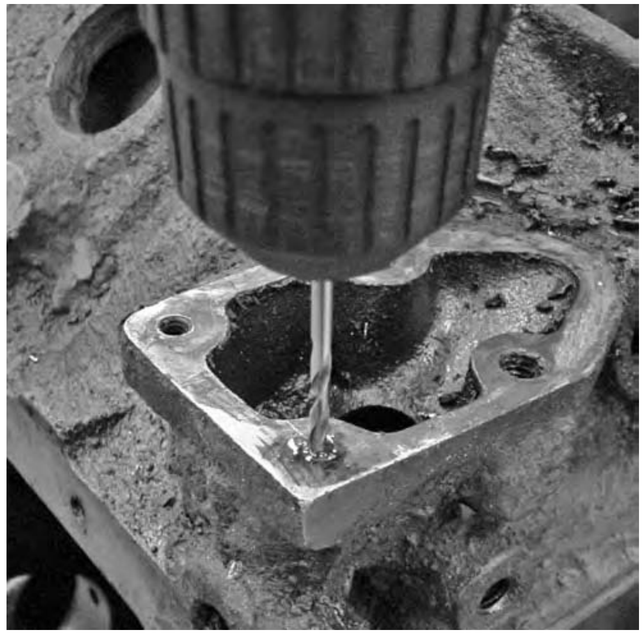


Figure 16.46 It is very important that the hole be drilled precisely on center. (*Courtesy of Tim Gilles*)

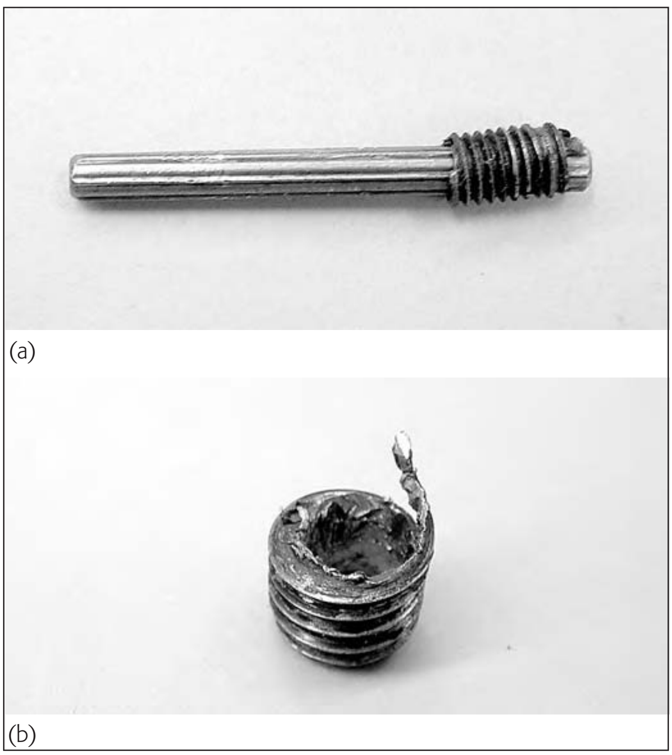
Figure 16.44 A fluted extractor set. (*Courtesy of Tim Gilles*)

Figure 16.47 Use a brass hammer to drive the extractor into the hole. (*Courtesy of Tim Gilles*)

Figure 16.45 Removing a broken stud or bolt. It is crucial that the stud be punched exactly on center. (*Courtesy of Tim Gilles*)

Figure 16.49a and **Figure 16.49b** show a successfully removed broken bolt.

Figure 16.48 Slip the fluted nut onto the extractor. Two wrenches are used to turn the nut counterclockwise. (*Courtesy of Tim Gilles*)



(a)

(b)

Figure 16.49 (a) An extractor holding the extracted fastener. (b) A successfully removed broken bolt. (*Courtesy of Tim Gilles*)

If the extractor begins to shear off, it should be removed from the drilled hole before it breaks off. The hole can then be heated with a torch **(Figure 16.50)**, and the broken fastener cooled by dripping water onto it or applying paraffin to it. Then try the extractor again.

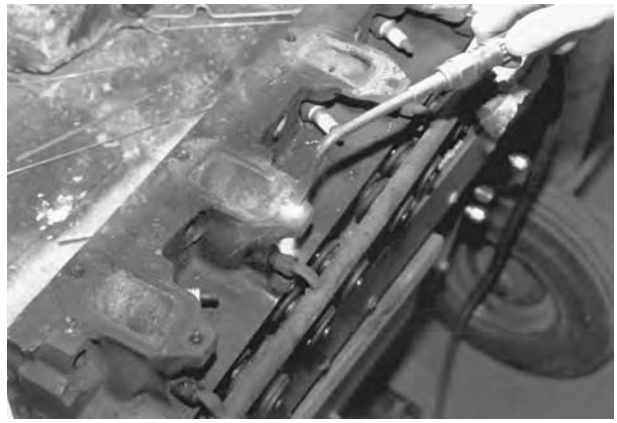


Figure 16.50 If the fastener will not come out, heat the drilled hole with an oxyacetylene torch. (*Courtesy of Tim Gilles*)

When a fastener is broken off below the surface of the part, a special pilot can be used to drill the fastener exactly on center **(Figure 16.51)**. A hole drilled on center is needed for successful fastener removal. After drilling a pilot hole, the next bigger size drill bit can be used to enlarge the hole. When the hole is drilled almost as large as the screw thread, removing the fastener is easier.

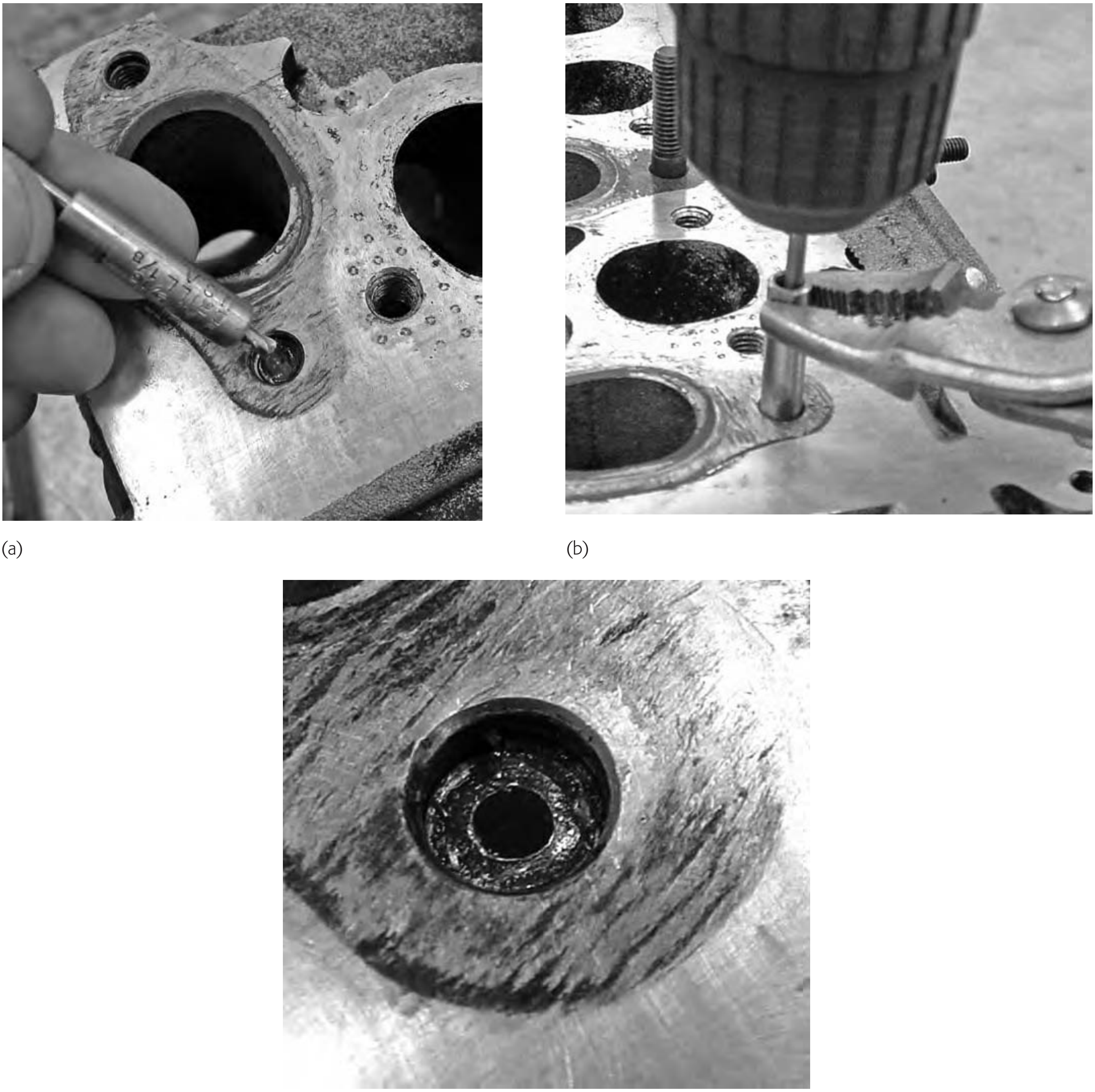
NOTE

If the hole is off center, the size of drill will be limited. Also, a thread insert might be required to repair the hole. The thread insert will be installed on center with the initial pilot hole, so an off-center hole will result in an off-center thread insert.

SHOP TIP

An accurate, perpendicular hole is required in many cases. A jig is required for drilling correctly aligned holes when removing broken cylinder head bolts **(Figure 16.52)**. **Figure 16.53** shows how to make a jig for drilling and tapping straight flywheel bolt holes before installing thread inserts in a crankshaft flange.

Easy Out. Figure 16.48 shows an extractor that is commonly known as an easy out. It is used in much the same manner as the other extractor set. A hole of a specified size is drilled into the center of the broken fastener. The extractor is pounded into the



(a) (b) (c)

Figure 16.51 Drilling a hole in a fastener broken beneath the surface. (a) Select the correct drill and drill guide. (b) Hold the drill guide with pliers while drilling the hole in the fastener. (c) A hole drilled on center is needed for successful fastener removal. (*Courtesy of Tim Gilles*)

hole and turned with a tap wrench (**Figure 16.54**). With luck, the broken fastener will come out. A problem with using a tapered extractor is that as it is pounded into the drilled hole in the fastener, it tends to bind as it forces the fastener tighter against the screw thread. A splined extractor is a better alternative.

Extractors are hardened, which makes them difficult to remove when they break. A broken extractor can sometimes be removed by heating it with a torch and letting it cool slowly. This softens the metal for drilling. If an extractor cannot be removed by this method, an EDM machine will be required.

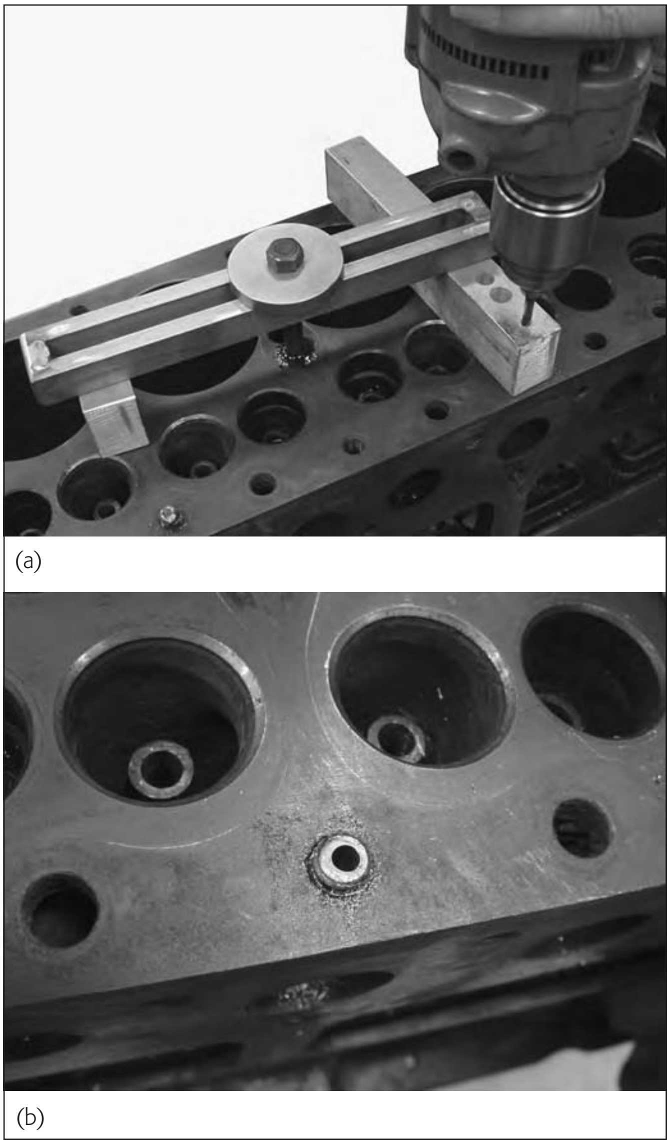

(a)
(b)

Figure 16.52 (a) A jig used to ensure a perpendicular hole when removing a broken head bolt. (b) Appearance of a broken head bolt after drilling using a jig. (*Courtesy of Tim Gilles*)

SHOP TIP

Some machine shops will remove a broken fastener by dropping a nut on top of it. Then the inside of the nut is welded to the fastener with nickel welding rod (ni-rod). A wrench is then used on the nut to unscrew the fastener.

Drilling and Retapping

Sometimes a broken fastener can be repaired by drilling it out. The hole is then carefully tapped. If this fails, the next step would be to drill and then tap to the next larger thread size. When using an

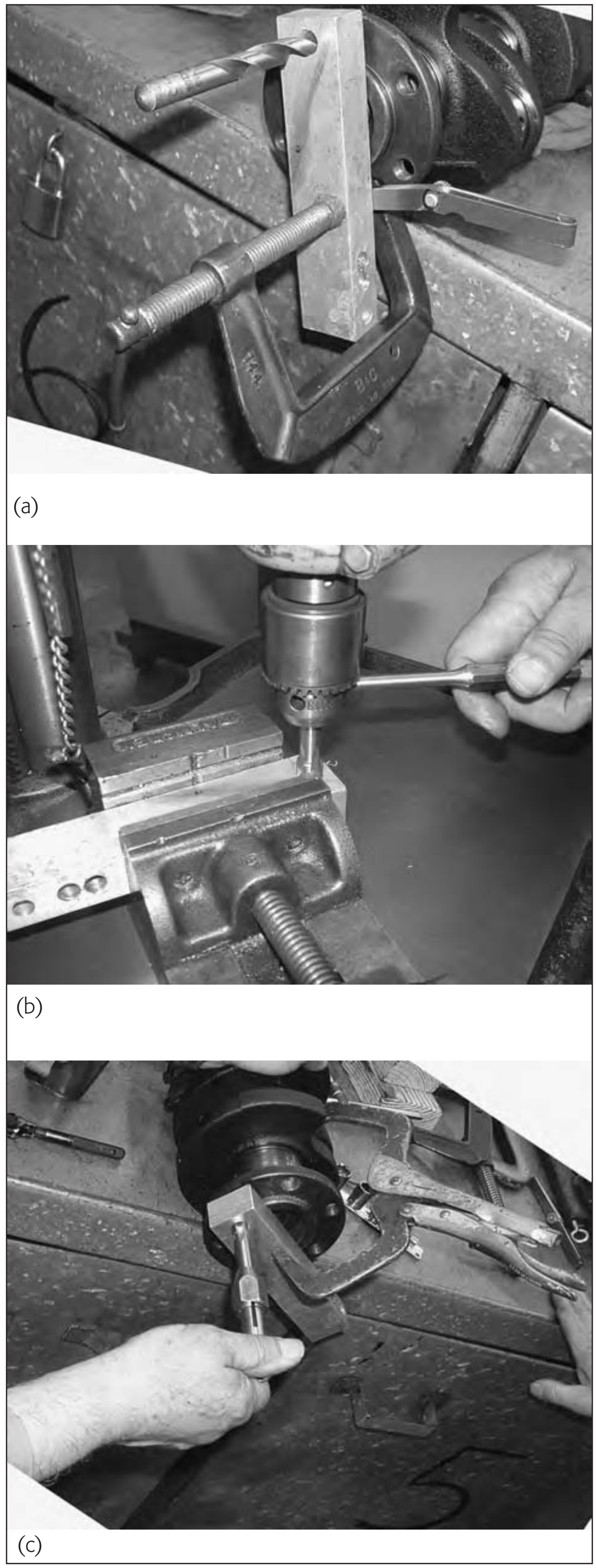

(a)
(b)
(c)

Figure 16.53 A jig for drilling and tapping straight flywheel bolt holes before installing thread inserts in a crankshaft flange. (a) Drilling the hole oversize. (b) Use the drill press to align the tap in the jig. The punch is used to turn the chuck. (c) Tapping an aligned thread in the crankshaft. (*Courtesy of Tim Gilles*)

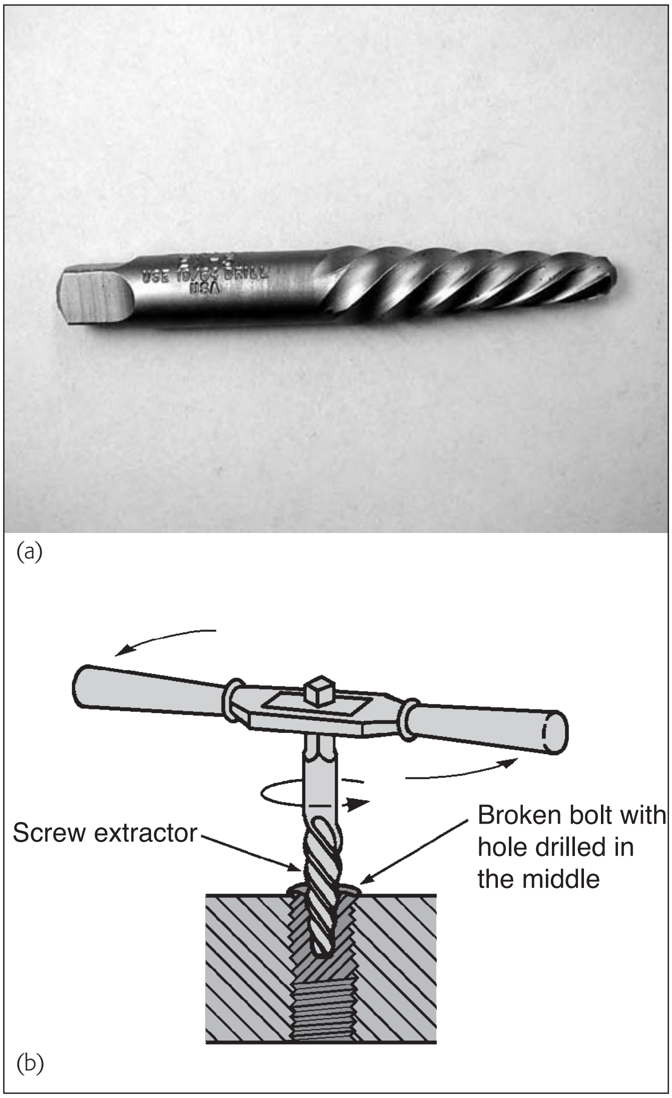


Figure 16.54 (a) An easy out screw extractor. (*Courtesy of Tim Gilles*) (b) After drilling a hole in the broken fastener, pound the easy out into the hole and attempt to remove it.

oversized screw thread, it is often necessary to drill an oversized hole in the part that the bolt fastens to (an exhaust manifold, for example).

Thread Inserts

A better repair is to use a thread insert to preserve the original thread size **(Figure 16.55)**. There are several varieties of thread inserts. They all require drilling and tapping a larger hole. The insert is then threaded into place.

A heli-coil is an oversized spring coil of stainless steel. **Figure 16.56** shows a thread before and after repair. **Figure 16.57** shows how to use a heli-coil.

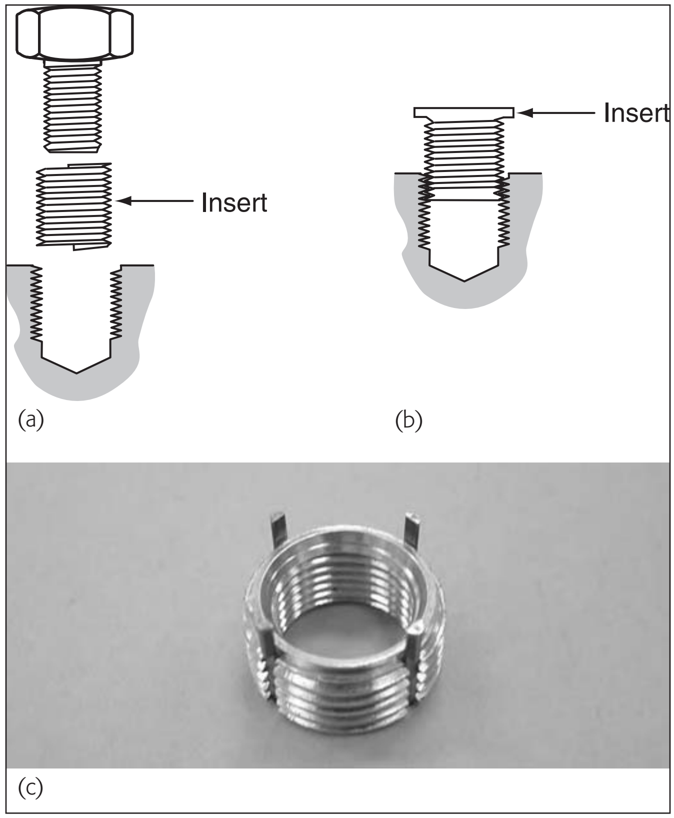


Figure 16.55 Types of thread inserts. (a) A heli-coil thread insert. (b) A solid threaded insert. (c) A Keensert™. *([c] Courtesy of Tim Gilles)*

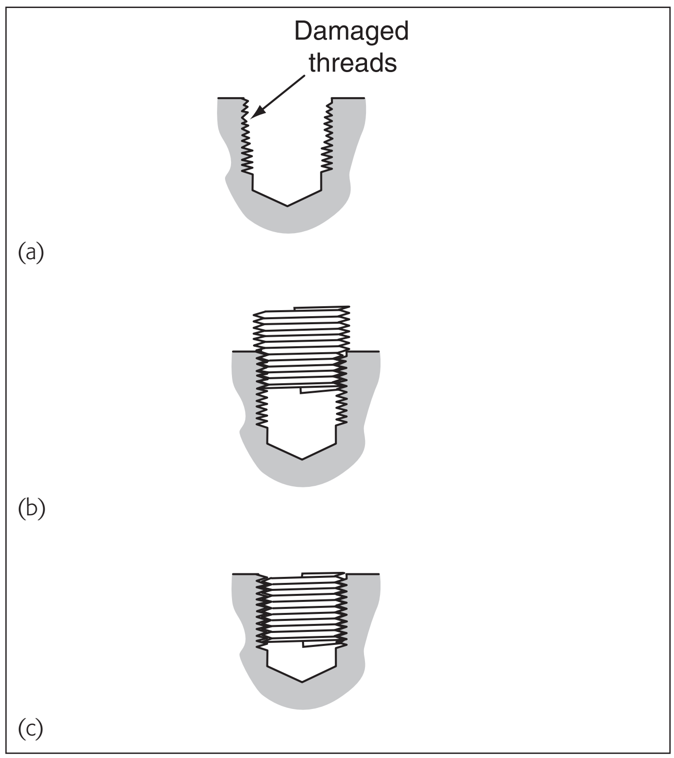


Figure 16.56 The heli-coil process. (a) A thread before being repaired with a thread insert. (b) The coil is larger than the threaded hole that has been tapped for it. (c) A repaired thread.

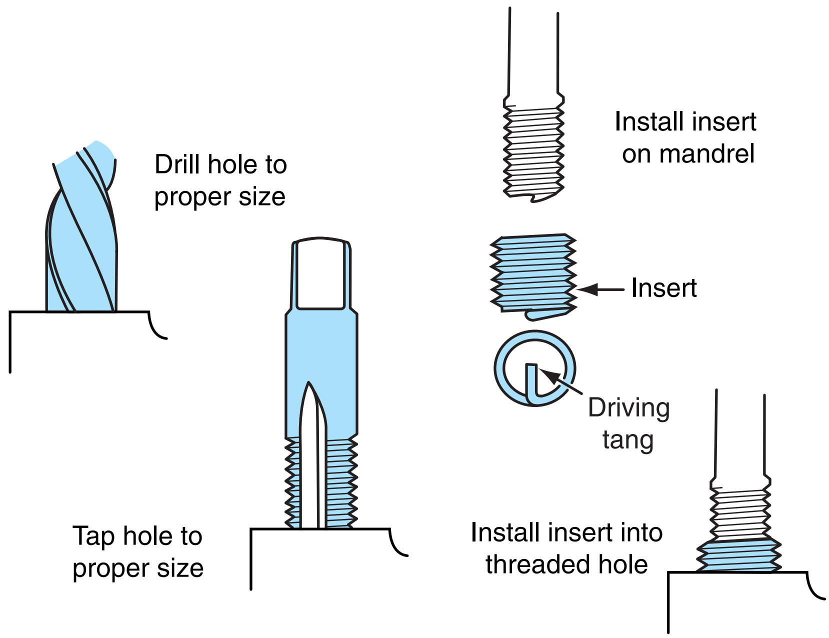


Figure 16.57 The heli-coil repair method. *(Courtesy of Emhart Fastening Technologies)*

- First drill an oversized hole.
- Tap the hole.
- Apply Loctite® or a similar thread locking compound to the insert.
- Install it in the hole with a special tool. There is a drive tang at the bottom of the heli-coil that locks to the tool during installation. It is notched for easy removal.
- Break the drive tang off the bottom of the heli-coil with a hammer and punch.

Be sure to insert the heli-coil far enough into the hole before breaking off the bottom tab. There are no second chances. **Figure 16.58** shows correct and incorrect heli-coil installations.

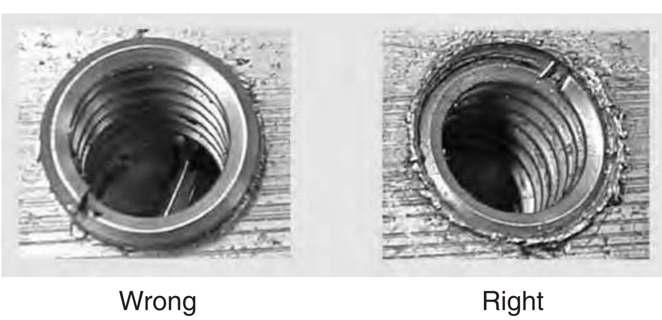


Figure 16.58 The heli-coil on the left has not been installed to a deep enough depth. It should be beneath the surrounding surface like the one shown on the right. (*Courtesy of Tim Gilles*)

Tapered heli-coil inserts are also available for pipe threads.

Solid Threaded Inserts. Solid threaded inserts (**Figure 16.59**) are used in applications that require high strength, such as repairing stripped head bolt holes or main bolt holes in a block. The bottom internal threads are cold rolled. The installation tool locks

Figure 16.59 A solid thread insert. (*Courtesy of Tim Gilles*)

the insert into place by forcing the bottom threads to expand the mating external threads into the threads cut into the block. Heli-coil also makes a screw lock insert for use with permanent studs. The center coil has a series of flats that hold the insert in place. One type of insert has a locking feature that is activated by pounding it into place. This method—the Slimsert® method—requires a special, stepped drill.

- Tap the hole.
- Screw the insert into place; the top of the Slimsert should be approximately 0.015" below the work surface.
- Strike the top of the driver with a hammer until the nylon washer touches the work surface. This locks the Slimsert in place.

Another type of locking insert, called the *Keensert*®, has locking keys that are pounded into place (see Figure 16.55).

Spark Plug Inserts. There are inserts available for repairing spark plug threaded holes in cylinder heads. Installation is the same as for other inserts, but one caution must be observed. Some spark plugs have tapered seats, whereas some are flat and require a gasket. Be sure to install the correct insert that corresponds to the rest of the spark plugs in the engine. Installing the insert from the bottom side often works well for gasketed plugs because the insert can never come out.

SHOP TIP

The older Ford 18 mm spark plug thread is the same thread that is used for O_2 sensor threads.

AUTOMOTIVE TUBING REPAIR

Tubing is used in automotive drivetrains for vacuum, oil, transmission, and fuel lines. It is sometimes damaged, requiring replacement. When replacing a section of tubing, be careful to copy the original piece as closely as possible. If you are replacing a piece of tubing that is not straight, measure it using a piece of string. This will help determine the correct length, including bends. Sometimes a loop or bend can be put into a precut line to shorten it to the desired length without having to cut it and reflare one of its ends.

Tubing diameter ranges from $^1/_8$" to $^3/_8$". It comes in several precut lengths with flared ends and fittings installed or in 25-foot rolls. When unrolling bulk tubing, be careful not to kink it. Unroll it in the same direction that it was rolled. When fittings are to be installed on the tubing, add an additional $^1/_8$" at each end to allow for forming of the flare ($^1/_4$" total).

There are two kinds of flares used to finish the ends of automotive tubing: the *SAE-type 45° double flare* or the *ISO flare*, also called *a bubble flare* (**Figure 16.60**).

SAE Double Flare

The end of an SAE flared line is tapered outward. This is called a **flare**. The flare on the end of the line is wedged between the flare fitting and the **flare nut** on the line.

NOTE

Long and short flare nut designs are available. The long nut is used when the part is subject to vibrations because it supports the tubing further away from the connection. Precut lengths of flared steel tubing are usually equipped with one long flare nut and one short one.

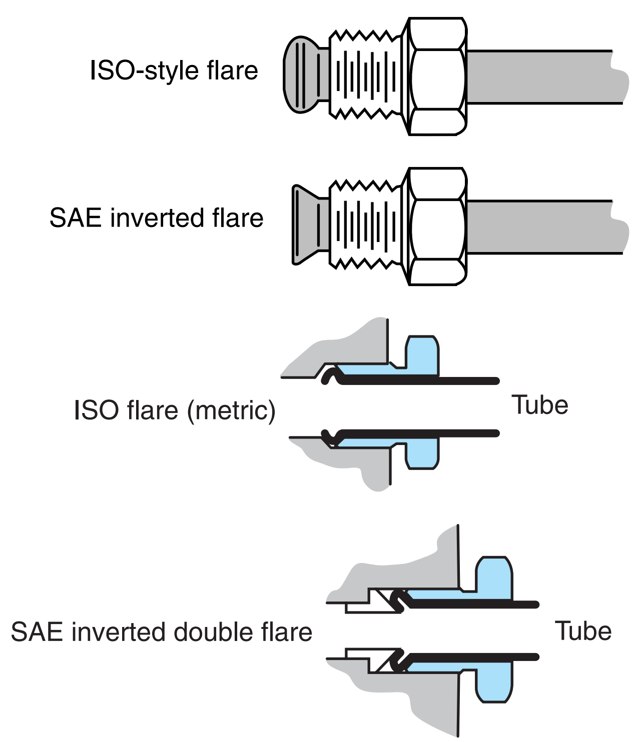


Figure 16.60 SAE and ISO flares.

SAE automotive fittings are flared at 45º, but there are also 37º SAE flares. Be sure you are using SAE 45º fittings. The male nut will have a 45º angle and the female fitting will have a 42º angle. This intentional mismatch creates an interference fit for positive sealing.

A 45º SAE-type double flare is usually used with an *inverted flare* nut, which is more common on automobiles. The standard flare is found in such applications as household natural gas lines.

A single flare is not used on small automotive tubing. Automotive lines are either double flared **(Figure 16.61)** or bubble flared because a single flared line tends to split the tubing at the seam.

ISO Bubble Flare

ISO flared tubing has been found on automobiles since the early 1980s. Bubble flares used to be common only on imported vehicles but are now common on domestic vehicles as well. A bubble or ridge is formed in the line a short way back from its end **(Figure 16.62)**. A single flaring operation can be done without danger of splitting the line (like with a single 45° flare).

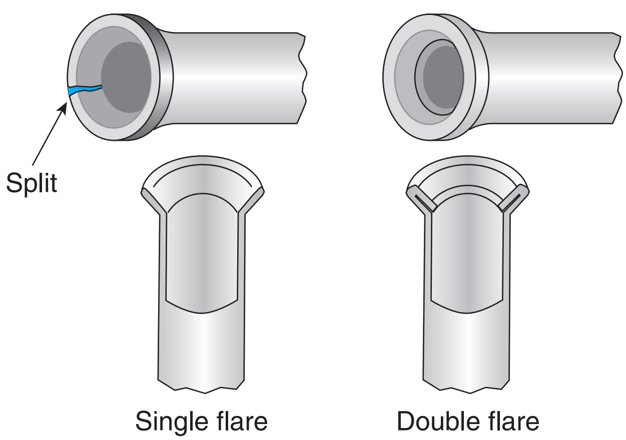


Figure 16.61 A single flare will cause the tubing to split.

Figure 16.62 A bubble flare. (*Courtesy of Tim Gilles*)

Like the SAE flare, the ISO flare uses an interference fit between the male and female parts. The outer surface angle is about 32.5º, the flare seat is 30º, and the angle at the end of the flare nut is 35º. These fittings are popular with manufacturers because they seal well and machining is simplified. An added advantage is that no seat is necessary as with the SAE flare.

NOTE

Low-pressure applications such as vacuum lines often use flareless compression fittings with a brass sleeve that pinches tightly into the wall of the tubing to provide the seal **(Figure 16.63)**. This type of compression fitting should not be used on high-pressure applications such as fuel, brakes, or power steering systems.

When loosening a flare fitting, a tubing wrench or flare nut wrench is used (see Chapter 4). Flared lines are held against a seat in the fitting. *Always* use two wrenches. The second wrench holds the female part of the fitting. The female fitting will tend to rotate when the male flare fitting is turned with a wrench. If this is allowed to happen, the line will become kinked **(Figure 16.64)**. Damaged steel lines can be cut and repaired or new lines can be fabricated using a flaring tool.

SAFETY NOTE

Use only seamless steel tubing and do not replace steel tubing with copper.

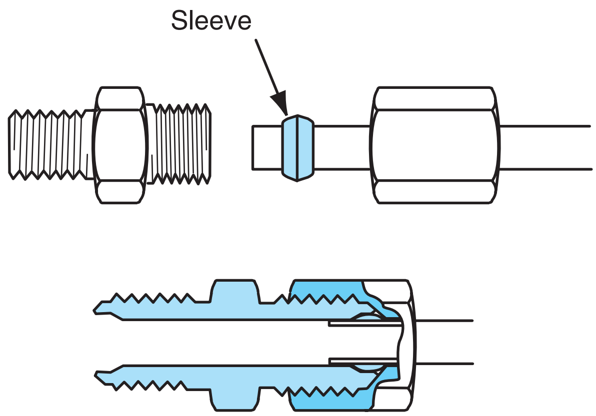


Figure 16.63 A compression fitting like the one shown here is only used in low pressure applications. It should not be used to repair a high-pressure line.

Figure 16.64 This tubing was damaged when the technician tried to loosen it without using two wrenches. (*Courtesy of Tim Gilles*)

Cutting Tubing

When cutting tubing to length, be sure to cut it so it is square on the end. It is best to use a *tubing cutter* **(Figure 16.65)**. A hacksaw will leave a rough edge that might not be square, and metallic debris can be left in the tubing. When the end is dressed off with a file, metal chips can get into the end of the tube. If these are not thoroughly cleaned out, serious damage to a component can result.

The tubing cutter is first tightened against the tubing, and then the cutter bit is rolled around the tubing. The handle is tightened to advance the cutter as the tubing is cut. Do not overtighten it or the cutter will cut through too soon and the tubing could be damaged.

Following cutting, a burr usually remains on the end of the tubing. This should be removed with the reamer blade that is a part of most tubing cutters. Be sure to remove any chips from the end of the tubing after completing the cut.

Some tubing cutters are very small. In tight quarters they can be used for repairing damaged tubing on the vehicle. The tubing cutter shown in **Figure 16.66** is especially handy for this.

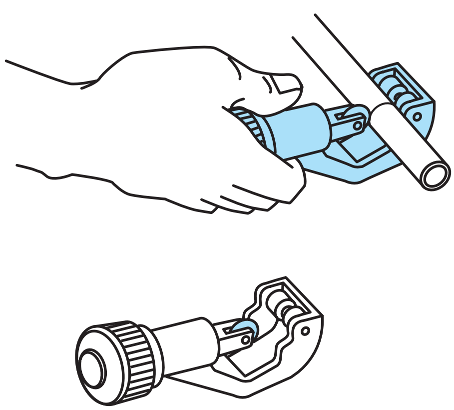


Figure 16.65 Using a tubing cutter to cut tubing.

Figure 16.66 A miniature tubing cutter is handy for working in tight locations. (*Courtesy of Tim Gilles*)

Bending Tubing

When bending tubing, remember that too sharp a bend will result in a kink or restriction. Tubing can be bent with a *tubing bender* **(Figure 16.67)**. It is better to install fittings and flare both ends before bending tubing. Otherwise, if the bend is too close to the flare, the flaring tool will not be able to clamp to the tubing. It is best if the bend is not too close to the flare. Leave at least a couple of inches when possible.

Figure 16.67 When using a tubing bender, install the fitting and flare the end of the tubing before bending it. Attempting too sharp a bend will result in a kink or restriction in the tubing. (*Courtesy of Tim Gilles*)

SHOP TIPS

- To make a sharper bend, move the tubing along the roller and bend it a small amount in several positions.
- If you do not have a tubing bender, tubing can be formed by bending it over a large piece of pipe. A coolant pump V-belt pulley held in a vise also works well. Slowly form it using the tubing that is being replaced as a guide when possible. Be careful not to bend the tubing too sharply.

A bending spring **(Figure 16.68)** can be installed over the tubing. It will help keep the tubing from becoming kinked during the bend. When using a bending spring, one end of the line must not have its fitting installed yet. This is so that the spring can be installed and removed from the line.

Flaring the Ends of Tubing

A flaring tool is used to flare the ends of the tubing with either an SAE double flare or an ISO (metric double) flare. Different tools are required to perform these jobs. Be sure to use the same kind of flare that was used on the original line. The different types of flares are not interchangeable.

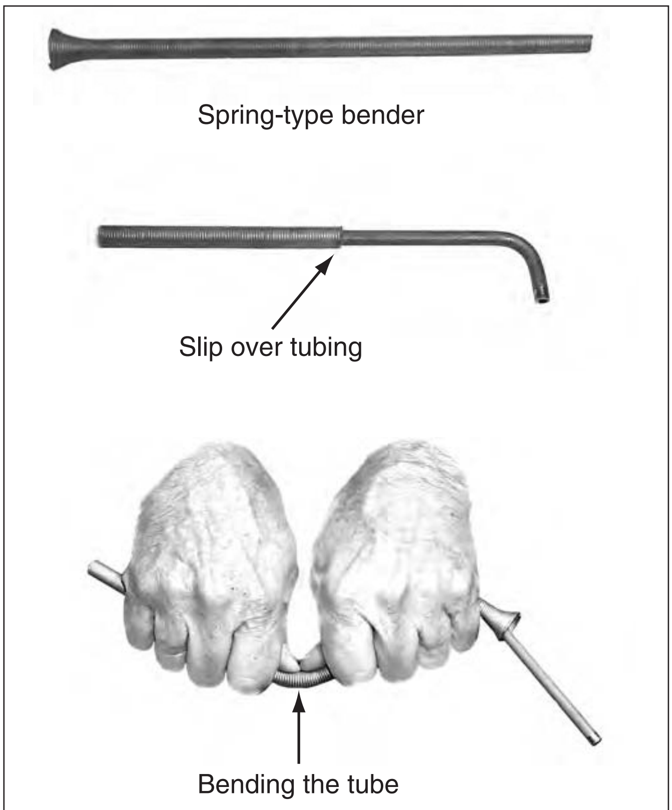


Figure 16.68 A bending spring helps prevent the tubing from becoming kinked.

SAE Double Flaring

An SAE double flaring is a two-step process. The line is clamped in a special tool while its end is formed. The tube is then folded over itself to complete the double flare. **Figure 16.69** shows the double flaring process.

Be sure to first slip the fitting onto the line. Then select the correct size hole in the flaring tool bar and clamp the line in it. It should extend out of the bar by the width of the flaring tool adapter **(Figure 16.70a)**. A threaded flaring cone, adapter, and clamp are used to form the end of the tubing **(Figure 16.70b)**. The appearance of the end of the tubing following the first part of the forming operation is shown in **Figure 16.70c**. Following this, remove the adapter and tighten the flaring tool against the line again to complete the flare **(Figure 16.70d)**. A completed flare with its fitting is shown in **Figure 16.70e**.

If the flare is not formed correctly, you will have to cut the end off the line and form another flare.

REMEMBER:

- **Always put the fitting on the line before flaring it.**
- **Leave enough space between a bend and the flared fitting so that the fitting can slide.**

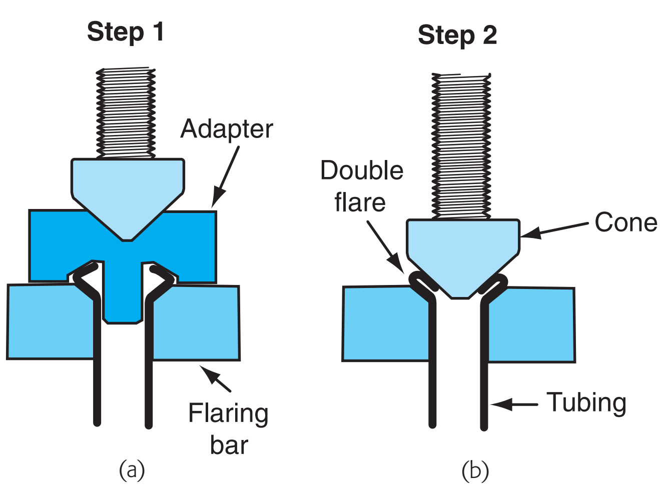


Figure 16.69 (a) The adapter is forced into the end of the tube. (b) The flaring cone completes the double flare.

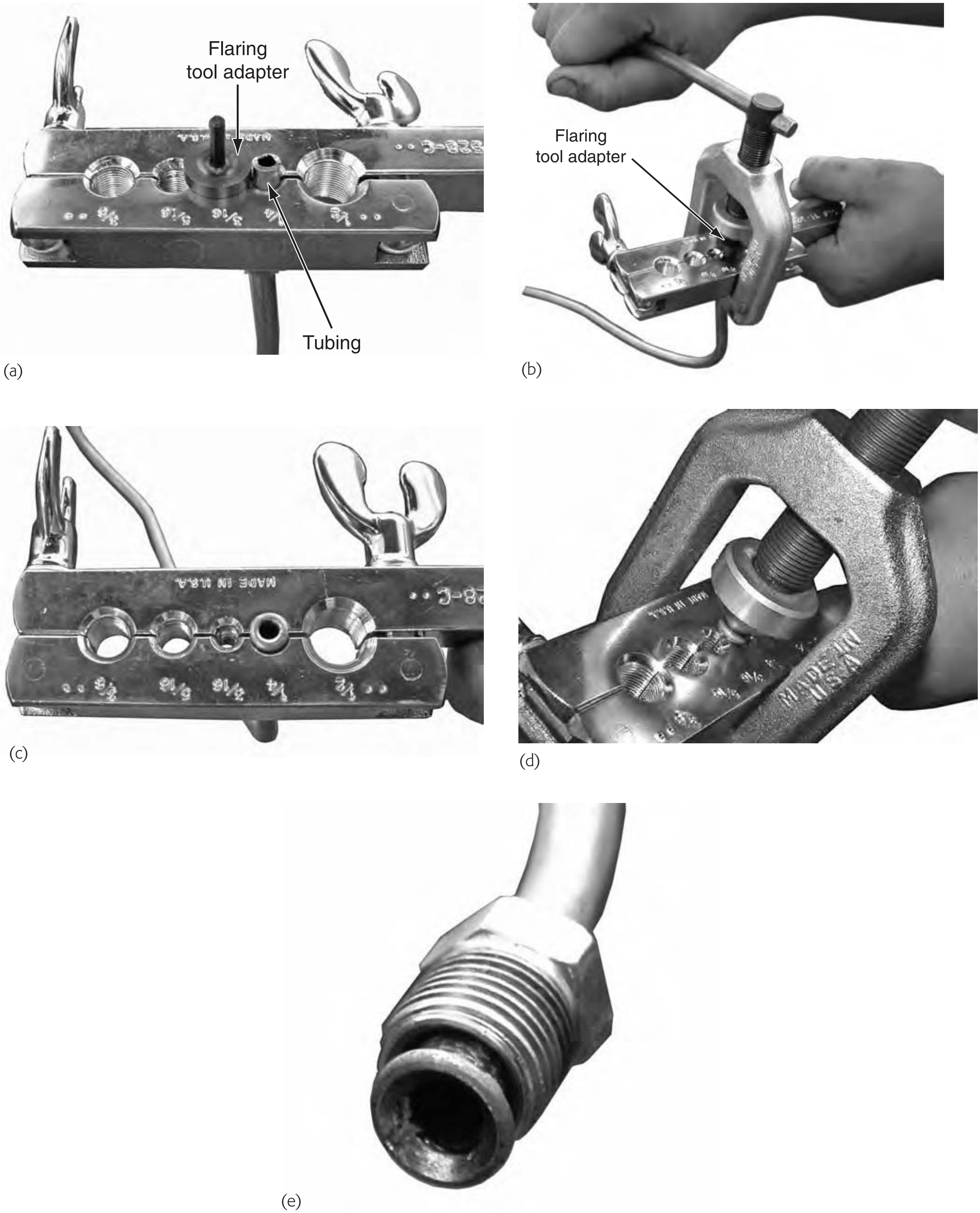


Figure 16.70 (a) Extend the tubing out of the bar by the width of the flaring tool adapter. (b) Tighten the flaring cone against the end of the adapter to form the end of the tubing. (c) The end of the tubing following the first forming operation. (d) Remove the adapter and finish the end of the double flare by tightening the flaring cone against the preformed end of the tubing. (e) A completed double flare.

SHOP TIP

Thread sealers or Teflon tape are not necessary when using flare fittings. A flare fitting seals internally and the threads should not be exposed to liquids. If the threads get wet, the flare is not a quality joint.

Installing Flared Tubing

When you install a length of tubing, leave the first flare nut loose after turning it by hand into the threads in the fitting. After starting the fitting on the other end of the tubing, tighten them both. Hold the fitting with a wrench while tightening the flare nut. Do not overtighten the fittings. After the flare is brought into contact with the fitting, turn it an additional $^{1}/_{6}$ turn only.

ISO Flaring

To form an ISO flare, a bubble or ridge is formed in the line a short way back from its end (see Figure 16.62). A single flaring operation can be done without danger of splitting the line (like with a single 45º flare). Two different types of flaring tools are available for creating bubble flares. Both of them grip the outside of the tubing while a pressure screw is tightened against a mandrel to form the bubble on the tubing. **Figure 16.71** shows one type in use. To achieve the correct shape to the bubble, the tubing is clamped evenly with the top of the clamping fixture **(Figure 16.72)**. **Figure 16.73** shows the tubing after it has been shaped by the mandrel.

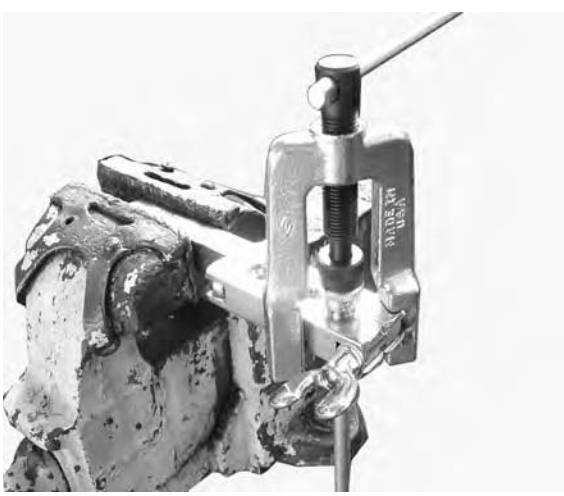


Figure 16.71 A bubble flaring tool in use. The mandrel beneath the pressure screw forms the end of the tubing. (*Courtesy of Tim Gilles*)

Figure 16.72 To make an ISO bubble flare, clamp the tubing evenly with the top of the flaring bar. (*Courtesy of Tim Gilles*)

Figure 16.73 The appearance of the tubing after ISO flaring. (*Courtesy of Tim Gilles*)

Another type of ISO flaring tool is shown in **Figure 16.74**. The tubing is inserted through the end of the clamping nut. When the clamping nut is tightened into threads in the flaring tool body, a *collet* is compressed to grip the outside of the tubing. The tubing must be positioned inside the tool mandrel at the correct height, using the gauge end of the flaring

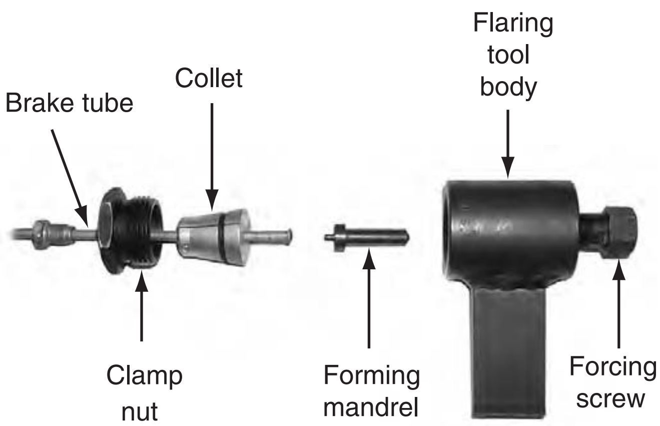


Figure 16.74 Another type of flaring tool used to form an ISO flare.

tool. Then reverse the flaring tool/gauge and thread it into the tool mandrel to form the bubble flare.

A union **(Figure 16.75)** is the best repair for the higher pressure (30–35 psi) automatic transmission cooler or fuel injection supply lines. If a rubber hose is used to repair these lines, be sure to flare both ends of the metal tubing that is being joined. Otherwise, the high pressure will blow the hose off the lines.

NOTE

Be sure to use transmission oil cooler hose for automatic transmission lines. Fuel hose will fail when used with transmission fluid.

If there is enough straight line remaining behind the flare, cut the kink from the line and install a union to couple the two pieces of line together.

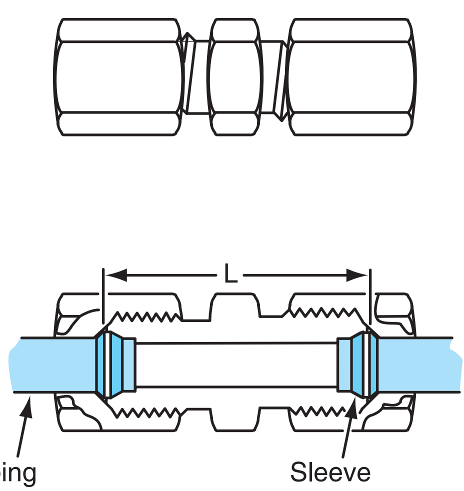


Figure 16.75 A union. The length that is removed from the steel tubing should equal L.

CASE HISTORY

A technician repaired a damaged transmission cooler line by cutting out the bad section, single flaring both ends of it, and installing a piece of hose with worm gear hose clamps. After a few thousand miles, the sharp edge of the flared line cut through the rubber hose, resulting in a serious fluid leak. Luckily, the owner spotted smoke and stopped the car before a fire or damaged transmission could occur. A double flare, or bubble flare, would have presented a smoother edge for the hose to squeeze against.

NOTE

Do not use copper tubing for fuel or brake lines. Also, when an engine fuel line is damaged, do not replace it with a rubber hose. Steel lines allow better cooling of the fuel. A small section of rubber hose used to repair a defect in a low-pressure line is acceptable, however.

SAFETY NOTE

If the engine is fuel injected, it probably has higher fuel pressure. A hose must not be installed unless the metal line is ridged or double flared. Also, hose clamps for high-pressure use are different than standard worm gear clamps.

Pop Rivets

Pop rivets are sometimes used to fasten sheet metal parts to other engine parts **(Figure 16.76)**. A nail is pulled through inside of an aluminum rivet to expand it and fasten it securely to the hole. Common uses include attaching ID number plates, baf-

Figure 16.76 A pop rivet. (*Courtesy of Tim Gilles*)

VINTAGE ENGINES

Older cars had carburetors rather than fuel injection. Carburetor base gaskets are usually not included in a full gasket set. A 1955–1980, small-block General Motors gasket set would have to include 28 different carburetor gaskets to meet all possible needs. Be sure to save the old carburetor base gasket for comparison.

fles, or heat deflectors. Pop rivets are inexpensive and easy to use. A pop rivet installation tool is shown in **Figure 16.77a**.

- Insert the nail end of the pop rivet into the installation tool **(Figure 16.77b)**.
- Position the pop rivet in the hole **(Figure 16.77c)**.
- An important step in the installation process is to push the installation tool firmly against the rivet head **(Figure 16.77d)**.
- Squeeze the handle on the installation tool to pull the nail through the rivet and tighten it to the hole **(Figure 16.77e)**.
- Increase the grip on the tool until the nail breaks off, leaving a finished pop rivet installation **(Figure 16.77f)**.

GASKETS

Gaskets are installed between two surfaces to prevent leakage. Some gaskets seal low-pressure fluids. Head gaskets seal the high pressures of combustion as well as lower pressure oil and coolant passages.

Seals are used to prevent lubricants from escaping around a rotating shaft. **Figure 16.78** shows the locations of many gaskets and seals used in an engine.

Gasket Sets

Gaskets can be purchased individually or in sets. A *full set* (FS) contains everything needed for an engine rebuild. Often, extra, unnecessary gaskets are included in a full gasket set. This helps keep to a minimum the number of part numbers stocked by parts suppliers. Although there are more gaskets in the set, the cost is still lower for the manufacturer.

SHOP TIP

Be sure to read the contents on the cover of the box. Sometimes a full set does not include valve guide seals or a crankshaft rear main seal.

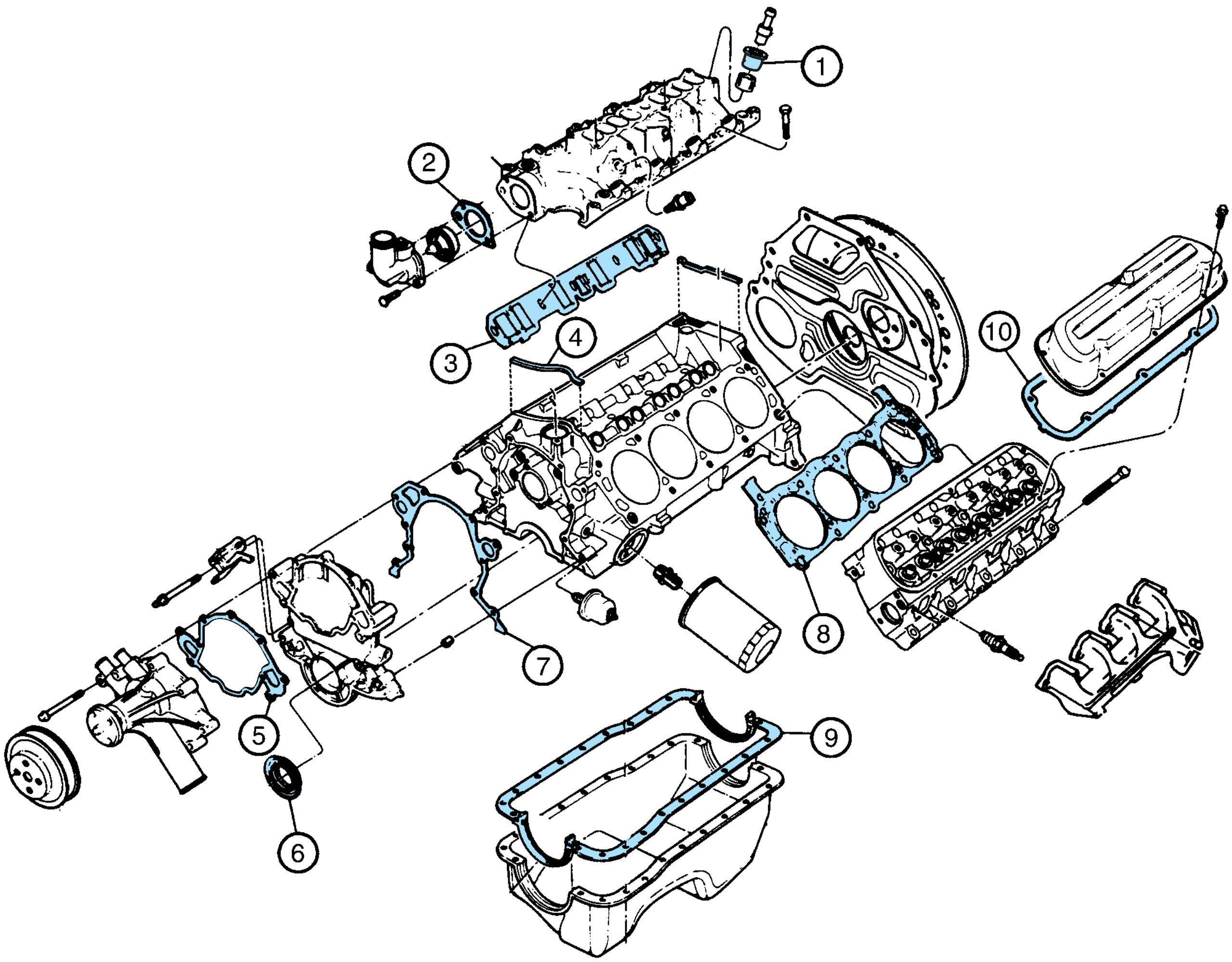
Other available gasket sets include the head set, oil pan set, and timing cover set.

Cylinder Head Gaskets

Modern head gaskets have a more difficult job of sealing than head gaskets of the past on older engines. Today's cylinder blocks are lighter and more flexible than vintage engine blocks. Some engines have aluminum heads and blocks, others have an aluminum head and an iron block, or vice versa. These are called *bimetal engines*. A head gasket has an especially difficult job sealing these engines because aluminum expands twice as much as cast iron when heated **(Figure 16.79)**. If the engine overheats, extreme stress in an aluminum head can result in head bolt overstretching, head warping, and failure of the head gasket.

Manufacturers have had some very expensive recall programs when bimetal engines experienced high failure rates in head gaskets sometimes in as little as 50,000 miles. The shearing action when the head and block expand at different rates destroys the gaskets. Smooth head and block surfaces are the norm for bimetal engines. Surface texture is covered later in this chapter.

Figure 16.77 (a) A pop rivet installation tool. (b) Thread the correct size adapter into the tool and insert the pop rivet into the tool. (c) Position the head of the pop rivet in the hole. (d) Push down firmly on the pop rivet flange. (e) Squeeze the handle on the rivet tool to expand the rivet until the nail breaks off. (f) A finished pop rivet installation.



1	PCV valve grommet	6	Front crankshaft seal
2	Thermostat housing gasket	7	Timing cover gasket
3	Intake manifold gasket	8	Cylinder head gasket
4	Intake manifold end seal	9	Oil pan gasket
5	Water pump gasket	10	Valve cover gasket

Figure 16.78 Typical engine gasket and seal locations.

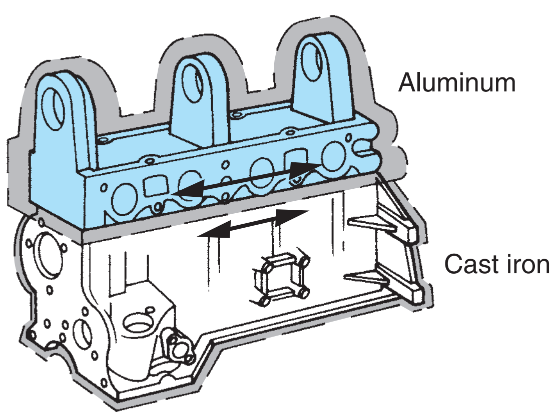


Figure 16.79 Aluminum expands two to three times as much as cast iron when hot.

Composite Head Gaskets. A modern nonretorque composite gasket has a facing, core, and coating **(Figure 16.80)**. The core is constructed of either solid steel or perforated clinched steel. The core is faced with materials such as expanded graphite or composite fibers bound with nitrile rubber. These materials are dense so they do not compress much, but they can compress enough to conform to the minor irregularities of a sealing surface.

Graphite Head Gaskets. Graphite-faced gaskets are premium gaskets. One of graphite's limitations

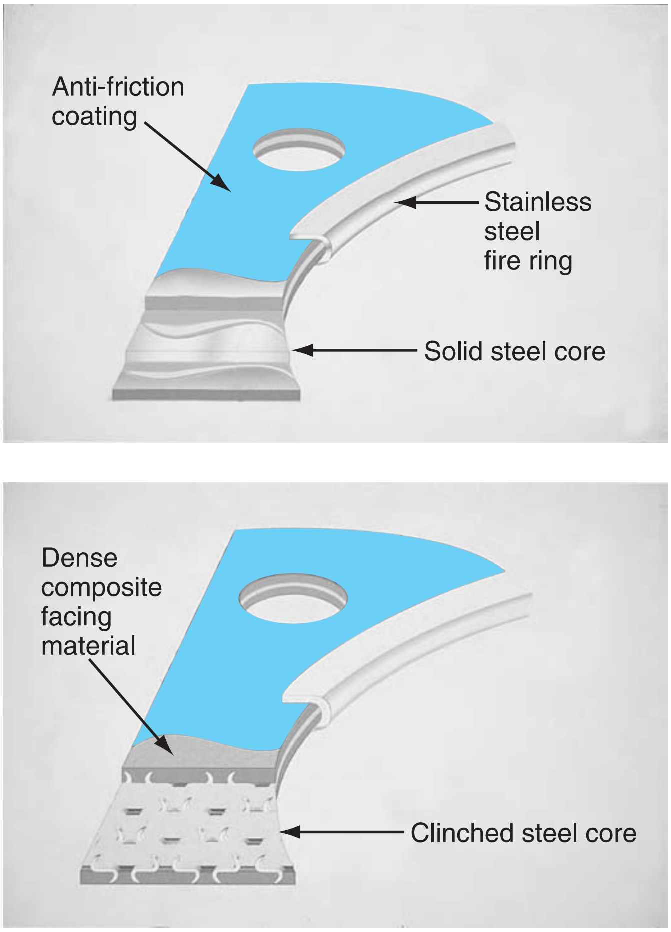


Figure 16.80 A modern composite gasket with a facing, coating, and core. (*Courtesy of Federal-Mogul Corporation*)

is its cost. It is more expensive than other nonasbestos gasket materials but its performance often requires its use. Graphite transfers heat from the engine to the coolant more quickly. This is why a graphite gasket is helpful when an engine is prone to detonation. Because graphite is soft, it does a good job of sealing a cold engine, too. Graphite gaskets are sometimes coated to reduce sticking and cleanup.

Teflon® and Silicone-Coated Gaskets. Teflon, moly, or silicone-based antifriction coatings can seal minor surface imperfections. These gasket coatings do not stick to parts, so they allow much more movement between the head and gasket on bimetal engines **(Figure 16.81)**. They also have the added advantage of easy disassembly.

Some premium Teflon gaskets used on cast iron engines have silkscreened silicone beads that help them provide a good, cold seal around cooling passages **(Figure 16.82)**. This is a good feature on engines with cast iron blocks and heads, but the silicone holds tight to the head and block. Having the head stuck to the block would not be good for bimetal engines.

NOTE

Teflon-coated gaskets should be used without gasket sealers.

Multilayer Steel Gaskets. Multilayer steel (MLS) gaskets have been used in engine locations other than head gaskets in the past. Recently, they have become more common as head gaskets with most manufacturers.

Having multiple layers causes the gasket to spring apart, providing a further increase in clamping force. This "springiness" is called recovery. It allows the use of lower torque on fasteners, which results in less cylinder wall distortion.

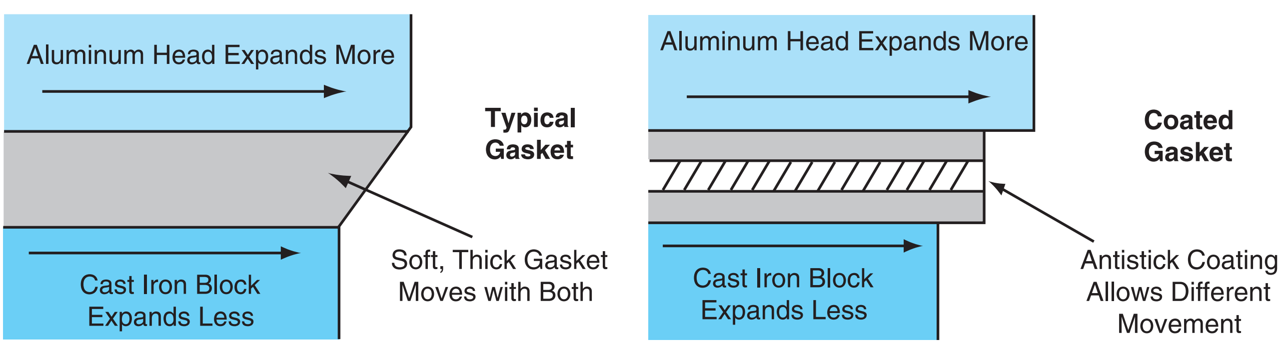


Figure 16.81 Coated gaskets allow more movement between an aluminum head and the block.

VINTAGE ENGINES

In the 1970s and earlier, an inexpensive embossed steel-shim head gasket, called a beaded steel gasket, was used extensively as original equipment on engines with thick iron heads and blocks **(Figure 16.83)**. Today, OE manufacturers do not use these gaskets and their use is not recommended in the aftermarket on late-model, lightweight heads. Beaded steel gaskets were used on new engines because mating surfaces between new parts are nearly perfect. This type of gasket will not seal scratches in the head or block, and it will not recover its shape after an engine has been overheated.

The embossed area of a steel-shim gasket is created with 100 tons of pressure in a very large (400-ton capacity) press. The embossed area works like a lock washer to help the gasket maintain its seal. A beaded steel gasket was the original equipment gasket on the 350 Chevrolet. Feel the cylinder head surface on one of these heads after it is cleaned. It is sometimes indented (brinelled) from the gasket embossing, which is installed with the raised side toward the head so it will not indent the block. If the surface of the head is indented, the head should be resurfaced.

Replacement gaskets are about twice as thick as the steel shim. Their extra thickness compensates for the amount they will compress and also makes up for metal removed during routine head surfacing.

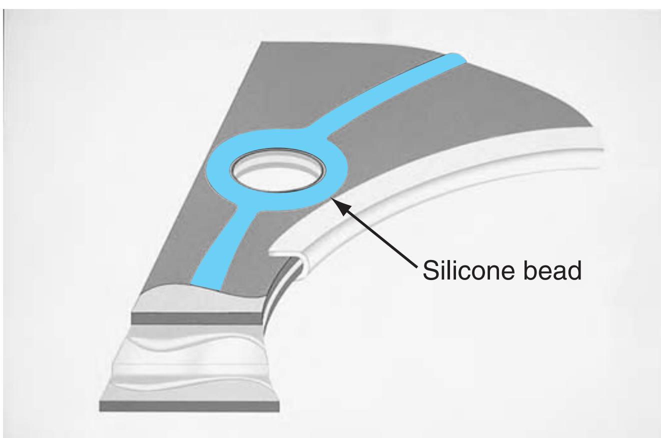


Figure 16.82 On engines with iron heads and blocks, a silicone bead provides a better cold seal around cooling passages. (*Courtesy of Federal-Mogul Corporation*)

MLS gaskets have from three to seven layers **(Figure 16.84)**. A rubber coating often separates the layers. The outer layers of an MLS gasket are stainless steel and embossed at 200 tons in an 800-ton capacity press. Workers in the building say that the whole building shakes when the press is working!

Most multilayer gaskets are coated with a very thin layer of rubber so they will seal when cold. Multilayered gaskets require more careful surface preparation. The head must be flatter and much smoother than for any other type of head gasket. For this reason they are not used by all engine rebuilders in the aftermarket. Some shops do not have the expensive equipment capable of producing the fine mirror-like finish that is required.

There are replacement MLS gaskets available for special applications, although they are quite costly to produce. They have a thicker coating, so they can be used with a surface preparation similar

Figure 16.83 Vintage embossed steel head and intake manifold gaskets. (*Courtesy of Tim Gilles*)

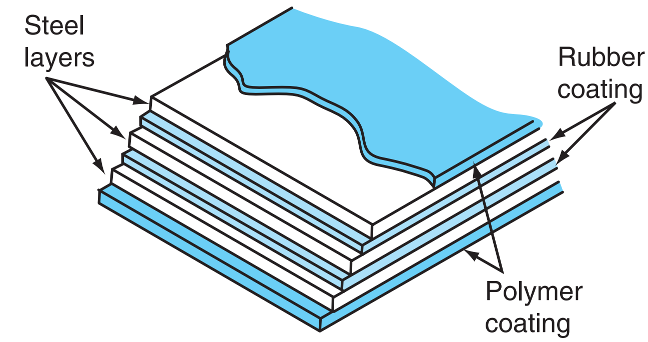


Figure 16.84 A multilayer steel (MLS) head gasket. (*Photo Courtesy of Tim Gilles*)

to that required of conventional gaskets. For many engine builders they have become the gasket of choice. MLS head gaskets are also available in different thicknesses. This gives a turbo engine builder a chance to drop the engine's static compression ratio without having to use a separate shim.

Importance of Correct Surface Texture. Metal surfaces in the engine are designed to have various surface textures. If a gasket is used with too rough a surface, a leak could result. Too smooth a surface can allow composite gaskets to slide around. Aluminum heads require a finer surface finish because the head must expand and contract against the gasket. Too rough a surface can tear the gasket apart.

CASE HISTORY

One curious machinist wanted to know just how much an aluminum head would expand from cold to hot, so he heated a cylinder head to engine operating temperature. He attached a dial indicator to the end of the head, set it to zero, and went home for the night. The next morning, the dial indicator face had moved 0.020", leading the machinist to believe that an aluminum head on a four cylinder engine grows about 0.020" in length during a heating/cooling cycle.

The head must move back and forth on an MLS gasket, so it is very important that the head be extremely smooth. If the head cannot move, its metal must become compressed. Compressed metal will not return to its original shape, so a void will develop in its surface, leading to compression loss and a failed head gasket.

For determining finer surface textures than a fingernail, which is relatively wide, a profilometer is used **(Figure 16.86)**. It reads with the end of a very small ball—a diamond stylus tip, like a record player needle—with a 0.0004" radius.

Measuring Surface Texture. Measurements of surface texture are rated on the ANSI scale. There

VINTAGE ENGINES

In vintage engines with iron cylinder heads, the surface left by the machine used to grind or mill the head is quite rough **(Figure 16.85)**. In fact, it is rougher than would be used for modern gaskets. For head gaskets used with cast iron heads, a rough surface (60–90 RA) helps the gasket take a "bite" into the materials being sealed. With these surfaces, it should be possible to feel the texture with your fingernail.

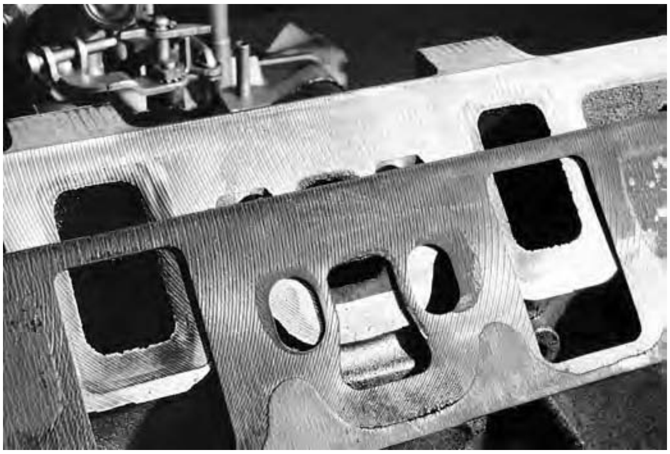


Figure 16.85 When a vintage Teflon gasket flowed into the machined grooves in the iron surface, this was called gasket "bite." (*Courtesy of Federal-Mogul Corporation*)

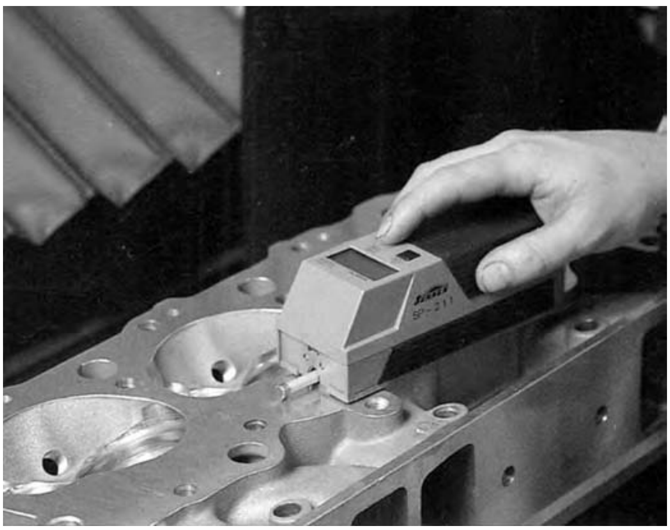


Figure 16.86 A profilometer measures surface texture. (*Courtesy of Sunnen Products Company*)

are several types of measurements, but roughness measured in microinches is the most important.

NOTE

A microinch is one millionth of an inch.

Roughness above 63 microinches can be checked visually. Visual comparator scales are available from gasket manufacturers **(Figure 16.87)**.

Roughness average (Ra) is the most widespread surface texture measurement because it is simple and uses inexpensive measuring devices. It is not the best, but it is adequate for automotive reground or polished surfaces. To determine an RMS reading from a meter reading in Ra, add 11% to the meter reading.

The following are some manufacturers' recommendations used as guidelines by machinists:

- 54–113 Ra (60–125 RMS) microinches. 80–100 Ra (90–110 RMS) is recommended for cast iron (non-MLS).
- A finer finish is recommended (45 Ra) for aluminum heads. Head flatness is also more critical with aluminum heads.
- Viton-rubber coated, MLS head gaskets = 10–30 Ra
- Graphite coated composite gaskets = less than 60 Ra
- Kevlar composite gaskets = 60–125 Ra
- *Intake or exhaust manifolds* (cast iron or aluminum) = 45 Ra

NOTE

Using a crosshatch pattern reduces the roughness of the surface finish by half.

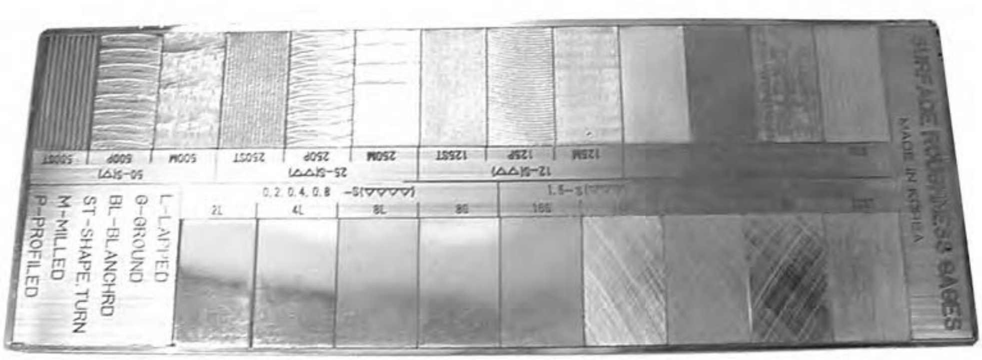


Figure 16.87 A surface finish visual comparison gauge. (*Courtesy of Tim Gilles*)

Copper Head Gaskets. Copper head gaskets are available for use in corrosive environments, such as marine applications. They are also effective in high vibration uses. Top fuel dragsters and "funny" cars often use copper head gaskets.

Head Shims. When too much metal has been removed from a head's surface, a shim can be installed to compensate. This protects against detonation that can result from too high a compression ratio. Shims are widely available. They are generally 0.020" thick and are either copper or steel **(Figure 16.88)**. Copper conforms better to surface imperfections, and steel is more durable. Sealer is used between the head and the shim but not between the shim and head gasket **(Figure 16.89)**.

Nonretorque Head Gaskets. Modern head gaskets are called permanent torque or nonretorque. They retain their resistance to compression better than older style gaskets; therefore, bolt stretch during torquing does not diminish their clamping force as much **(Figure 16.90)**. A gasket must be able to maintain a good seal over its lifetime. Small changes in the gasket's thickness can result in a substantial loss of clamping force. Continuous elongation of the bolt is necessary so that clamping force is maintained. The greatest torque loss will occur in the first hour of operation of a rebuilt engine.

Although modern head gaskets compress less than older head gaskets, all gaskets will relax somewhat during use. This is called creep relaxation.

Figure 16.89 Use sealer when installing a shim to correct for head surface machining. (*Courtesy of Tim Gilles*)

Older head gaskets required retorquing after about 500 miles, but cylinder head gaskets are not commonly retorqued today. Many of today's engines have intake manifolds, air conditioning, turbochargers, or other accessories that make head bolts inaccessible. Nonretorque gaskets can save 20 minutes to 2 hours of the labor time usually required for retorquing.

NOTE

Whether or not the gasket is a permanent torque type, always follow the gasket manufacturer's torque and retorque recommendations.

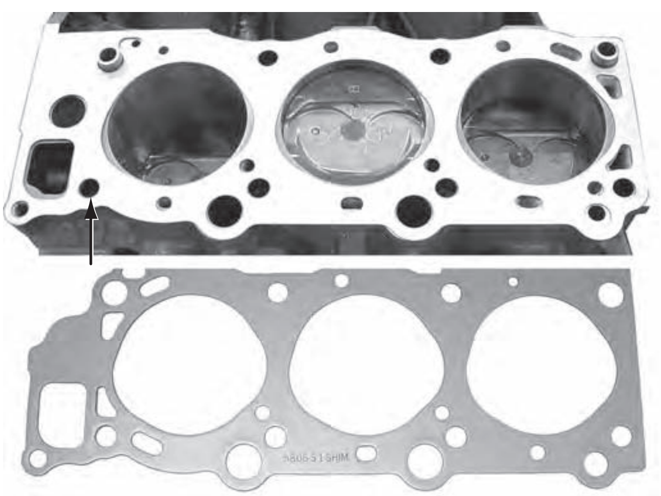


Figure 16.88 A shim is used with a head gasket to compensate when a substantial amount of metal is removed from the surface of a cylinder head. (*Courtesy of Tim Gilles*)

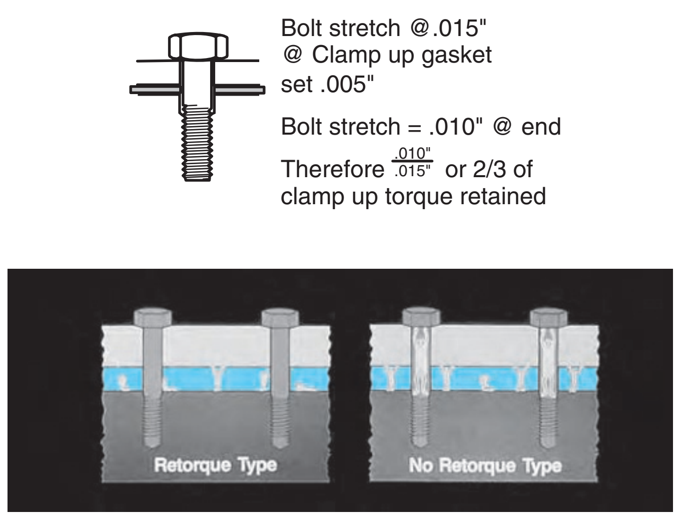


Figure 16.90 Clamping force on a nonretorque gasket. (*Courtesy of Federal-Mogul Corporation*)

Although retorquing is not required, modern nonretorque gaskets can benefit from retorquing after several heating and cooling cycles. The recommendation is usually for a gasket retorque at 500 miles because this is when the car should come back for its first oil change and a thorough inspection.

Cleaning the Head. Clean cylinder head and block surfaces thoroughly before engine assembly. Be careful not to nick the surface when scraping gaskets, especially on aluminum heads, which are softer. Many late-model heads do not allow for resurfacing to remove any remaining gasket material.

SHOP TIP

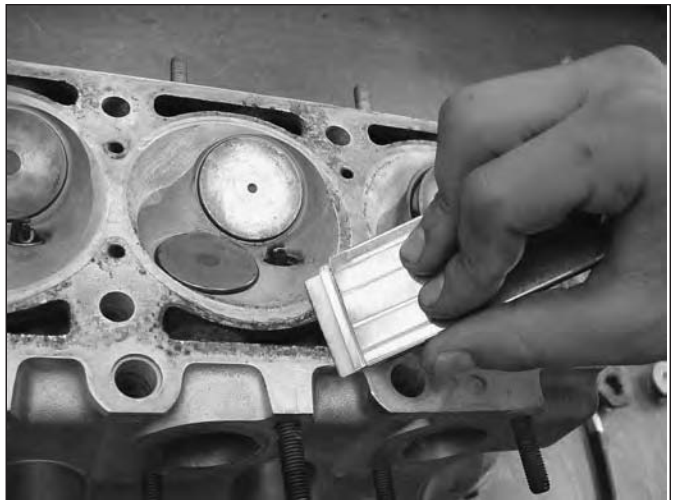
When cleaning aluminum heads, it is better to use a chemical gasket remover, lacquer thinner, or alcohol with a plastic scraper **(Figure 16.91a)** to prevent damage to the sealing surface. Plastic razor blades **(Figure 16.91b)** are available in parts stores. Spray gasket cleaners can be left to penetrate for 5–10 minutes.

SAFETY NOTE

Spray cleaners can damage skin and eyes. Be sure to follow the instructions printed on the can and check the material safety data sheet (MSDS) for hazards.

A blunt-end gasket scraper **(Figure 16.92)** can be an effective tool for cleaning aluminum surfaces because it is less likely to dig into the surface of the metal. A gasket scraper used on iron or steel surfaces must be sharp if it is to thoroughly remove a gasket from a head or block surface. Sharpen a gasket scraper on one side only **(Figure 16.93)**, using a file or whetstone.

Abrasive Disk Cleaning. Some technicians like to use abrasive bristle disks (see Chapter 5), called "cookies," to clean head and block surfaces **(Figure 16.94)**. Die grinders spin at a very high rpm, and damage can be done quickly to the surface of an aluminum head, so be sure your disk is rated for high speed if you use it with a die grinder.



(a)

(b)

Figure 16.91 (a) Cleaning an aluminum head surface with a plastic scraper. (b) A plastic razor blade. (*Courtesy of Tim Gilles*)

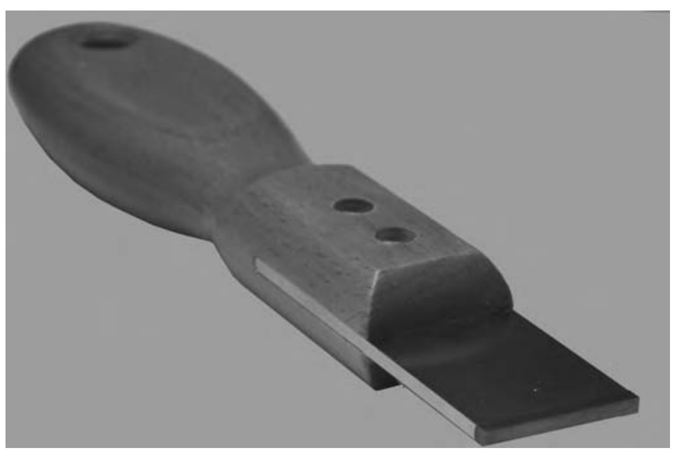


Figure 16.92 A blunt-end gasket scraper is less likely to dig into the surface of the metal. (*Courtesy of Tim Gilles*)

Figure 16.93 Sharpen a gasket scraper used on iron or steel on one side only. (*Courtesy of Tim Gilles*)

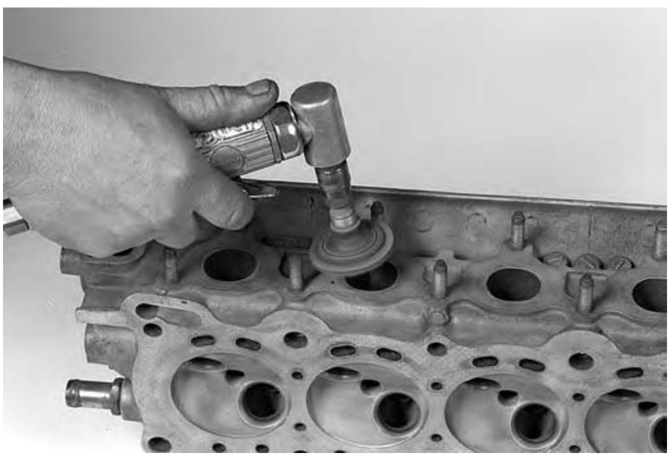


Figure 16.94 Using an abrasive disk to clean a gasket sealing surface. Using the wrong abrasive is a good way to damage the sealing surface of an aluminum head.

CAUTION

White bristle disks are finer so they remove material more slowly than yellow ones; therefore, they are safer to use. It is not necessary to clean the "ghost" marks left when the gasket stains the aluminum head surface around water jacket openings. Attempting to do this will result in metal removal. Be careful not to clean in one area longer than another.

To demonstrate how much metal you actually remove from the head surface during the disk cleaning operation, take a newly surfaced aluminum head and clean it extensively with a bristle disk. Coat the surface with dykem blue and machine it lightly (0.002") with a surface grinder.

Material thrown about by the disks must be carefully removed so it cannot ruin an engine.

SAFETY NOTE

Older gaskets often contained asbestos, which has been phased out as a gasket material. Manufacturers now use substitute materials. When cleaning a gasket surface, remember that the gasket might contain asbestos.

Head Gasket Installation. Installing a head gasket correctly will help guard against combustion leakage. Head gaskets perform the most difficult sealing job in the engine. Combustion sealing is very critical. Cylinder head bolts must hold against the pressure of combustion trying to push the head off the block. The clamping pressure on the bolts is greater than the combustion pressure, so the head bolts never receive the stress as long as proper bolt torque is maintained.

NOTE

About 75% of the clamping load of the head bolts is used to seal combustion. The remaining load is to seal coolant and oil.

- Chase all bolt holes with a tap (see Figure 16.22).
- Wire brush the bolt threads and the underside of the bolt head. This is where most of the friction during torquing comes from.
- Lubricate each bolt with 10W-30 oil and wipe off the oil with a shop towel. Check the manufacturer's recommendations. Some head bolts that protrude into coolant jackets call for the application of a liquid thread sealant instead of oil.

Head bolts should be torqued in the sequence prescribed in the service literature **(Figure 16.95)**. This torque pattern ensures that the head is pulled evenly against the head gasket and block. Remember to torque the head bolts in three or four stages as described earlier.

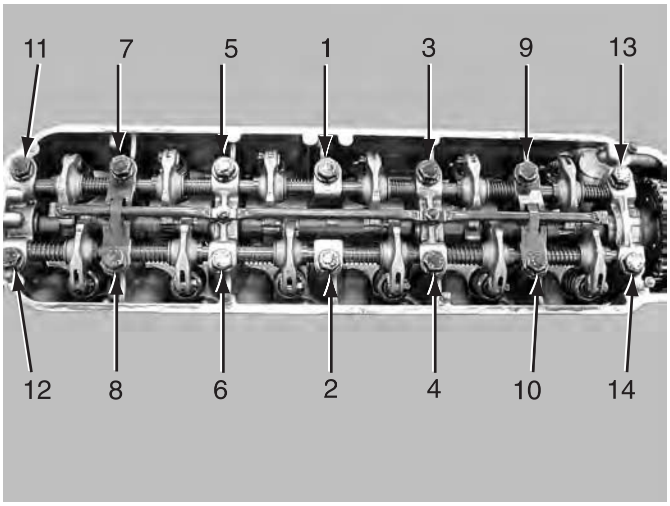


Figure 16.95 Follow the cylinder head bolt tightening sequence. (*Courtesy of Tim Gilles*)

Head Gasket Selection. Carefully match a new gasket to the old one or to the block and head to be sure it is the correct one. Head gaskets have small holes that control the flow of coolant in the head **(Figure 16.96)**. When possible, compare the new gasket with the old gasket. If the cooling and oil holes do not match up, serious lubrication or cooling problems can result. Some manufacturers have used different head gaskets for the same size engine built in different years. Use of the wrong gasket in one of these engines can result in cooling or oiling problems.

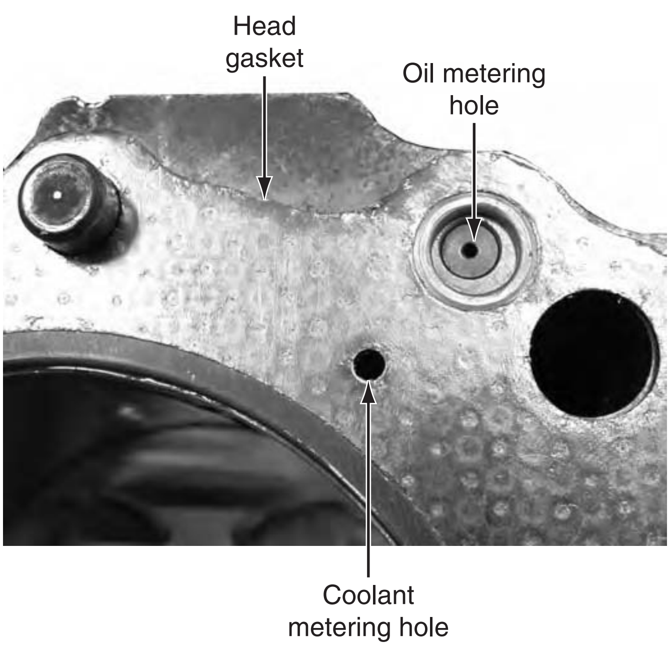


Figure 16.96 Cylinder head gaskets often have coolant metering holes. Some have oil metering holes, too. (*Courtesy of Tim Gilles*)

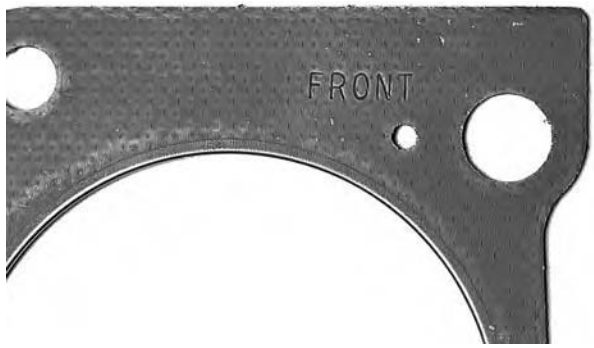


Figure 16.97 Some head gaskets are printed with installation directions.

Some engines have head gaskets that are directional. These will have an imprint marked "top" or "front" **(Figure 16.97)**. Some V-type engines have head gaskets that interchange from side to side. Others do not.

Other Engine Gaskets

Other gaskets are used at several locations to seal oil and coolant in the engine. **Figure 16.98** shows several kinds of gasket materials.

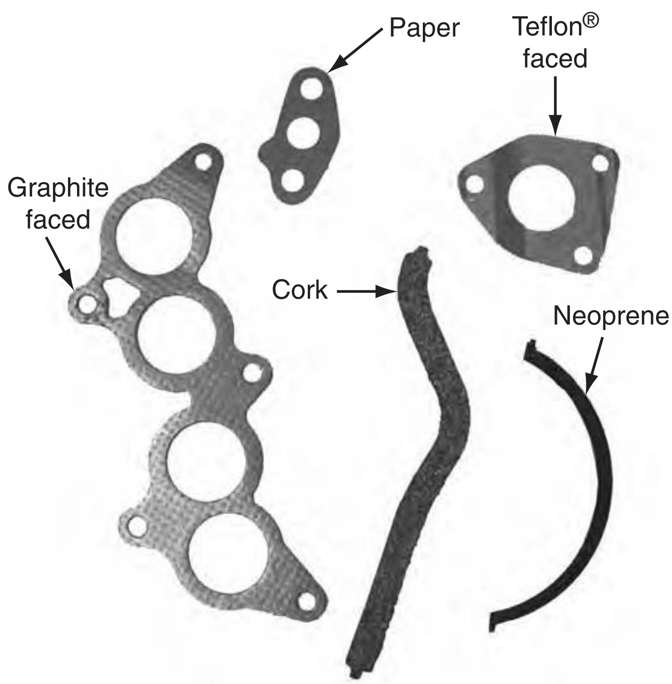


Figure 16.98 Various gasket materials. (*Courtesy of Tim Gilles*)

Valve Cover, Timing Cover, and Oil Pan Gaskets. Valve cover and oil pan gaskets can be made of different materials. Valve cover gaskets are molded to fit the shape of the cover. They often have tabs that fit into slots in the valve cover to hold them in place. Cast aluminum valve covers on overhead cam engines often have rubber semicircular plugs that fill holes in the head that were left from manufacturing **(Figure 16.99)**. These harden with age and begin to leak. They are not included with a valve cover gasket and must be ordered separately. Valve covers used with hemi heads have centrally located spark plugs installed in tubes that intersect the cylinder head and valve cover. Round seals supplied with the valve cover gasket are installed to prevent oil from leaking into the spark plug tubes **(Figure 16.100)**. If you find oil in these tubes when changing spark plugs, these seals are the cause of the leak, which can result in a smell of burning oil from under the hood.

Overhead camshafts with timing belts have seals located behind the camshaft sprocket(s) **(Figure 16.101).** This sometimes presents a difficult diagnosis and replacing the seals can be a time-consuming job. Be sure to install them carefully.

SHOP TIP

The top part of the seal is often held in place by the front camshaft cap. Loosening the cap makes it easier to install the seal **(Figure 16.102)**.

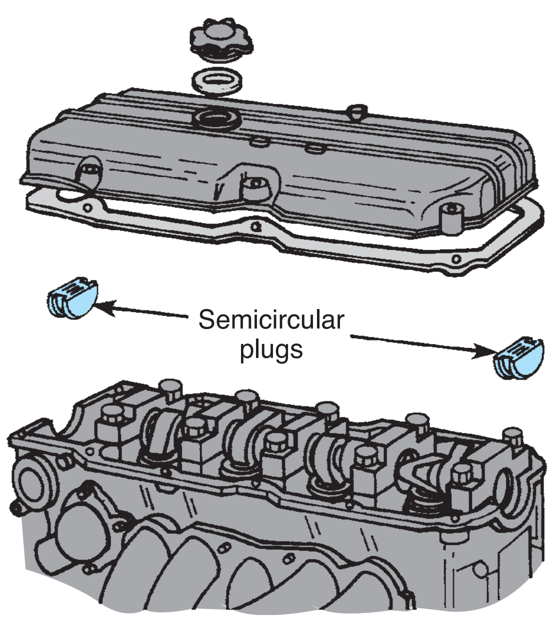


Figure 16.99 Some OHC heads have semicircular plugs at the ends.

Figure 16.100 Round seals are supplied with the valve cover gasket to seal the spark plug tubes on heads with centrally located spark plugs. (*Courtesy of Tim Gilles*)

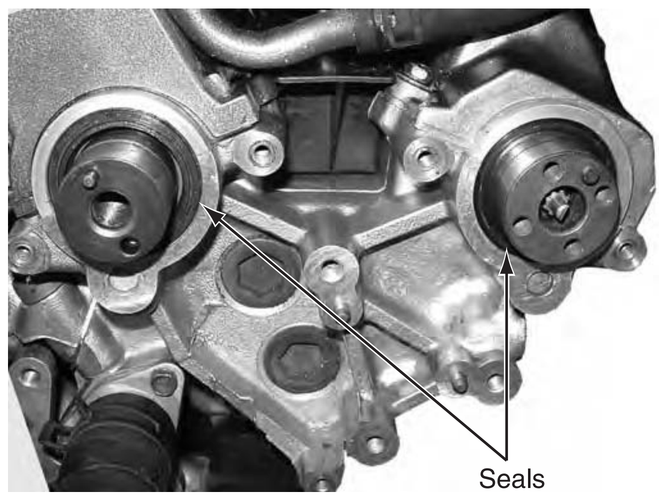


Figure 16.101 OHC engines with timing belts have seals behind the camshaft sprocket(s). (*Courtesy of Tim Gilles*)

Oil pan gaskets used on sheet metal oil pans are sometimes made up of several pieces **(Figure 16.103)**. Rubber seals on the ends join with side gasket strips. Sometimes a timing cover gasket is replaced without removing the oil pan. **Figure 16.104** shows how to cut a pan gasket and install a new piece of gasket.

Sheet metal parts often become distorted when bolts are tightened against them during assembly. Always check to see that the valve cover or oil pan is straight before assembly **(Figure 16.105)**.

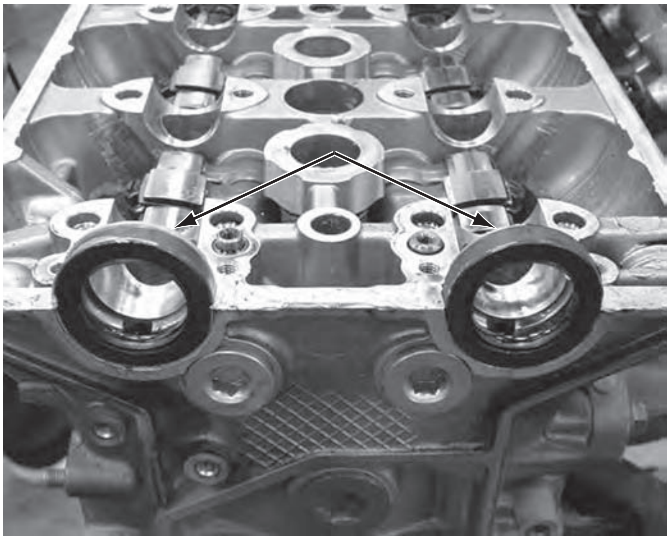


Figure 16.102 These seals are held in place by the cam bearing caps. Install them before installing the caps. (*Courtesy of Tim Gilles*)

When a cast aluminum oil pan is installed on a deep skirt cylinder block, the pan is a structural member and the timing cover is, too. Therefore, it is important to follow the recommended torque sequence when tightening these parts.

CAUTION

Torque applied to sheet metal parts with gaskets should be very light. Check the manufacturer's specification. Overtorquing can damage the gasket **(Figure 16.106)**. Most newer oil pan and valve cover gaskets have steel inserts to allow for equal tightening of the fasteners **(Figure 16.107)**.

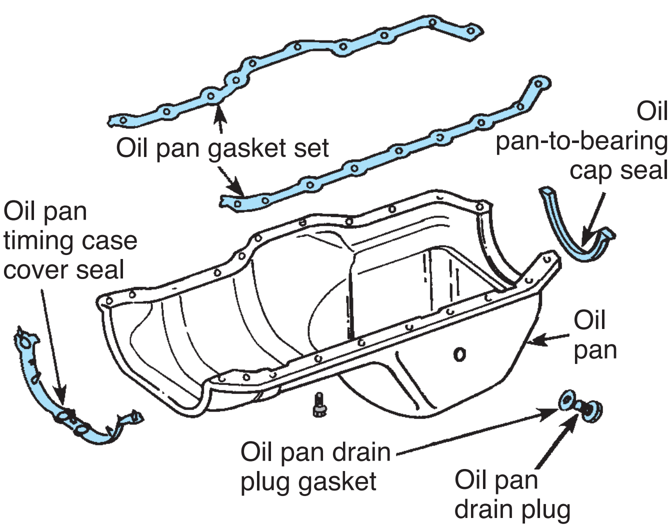


Figure 16.103 Oil pan gaskets and end seals.

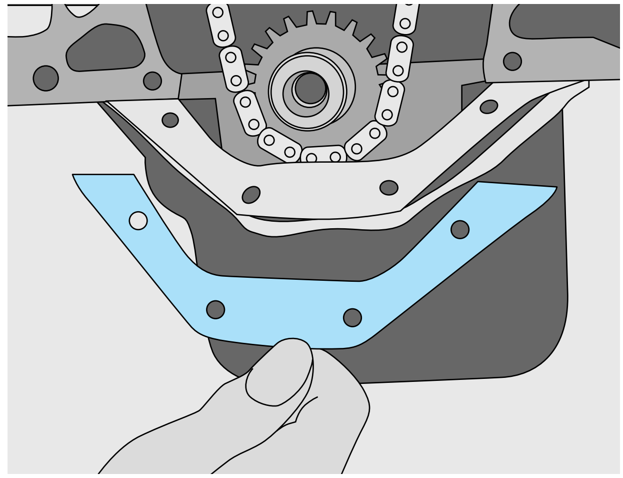


Figure 16.104 When the timing cover is removed without removing the oil pan, the front part of the old pan gasket is removed and replaced.

The two most common gasket materials used for valve cover gaskets are rubberized cork and synthetic rubber. Modern cork gaskets are rubberized cork **(Figure 16.108)**. This material is superior to regular cork because it does not shrink. All cork gaskets are somewhat resilient—that is, they are "springy"—but they should only be lightly torqued. Follow the torque recommendations to guard against breaking the oil pan or valve cover gasket screws.

Recommendations range from 5 to 15 foot-pounds. This is about the same amount the bolts could comfortably be tightened with a screwdriver or nutdriver.

NOTE

Typical torque on a valve cover or oil pan is about 60 inch-pounds. This is the torque required to correctly compress the gasket, not the torque required for stretching a fastener.

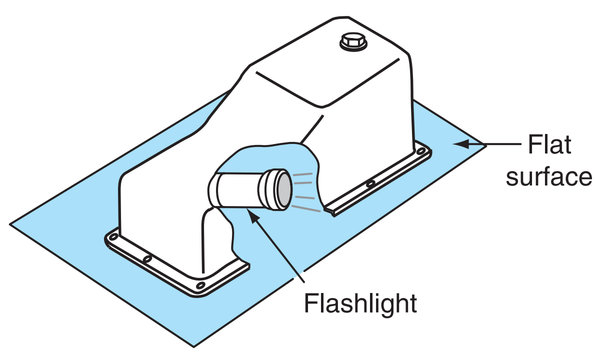


Figure 16.105 Check to see that the oil pan is straight before installing it on the engine.

VINTAGE ENGINES

Cork Gaskets

Cork used to be a common gasket material. Cork shrinks in the presence of air, so it required storage in a vacuum-sealed package. Old-time mechanics would commonly soak a shrunken cork gasket in water for a few minutes to help it regain its size. Cork also becomes brittle with heat. A brittle gasket can crack if screws are tightened further in an attempt to correct a leak.

Cork is no longer used as a gasket material, having been replaced with rubberized cork.

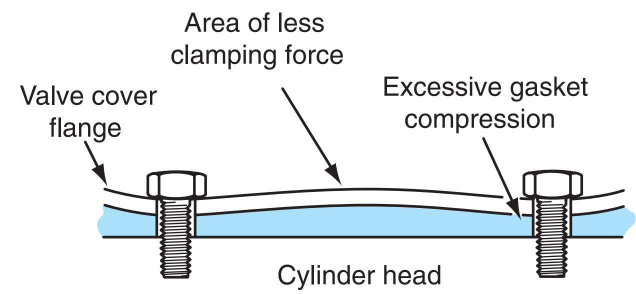


Figure 16.106 Do not overtorque valve cover gaskets.

Use the inch-pound torque wrench because foot-pound torque wrenches are not accurate at less than 15 foot-pounds of torque. To convert foot-pounds to inch-pounds, multiply by 12.

Silicone and Neoprene Gaskets. Molded silicone and neoprene (artificial rubber) gaskets are the best, but they are expensive. Because they are sometimes reusable, these gaskets are especially useful for valve covers that must be periodically removed—to adjust mechanical valve clearance, for instance.

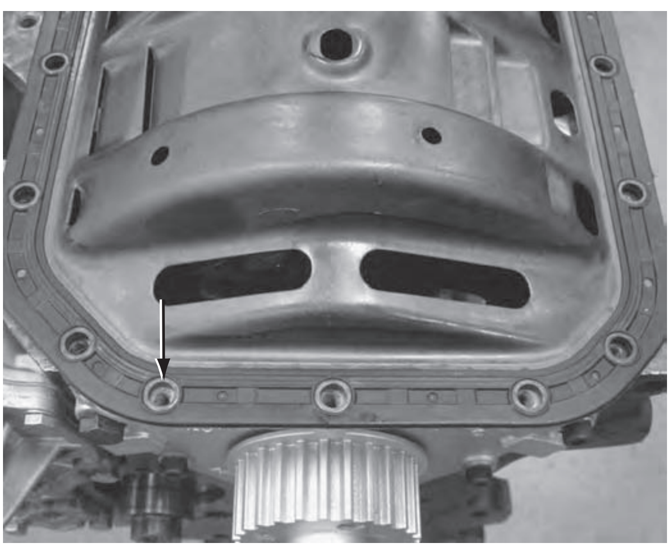


Figure 16.107 Most newer oil pan and valve cover gaskets have steel inserts to allow for equal tightening of the fasteners. (*Courtesy of Tim Gilles*)

Figure 16.108 When cork gaskets are found today, rubber has been mixed with cork to improve the gasket characteristics. (*Courtesy of Tim Gilles*)

REMEMBER:

Silicone and neoprene gaskets are used without sealers. If these gaskets must be held in position, use an adhesive on the cover side of the gasket only, and allow the adhesive to dry before torquing fasteners.

Paper Gaskets. Paper gaskets are generally the only gaskets, other than retorqueable head gaskets, that require the use of a sealer. Paper gaskets can be found on some timing covers, coolant pumps, coolant outlets, fuel pumps, and at the base of carburetors.

VINTAGE ENGINES

Some V-type engines with carburetors require installation of a small restrictor to block off the exhaust crossover that heats the intake manifold floor under the carburetor. Some engines use this and others do not. Leaving it out can cause vapor lock, resulting in surging and stalling.

SHOP TIP

Gasket paper can be purchased in sheets. A gasket can be roughed out by holding the paper against the part and tapping on it with a ball peen hammer **(Figure 16.109)**. Several manufacturers make tool sets for cutting the holes in paper gaskets **(Figure 16.110)**.

Intake Manifold Gaskets. Intake manifold gaskets must be resistant to air, water, and oil leaks. They are made of embossed steel shim, asbestos faced steel, or the nonretorque materials. Be sure to read any instructions that come with the gasket set. Many gaskets are also directional. Installing them in the wrong direction can result in engine overheating.

Exhaust Manifold Gaskets. Exhaust gaskets are not usually found on new, cast iron heads because the joined machined surfaces seal perfectly. Exhaust gaskets are used once the parts have been separated

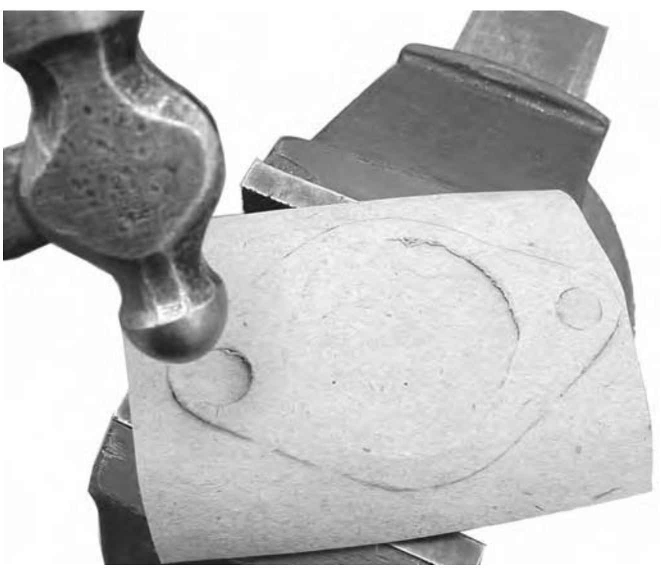


Figure 16.109 Using a ball peen hammer to form a gasket out of gasket paper. (*Courtesy of Tim Gilles*)

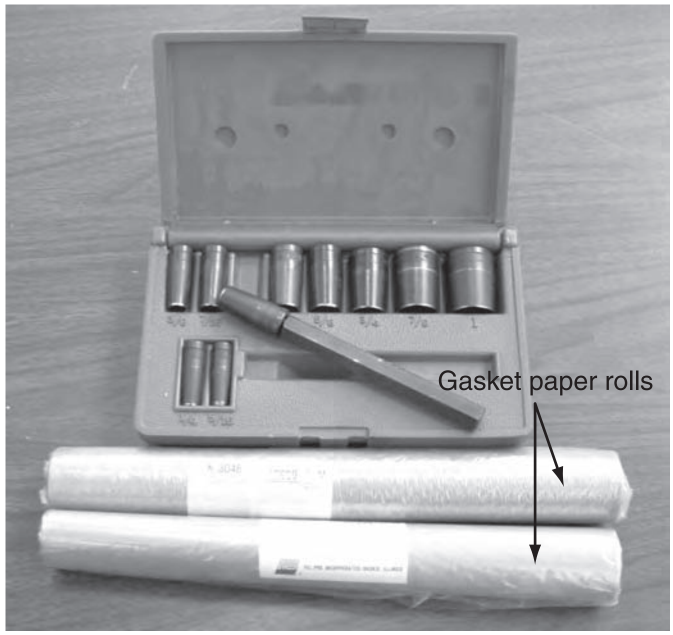


Figure 16.110 A gasket cutting set. (*Courtesy of Tim Gilles*)

during service, however **(Figure 16.111)**. Replacement gaskets are made of perforated steel with asbestos or another material. The manifold expands much more than the head.

- The steel side of the gasket faces toward the manifold.
- Do *not* torque the manifold at the outside ends first; it may crack **(Figure 16.112)**.
- When there is one hole smaller than the others, its bolt goes in first.

NOTE

When a manifold cracks or a manifold bolt breaks, it is not unusual to find a burned exhaust valve in a port close to the exhaust leak. This happens because of the shock of the relatively cold air (from the exhaust leak) on the red hot valve.

Figure 16.111 Various exhaust gaskets. (*Courtesy of Tim Gilles*)

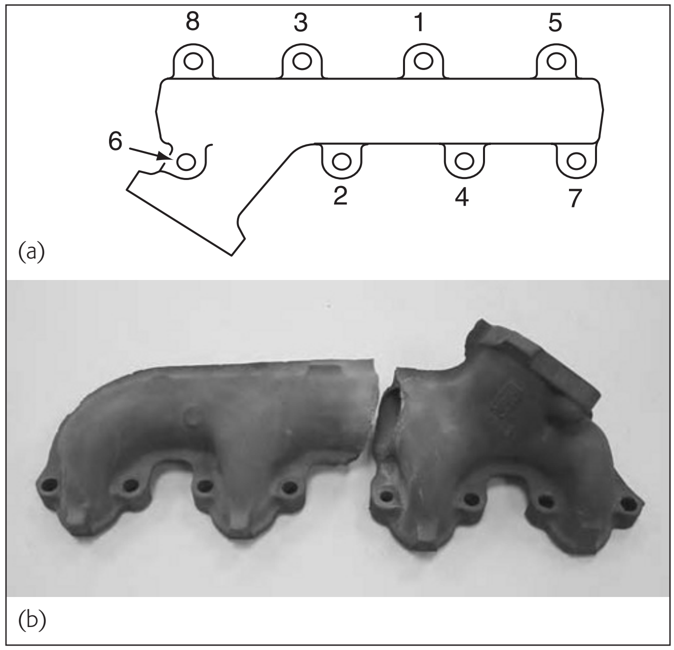


Figure 16.112 Exhaust manifold torque. (a) Exhaust manifold torque sequence. (b) An exhaust manifold that cracked because it was torqued first at the outside ends. (*Courtesy of Tim Gilles*)

Some exhaust manifold gaskets use a heat shield to protect the valve cover gasket from excess exhaust heat rising from the manifold **(Figure 16.113)**.

Sometimes a manifold will warp so badly that after surfacing, the bolts will not all be able to thread into holes in the head. If this happens, drill the bolt holes oversize by $^{1}/_{16}$" and try again.

The bottom of the manifold uses a "donut" O-ring gasket. In the past these were made of readily available and inexpensive asbestos. The trend is toward ceramic O-rings, which are also reusable.

In front-wheel-drive vehicles with transverse engines, acceleration and deceleration forces movement of ±4° (8° total possible) between the manifold and exhaust pipe. The seal for this must be flexible as well as durable. Stainless steel wire mesh or expanded graphite are used for these gaskets, which wear out. When they leak, they must be replaced. Simply loosening and retightening will result in a future failure.

Chemical Gaskets. Silicone and other chemical sealers are sometimes used instead of gaskets. These "formed-in-place" gaskets have been used since the mid-1970s in new cars. Chemical gaskets can be used for everything except the head gasket and fuel system gaskets.

Chemical gaskets are sometimes difficult to use in the repair trade, so aftermarket anaerobic materials are available for these uses.

Anaerobic sealers are used only on precision machine parts. They cure in the absence of air.

GASKET SEALERS

Gasket sealers serve three purposes.

- First, they help gaskets to seal.
- Second, they hold gaskets in place.
- Third, some gasket sealers, as mentioned previously, also take the place of gaskets.

Gasket sealers are usually not necessary. Some major gasket manufacturers suggest that sealers

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When older head gaskets are used with sealer, the sealer should be applied to both sides of the gasket, not to the block and head, where the sealer might get into oil or water passageways. Spray sealers are available for easy application to head gaskets.

Figure 16.113 Some exhaust manifold gaskets have a heat shield to protect the valve cover gasket from exhaust heat. (*Courtesy of Tim Gilles*)

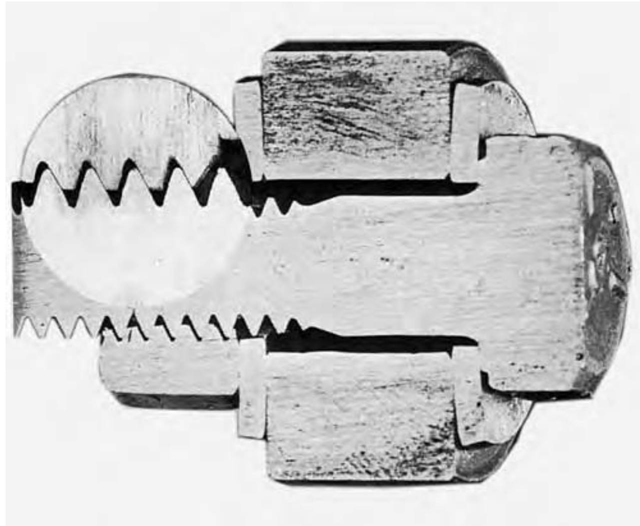


Figure 16.114 Anaerobic sealers. Anaerobic sealers harden in the absence of air. (*Courtesy of Henkel Corporation*)

are necessary only on paper gaskets to hold a gasket in position or to seal core plugs. No sealers should be used on the nonretorque head gaskets.

Neoprene intake manifold end gaskets on V-type engines sometimes "squish" out. Neoprene will usually stay in place if it is completely dry.

Do not use hardening gasket cements as sealers in automotive applications; they are inflexible and can begin to leak after vibration or heating and cooling. A small amount of hardening cement can be used on the corners of some gaskets, simply to hold them in place during assembly. Some technicians use grease to hold gaskets in place for assembly, but the greased parts can shift during assembly. A better choice would be an adhesive or an adhesive sealant. Refer to the chart in the appendix for the specific uses of different sealers.

Locking Thread Sealers

Thread locking compounds, often called Loctite (after one of several manufacturers of these products), are anaerobic. That is, they harden to their maximum strength when tightened between two metals without the presence of air (**Figure 16.114**). Chemical adhesives are not recommended for bolts over $^{3}/_{8}$" in diameter. Some adhesives have very little shear strength and their effectiveness is affected by elevated temperatures. There are several kinds of thread sealers, which are differentiated by their colors.

The blue thread locking compound is used when parts may be disassembled again. It is said that the torque required to fasten parts with the blue sealer will have to be doubled for disassembly. This sealer hardens only when torqued.

Red thread locking compound is used on parts that will not be disassembled again, although applying heat will cause it to fail and loosen if disassembly is required. As with other glues, use only a very small amount. If the surfaces are not clean, or if too much of the product is used, it will not work properly.

NOTE

- **Anaerobic** means that the chemical works only in the absence of air. That is why the container it comes in is not full; if all the air were removed, the sealer would harden. Silicone RTV, an **aerobic** sealer, comes in a full tube because it cures when exposed to air **(Figure 16.115)**.
- Although thread locking compound will not harden in its container, it will harden between the container and its cap. Be sure to wipe off the threads on the container before installing the cap.

Teflon Sealing Products

Threads can be sealed with Teflon tape to prevent liquid leakage. The photo in **Figure 16.116** shows Teflon tape stretched around an oil gallery

Figure 16.115 Anaerobic and aerobic sealers. Aerobic sealers come in a tube to prevent contact with air. Anaerobic sealers have space in the container for air. (*Courtesy of Tim Gilles*)

plug. If the tape unwinds as you attempt to install the fitting, try turning the tape in the opposite direction on the thread.

NOTE

Use caution when Teflon tape is used on a tapered pipe thread. The tape acts as a lubricant and overtightening can result in a cracked casting. Also, apply Teflon tape starting with the second thread to prevent some of it from entering and contaminating the system being sealed.

CAUTION

Teflon tape installed on a sending unit can change its electrical value, resulting in a different signal output.

Liquid Teflon sealants and thread sticks **(Figure 16.117)** are popular alternatives to Teflon thread tape.

Rubber Cement

Rubber cement sealers are very popular and easy to use. Be sure to keep the lid on the can as much as possible, because it will thicken when exposed to air.

Silicone RTV

Two well-machined surfaces make contact with one another on only 25–30% of their surfaces.

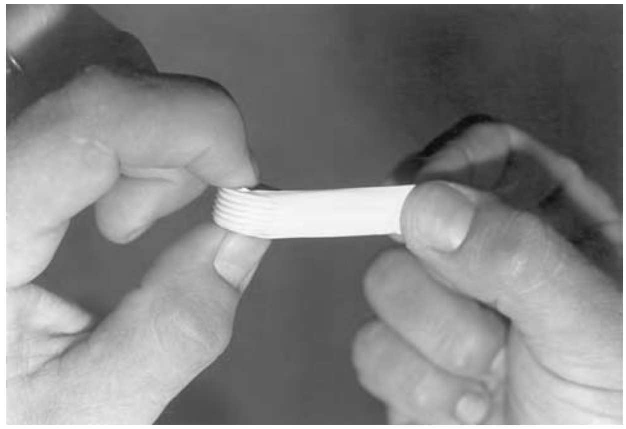


Figure 16.116 Sealing an oil gallery threaded plug with Teflon tape. (*Courtesy of Tim Gilles*)

A chemical gasket seals all of the surface imperfections, ensuring a complete seal. **Room temperature vulcanizing (RTV)** is a popular sealer, commonly known as silicone rubber. Because it cures when exposed to air, silicone is known as an aerobic sealer. It comes in several colors.

RTV silicones are suitable for use between dissimilar metals. They can stretch up to 600% and can work in temperatures ranging from –75°F to +700°F (–59°C to +371°C), and are impervious to engine oil and coolant. Much of the assembly of modern engines is done by robots. With the exception of cylinder head and intake manifold gaskets, many gaskets can be eliminated by substituting a bead of RTV applied by a robot. Because these parts are actually vulcanized together, disassembly can be

Figure 16.117 A thread sealant stick. (*Courtesy of Tim Gilles*)

difficult. Sometimes a sharp knife can be inserted between the parts to cut the bead of RTV. Oil pans and valve covers can be soaked in solvent for an hour or so to help soften the RTV for easier removal. Aftermarket gaskets are available as a replacement for most factory RTV applications.

RTV sets up faster in warm temperatures and high humidity. It usually begins to cure ("skin over") in about 15 minutes but does not set completely for about a day. This is a good feature if a part is forgotten, or parts must be disassembled for any other reason; the gasket will not be ruined.

CAUTION

Silicone should not be used around fuel because it is destroyed by gasoline.

Surfaces must be clean and dry before using RTV or anaerobic sealers. Use a non-petroleum cleaner such as alcohol to avoid leaving an oil film that can prevent the sealer from bonding.

When using RTV sealer in place of a gasket:

- Be sure to apply the bead of sealer to the sheet metal surface on the *inside* of screw holes to prevent leakage.
- Put the sealer in place and finger-tighten the fasteners.
- Give the material a chance to vulcanize so that it will not squish out.
- After it sets, the screws can be tightened further.

If the gasket film is too thin, heat and motion can cause leakage. For that reason, grooves and stopper devices are installed to ensure a thick enough gasket (0.020"–0.060" minimum).

NOTE

Excessive RTV can squeeze out and get into the oil, where it can clog the oil pump pickup screen and ruin the engine **(Figure 16.118)**.

Some pans that are used with liquid silicone have a raised bump on the gasket surface that prevents overtightening. Some oil pans can expand in use up to 0.100". There are dimples on these oil pans that make room for an RTV thickness substantial enough to compensate for expansion and contraction of the joint. When using RTV, parts must be assembled before the sealant "skins over" or the RTV will not vulcanize to the part and a leak can occur.

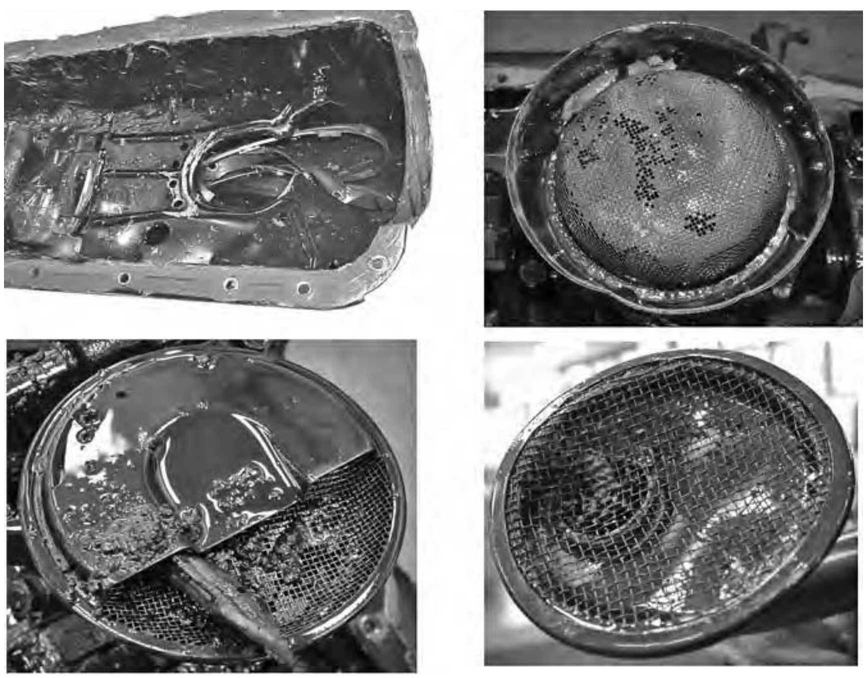
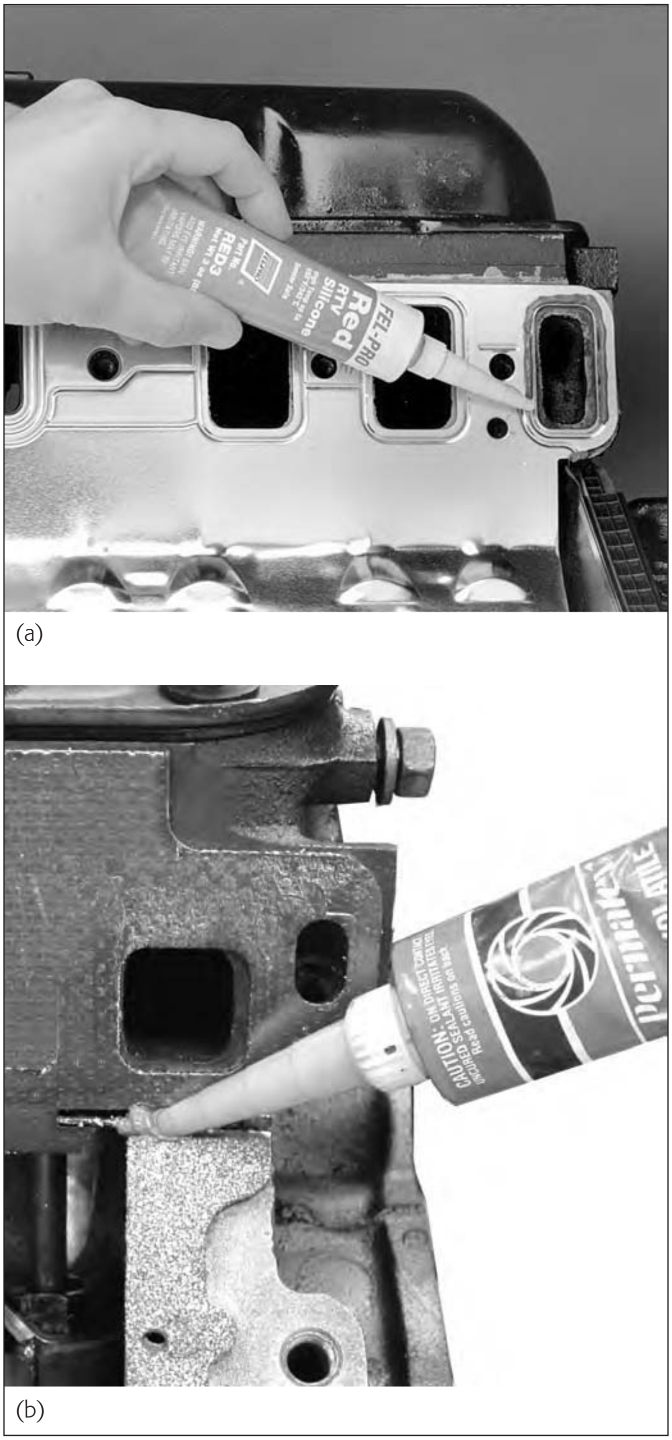


Figure 16.118 Examples of excess silicone use. Each instance resulted in serious engine damage. (*Courtesy of Tim Gilles*)

Silicone is recommended for use where gaskets join, and for sealing water passages in intake manifolds **(Figure 16.119)**. Most manufacturers of aftermarket aluminum intake manifolds for V-type engines recommend discarding the end seals and using RTV in their place.



(a)

(b)

Figure 16.119 (a) Sealing a V-type intake manifold water passage. (*Courtesy of Federal-Mogul Corporation*) (b) Using RTV to seal where gaskets join. (*Courtesy of Tim Gilles*)

NOTE

RTV will not vulcanize or bond to a gasket, so its use as a gasket *sealer* is not recommended.

Many new engines use preformed one-piece silicone gaskets that have steel washers around the bolt holes to prevent overtightening.

Low-Volatile RTV. The acetic acid in household silicone gives it the smell of vinegar as it sets up. General Motors has reported that acetic acid, which gives off formaldehyde fumes as it sets up, was responsible for coating the oxygen sensors of its computer-controlled fuel system. Low-volatile RTV has been developed by substituting an alcohol-related chemical for acetic acid. Be sure to use a low-volatile silicone on vehicles equipped with oxygen sensors. Low-volatile silicones take somewhat longer to cure than regular silicones.

High-Temperature RTV. Adding iron oxides to RTV can increase its temperature rating by 50–100°F (10–38°C). This silicone is red in color. Because silicone is not used in high-temperature areas of the engine, it may not be worth the extra cost to buy high-temperature RTV.

SEALS

Seals are generally made of butyl rubber or neoprene; they are known as dynamic seals because they seal moving parts. (Gaskets are static seals, because they seal nonmoving parts.) Dynamic seals, also called chevron seals, are used at the front and the rear of the crankcase.

Neoprene seals should always be lubricated during installation. This is to prevent damage due to overheating during initial startup of the engine. Sometimes seals fail due to some types of synthetic oil or methanol fuel additives.

Front Seals

Front seals are usually lip-type seals with a garter spring **(Figure 16.120)**.

NOTE

The seal lip, or open side of the seal, faces toward the oil.

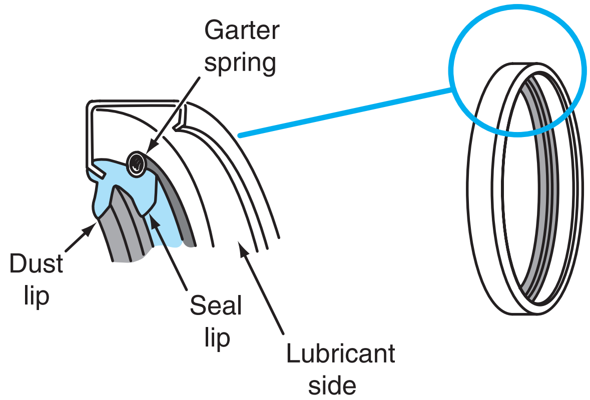


Figure 16.120 The lip of the seal faces the oil.

When a seal is exposed to outside air and dust, such as at the ends of the oil pan, it also has a dust lip which deflects dirt from the outside of the seal. The front seal is installed in the timing cover and seals against the hub on the vibration damper. The accumulation of dirt and the friction of the seal against the vibration damper hub sometimes cause wear. A *harmonic balancer repair sleeve* kit will repair a worn damper hub at minimal cost. A very thin stainless steel ring **(Figure 16.121a)** is pressed over the worn surface of the damper **(Figure 16.121b)** using a small amount of red thread locking compound. The new sealing surface is only slightly larger than the original so the new seal conforms to it.

Some replacement seals are designed so that the lip of the seal will meet the damper hub at a different place than the original seal **(Figure 16.122)**.

Front seals can be replaced with the timing cover on or off the engine. With the cover off the engine, the seal can be removed with a seal puller **(Figure 16.123)**. On a sheet metal timing cover, be careful not to ruin the timing cover by prying on the lip that the seal seats against **(Figure 16.124)**. Pound the new seal into place **(Figure 16.125)**. A seal can also be removed and installed without removing the timing cover.

Rear Main Seals

The crankshaft rear seal is called the rear main seal because it is located behind the rear main bearing. A leaking rear seal can ruin a clutch disk.

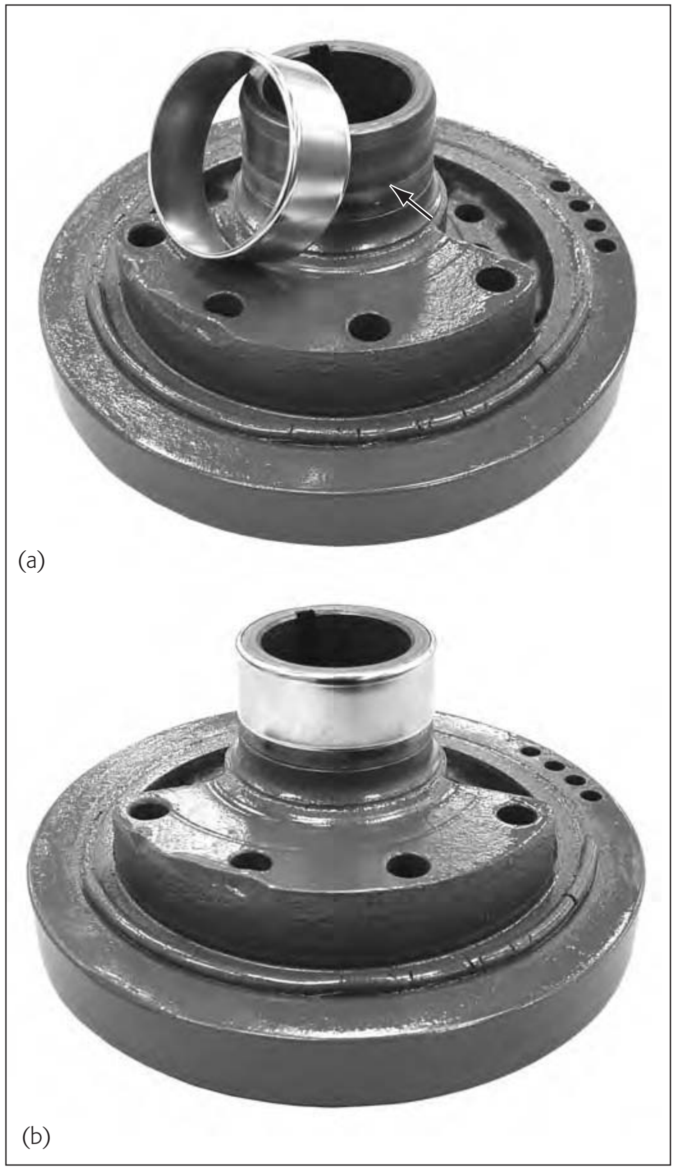


Figure 16.121 (a) This damper has a groove worn in its hub. (b) The sleeve installed on the damper hub. (*Courtesy of Tim Gilles*)

NOTE

Rear main seals are sometimes needlessly replaced when an intake manifold, valve cover, or oil pan gasket is the true source of the leak.

There are two types of rear seals: the neoprene lip seal and the rope seal.

Neoprene Rear Seal. Newer vehicles use a neoprene lip seal. Some of these are split in half, and others are a single piece. The split seal should be installed with its parting line offset, as in **Figure 16.126**, and with its lip facing toward the oil.

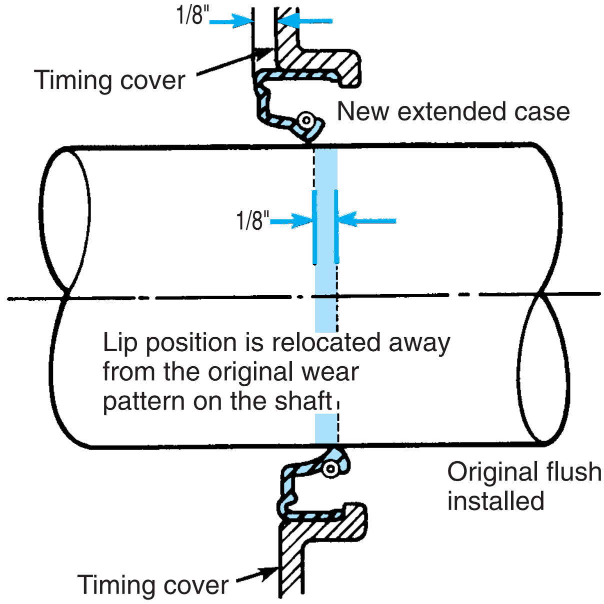


Figure 16.122 A seal with a relocated lip.

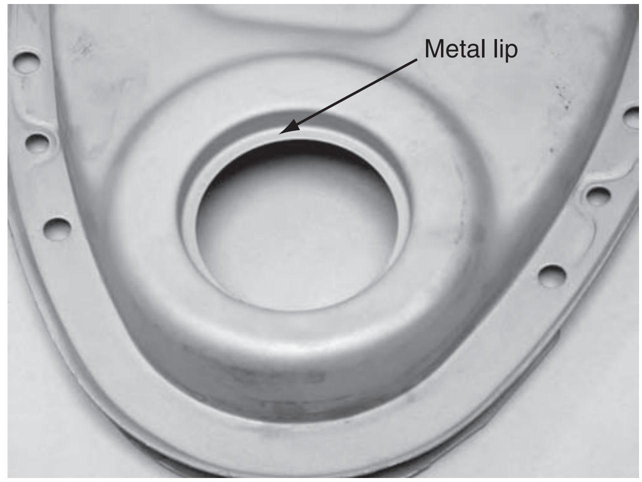


Figure 16.124 With the seal removed, you can see the metal lip in the timing cover. (*Courtesy of Tim Gilles*)

NOTE

Be sure to lubricate neoprene seals with grease during assembly. When the engine is started for the first time after a rebuild, there is a short interval before the seal gets any oil; greasing the seal will protect it from failure during this interval.

Prior to installing a crankshaft seal, be certain that the crankshaft rear sealing surface is clean and smooth **(Figure 16.127)**.

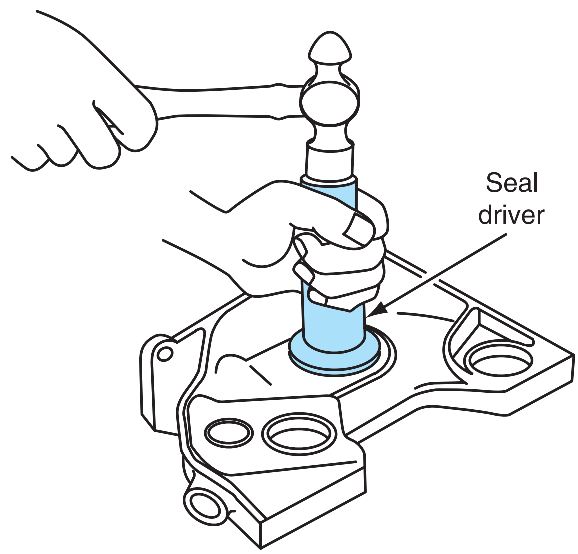


Figure 16.125 Pound or press the new seal into place.

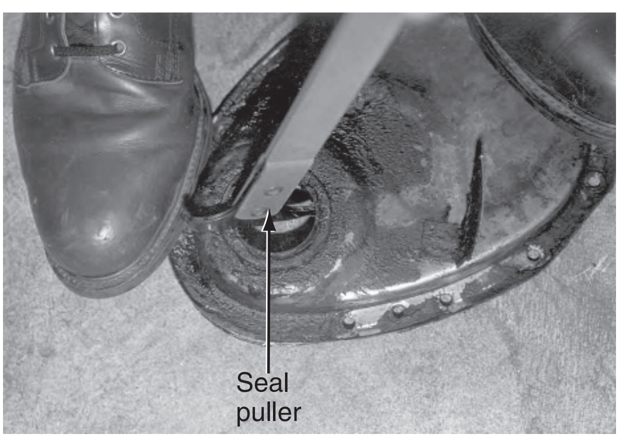


Figure 16.123 Removing a timing-cover seal. (*Courtesy of Tim Gilles*)

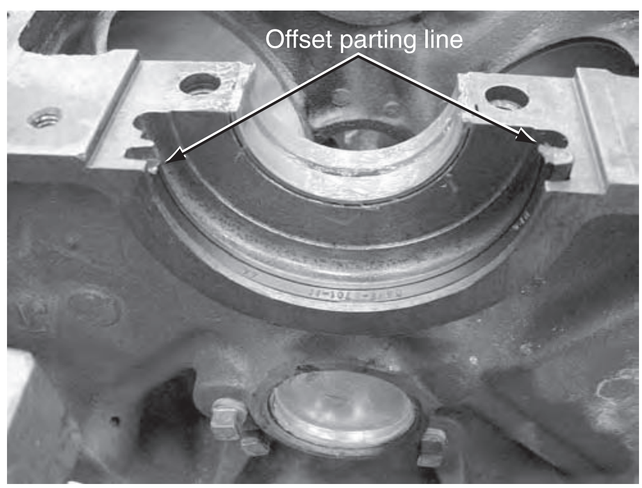


Figure 16.126 Rear seal installation. Offset the parting lines and face the seal lip toward the oil. (*Courtesy of Tim Gilles*)

Figure 16.127 Before installing the rear seal and crankshaft, be certain that the crankshaft surface is clean and smooth. Do not use abrasive material. Only use extremely fine sandpaper or crocus cloth. (*Courtesy of Tim Gilles*)

When a seal surface is worn or grooved the shaft can be ground slightly undersize. Lip seals have varying amounts of interference. Some can accommodate a smaller shaft than others. Most seals have from 0.012" to 0.030" interference.

Polished stainless steel crankshaft repair sleeves are available for repairing grooved rear seal surfaces. One sleeve style is installed over a standard shaft. Because it is very thin, the seal will still be able to work. Another style of sleeve is used with a shaft that has been ground undersize on the sealing surface. Besides the fact that the original size is maintained, the groove is removed ensuring proper heat transfer between the seal, the repair sleeve and the crankshaft.

Some seal leaks can result after crankshafts have been shot-peened without the sealing surfaces being adequately protected from the shot.

NOTE

Most rear seal leaks are caused by the buildup of excessive pressure in the crankcase. Without crankcase pressure, oil is not directly applied to the seals.

Single-piece neoprene seals are popular in newer vehicles. Manufacturers can reduce engine weight and length by not having a separate flywheel flange at the rear of the crankshaft.

Full round rear main seals on some engines are installed in a small casting bolted to the rear of the block with a gasket underneath it **(Figure 16.128)**. When removing the seal, be sure the casting remains fastened to the block to avoid cracking it **(Figure 16.129)**. One trick for removing a difficult single-piece seal is to screw a pair of sheet metal screws into the seal **(Figure 16.130)**.

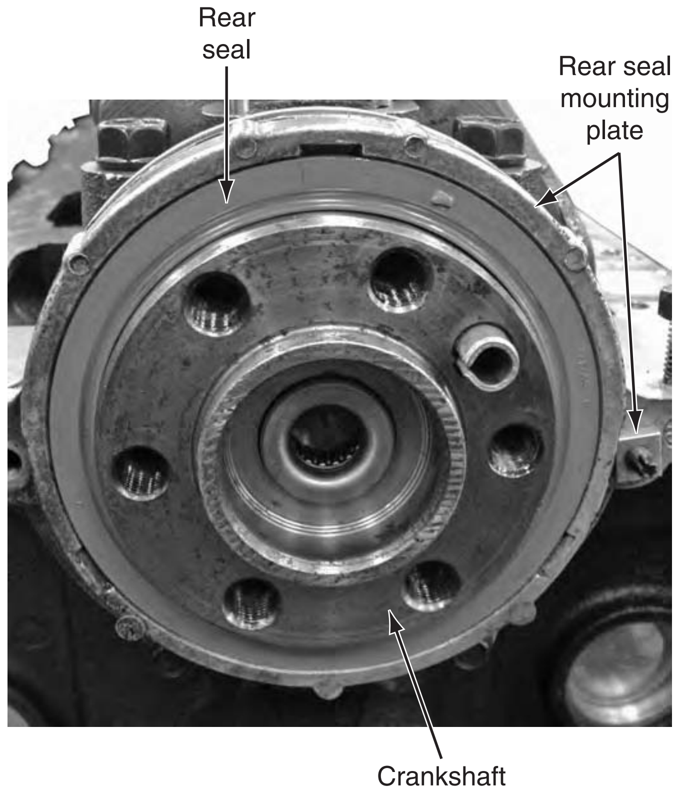


Figure 16.128 Some full round rear seals are located within a bolt-on casting. (*Courtesy of Tim Gilles*)

NOTE

Care must be taken that flywheel bolts are carefully torqued, or the crankcase rear main seal surface can become distorted, causing a leak.

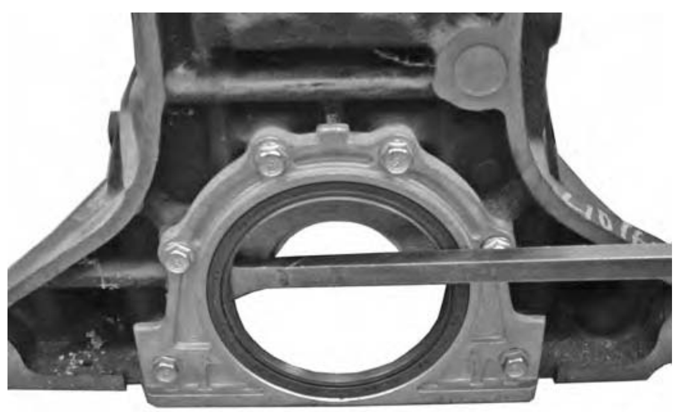


Figure 16.129 When prying a seal out of a cast housing, be sure the housing remains bolted to the block to avoid breaking it. (*Courtesy of Tim Gilles*)

CASE HISTORY

A technician replaced a clutch on an engine with a single-piece rear main seal. When he installed the flywheel, he used an impact wrench. The customer returned later with a rear main bearing seal leak because the crankshaft sealing surface was distorted by the uneven torque.

Flywheel bolts on some of these engines protrude into the crankcase **(Figure 16.131)**. Sealer must be applied to them to prevent oil leakage from the interior of the oil pan to the clutch surface.

Teflon Seals

A Teflon rear seal has a stiff lip that is effective in holding high crankcase vacuum. A Teflon seal is installed dry to allow it to "burn in." When the Teflon heats during initial startup, it conforms to the shaft and provides a long-lasting seal. During burn

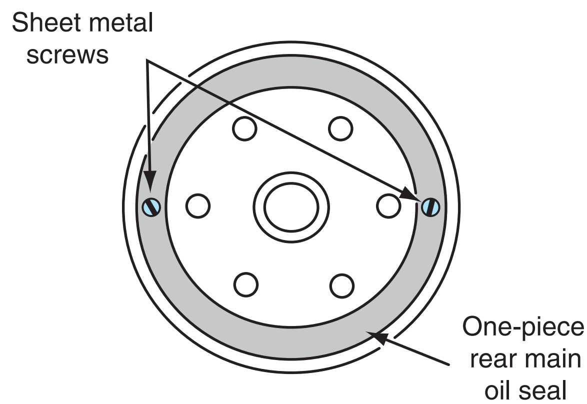


Figure 16.130 A one-piece seal can be removed by screwing sheet metal screws into it and pulling on the screws.

in, Teflon is transferred to the crankshaft journal, which subsequently rides on the Teflon layer. During warranty repairs for rear main seal oil leaks, some manufacturers use Teflon rear main oil seals.

Some rear main bearing caps have sealer or seals on the side (Figure 16.133) between the rear main cap and the block. Seals can be difficult to install. Instead, some machinists use $^1/_4$" wooden dowels with sealer.

VINTAGE ENGINES

Rope Seals

Almost all earlier engines used another type of rear seal, called the rope, or wick, seal. These seals are inexpensive, but their installation is more time-consuming than a lip seal. A conversion from a rope to a lip seal is often possible and is recommended when available.

When a rope seal is used, the crankshaft is knurled on the rear sealing surface to help return oil to the crankcase. The rope seal should not be used if there is no knurl on the crank. Fel-Pro recommends that rope seals *not* be soaked in oil before installation. Soaking the wick can cause it to disintegrate, and some of the seal's graphite impregnation might be lost. When installing a rope seal, it is easiest to shape the seal in the channel in the block, and then remove it and install it in the channel in the main cap **(Figure 16.132a)**. Then pound it into place with a special tool or a very large socket and use a sharp, razor blade type of knife to trim the seal flush with the block **(Figure 16.132b)**. *Lightly* lubricate the seal with chassis grease to avoid damage from a dry startup. When a rope seal is installed too tightly, heat can cause the rear main bearing to seize. The seizure will occur on the rear part of the bearing.

Some rope seals have a sharp pin in the main cap to keep them from turning. This pin must be knocked out with a punch if a lip seal is to be used. Also, some Buicks use a rope *front* crankshaft seal, which can be replaced with an aftermarket lip seal.

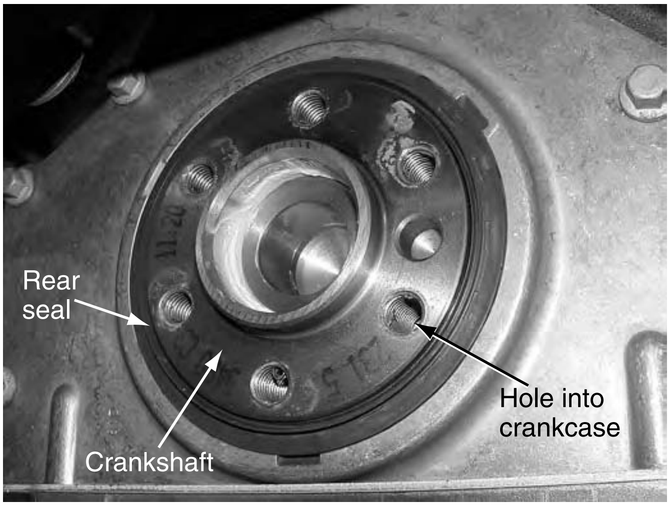
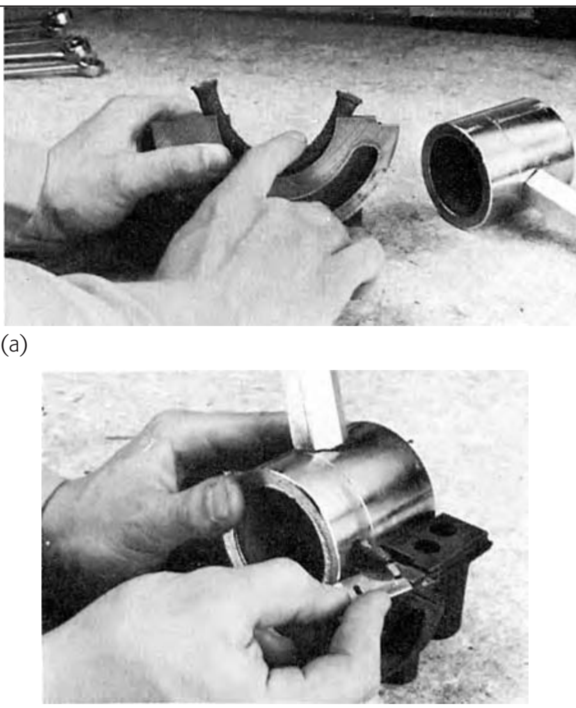


Figure 16.131 Oil can leak through the flywheel bolt holes from the crankcase onto the clutch. (*Courtesy of Tim Gilles*)



(a)

(b)

Figure 16.132 Vintage rope rear seal installation. (a) Install the seal in its groove. (b) Trim the seal. (*Courtesy of Federal-Mogul Corporation*)

Transmission Front Pump Seal

Another seal that is of interest to an engine technician is the front transmission seal. This seal keeps transmission oil from leaking out between the torque converter and transmission oil pump. It is a good practice to replace the seal when the engine is out of the car for an overhaul. It suffers the abuse of severe heat and often becomes brittle with age. When an engine is removed from a vehicle, the torque converter is often left hanging on the transmission, which can distort or crack the brittle seal.

Figure 16.133 Some blocks use seals or sealer between the sides of the main cap and the block. (*Courtesy of Tim Gilles*)

CASE HISTORY

A technician installed a rebuilt long block in a car with an automatic transmission. The original engine was removed and sent to a local machine shop for a custom rebuild. While the engine was being rebuilt, the torque converter was left hanging in the transmission, unsupported at the front. After the engine was reinstalled in the vehicle, the transmission seal began to leak. This condition is difficult to explain to an upset customer.

Replacing an Automatic Transmission Front Seal. To replace the seal, first remove the torque converter. Then remove the old seal using a seal puller or chisel **(Figure 16.134a)**. Do not attempt to install the seal without a seal driver. The seal can be easily distorted and if it leaks following installation, replacing it is a time-consuming job. Position the new seal on the seal driver **(Figure 16.134b)** and pound it into the transmission pump (**Figure 16.134c**)

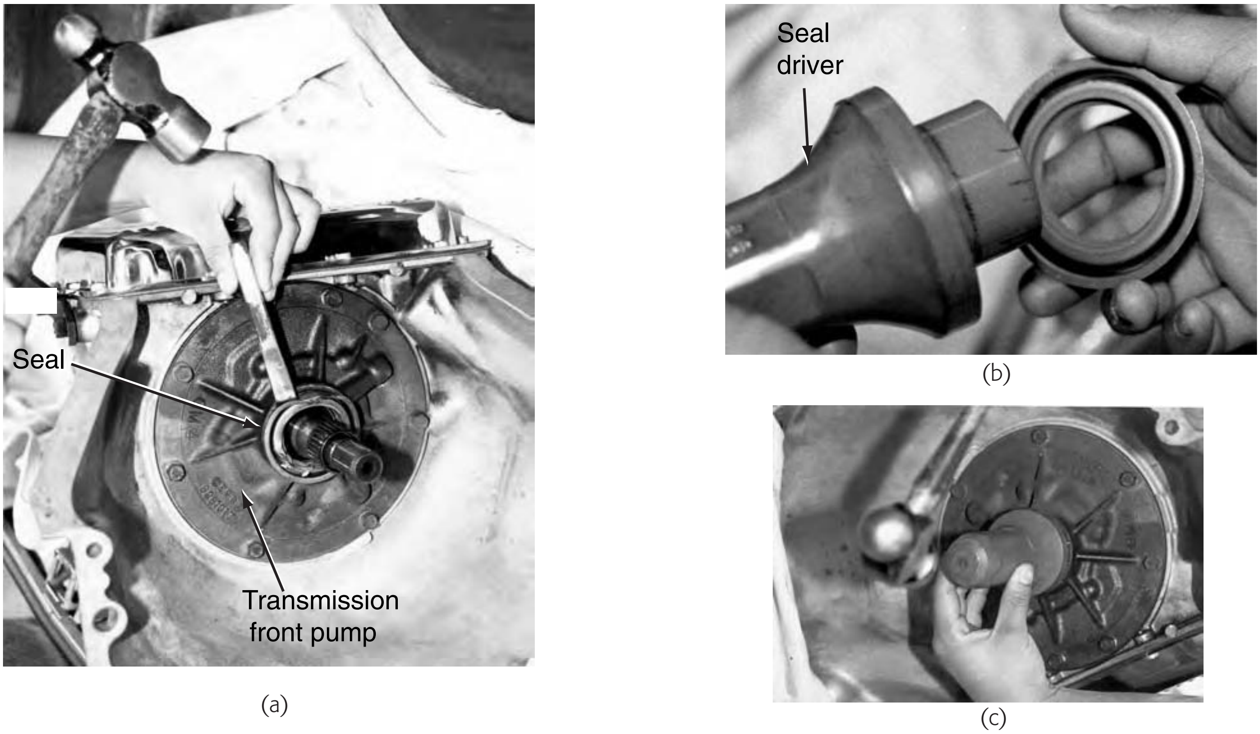


Figure 16.134 Removing and installing a transmission pump seal. (a) Remove the pump seal. (b) Install a new seal on the seal driver; grease the seal lip. (c) Pound the new seal into place. (*Courtesy of Tim Gilles*)

Key Terms

aerobic
anaerobic
clamping force
electrical discharge machine (EDM)
elastic limit
flare
flare nut
hydrostatic lock
room temperature vulcanizing (RTV)
tap drill
yield point

Study Questions

1. Name four types of taps.
2. Refer to a tap drill size chart. What is the correct tap drill for a $^{1}/_{4} \times 20$ screw thread?
3. Why is a tap turned backward after turning forward when cutting a thread?
4. To what percent of its elastic limit is a bolt usually torqued?
5. If a nut turns easily for a few threads on a bolt and then begins to turn hard, what could be the problem?
6. What is one of the trade names for a replacement thread insert?

7. Name one place where pipe threads are found in an engine.
8. What is the name of the machine shop process that erodes a broken fastener without damaging the screw thread?
9. Refer to a bolt torque chart. What is the proper torque for a grade 5, $^3/_8$" bolt with SAE 10 lubricant?
10. The lip of an oil seal faces _____ from the oil.
    a. toward
    b. away
11. When installing half of a rear main lip seal in a block, the parting line is positioned _____ with the parting line of the main cap.
    a. offset
    b. even
12. What color is the locking sealer used to glue parts that will not be disassembled again?
13. What does RTV stand for?
14. Silicone sealant that does not use acetic acid to cure and is used with oxygen sensor systems is called low _____ RTV.
15. Before putting a click-type torque wrench aside after using it, what should be done?

ASE-Style Review Questions

1. Technician A says that drill sizes are classified by letters. Technician B says that drill sizes are classified by numbers. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that the 20 in $^1/_4 \times 20$ signifies the total number of threads the fastener has. Technician B says that the $^1/_4$ signifies the socket size of the fastener head. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that a hole can be drilled in cast iron using no lubricant. Technician B says that a hole can be drilled in aluminum without the use of a lubricant. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that using a thread lubricant results in more bolt stretch. Technician B says that a grade 8 bolt has eight radial lines on its head. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that a nonhardened nut loses clamping ability each time it is retorqued. Technician B says that a high grade capscrew loses clamping ability each time it is retorqued to specification. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that head gaskets have small metering holes to direct coolant flow. Technician B says that occasionally one manufacturer's

engine might use different head gaskets for different model years. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

7. Technician A says that nonretorque head gaskets do not compress, so they maintain all of the original clamping force. Technician B says that a microinch is one millionth of an inch. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

8. Technician A says that sealers are used with all gaskets but paper ones. Technician B says that a broken exhaust manifold bolt can result in a burned exhaust valve. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

9. Technician A says that blue anaerobic thread locking compound is used when parts might be disassembled again. Technician B says that using some types of RTV for engine sealing can damage an oxygen sensor. Who is right?

a. Technician A only
b. Technician B only
c. Both A and B
d. Neither A nor B

10. The torque specification for a valve cover gasket is 5 foot-pounds. Which of the following is the best procedure?

a. Use a $^1/_2$" drive foot-pound torque wrench and torque to 5 foot-pounds.
b. Use a $^3/_8$" drive foot-pound torque wrench and torque to 5 foot-pounds.
c. Use an inch-pound torque wrench and torque to 5 foot-pounds.
d. Use an inch-pound torque wrench and torque to 60 inch-pounds.

CHAPTER 17

Reassembly and Starting

Contents

Objectives

Upon completion of this chapter, you should be able to:

- Reassemble an engine in a proper and organized manner.
- Install an engine in a vehicle.
- Prelube and make all required adjustments prior to starting an engine.
- Inspect and complete the job following engine starting and break-In.

Introduction

The intent of this chapter is to fine-tune your art of engine assembly. It is assumed that you have carefully read the rest of the text prior to reading this chapter, so you will know and understand many of the items referred to here. Be sure to refer to chapters that are highlighted, if you do not remember the material.

Remember:

The job will take much less time if you go slow now than if you try to hurry your work and suffer an engine failure. Mistakes in heavy line repair can be very costly to correct.

NOTE

In over 35 years of teaching automotive engine rebuilding, I have overseen countless engine projects. The one thing I cannot stress enough is the importance of cleanliness and organization. This is not difficult, but it is very important. A small error can result in a very costly and stressful result.

Before beginning engine assembly:

- Look through the service information for special instructions.
- Have all tightening specifications handy.
- Be sure all parts are thoroughly cleaned and reconditioned (**Figure 17.1**).
- Obtain all replacement parts.

Technicians often like to assemble their own engines because they can be certain that the engine is clean. Once an engine is assembled, the only way

FIGURE 17.1 Parts of an entire engine, cleaned, machined, and ready for assembly. *(Courtesy of Tim Gilles)*

for dirt to get in is past the air cleaner or accompanying oil or fuel. Cleanliness during assembly is a must! Another consideration is that assembly line rebuilt engines sometimes use cores that are not as easily rebuildable in the future. They may have crankshafts that are 0.030" undersize and pistons and blocks that are 0.060" oversize. On a custom rebuild of a core, a first time overhaul would usually result in a 0.010" undersize crank and 0.030" or 0.040" oversize pistons and cylinders.

WARRANTY

Some rebuilt engines have warranties lasting as little as 90 days or 4000 miles. A longer guarantee usually means a higher cost. When a rebuilt engine fails under warranty, some rebuilders reimburse for repairs using the listed flat rate for the repair. The percentage of flat rate paid is usually such that the installation shop will not make a profit on the warranty repair, but the technician will be compensated.

Proper diagnosis is very important here. If a problem causing the concern is not the fault of the rebuilder, under the terms of the warranty the rebuilder is not liable for the cost of the repair. A fuel system problem or engine overheating are factors that would result in a voided warranty. A piston can burn or seize in the cylinder due to an intake manifold air leak or another fuel system problem resulting in too lean an air-fuel mixture.

Temperature Indicating Tabs

When an engine fails because it was overheated, a coolant temperature sensor or the fan relay could be defective. Many rebuilders install temperature-indicating tabs or strips (see Figure 15.45a) to indicate whether an engine has been run at a temperature that would damage the engine and void the warranty.

A needlessly replaced long block can be a very costly expense to the installation shop. Quality diagnosis before removing the engine can save many unneeded hours in replacing a second engine.

Hoses and Cooling System Parts

All fuel and cooling system hoses must be replaced if they are not in like-new condition. This cost needs to be included in the customer's preliminary estimate. If the customer does not agree to this, the shop cannot guarantee the job. Be certain that the coolant pump and radiator are in like-new condition. If a careful and methodical engine reassembly is not done, all your work will be wasted.

REASSEMBLY

Before beginning reassembly, inspect and count all new parts to be certain that too many parts have not accidentally been included in a parts kit. For instance, if there were too many oil gallery plugs or compression rings in a set, the extra one might appear to be left over. It will be frustrating to have to disassemble the engine just to see if a part had been forgotten.

After the block has been thoroughly cleaned and the cam bearings and core plugs are installed as described in Chapter 11, you can begin to reassemble the engine. All threaded holes should have been chased with a tap. Before installing bolts, retap any threads that appear to have been overlooked.

- A fastener should turn into a hole with finger pressure only. If it does not, something is wrong. *Never force threads together with hand tools or an impact wrench.*
- Finger-start all bolts that fasten a particular part before you tighten any of them. This will allow a part to be shifted around so that the threads of all the bolts can be started more easily (**Figure 17.2**).

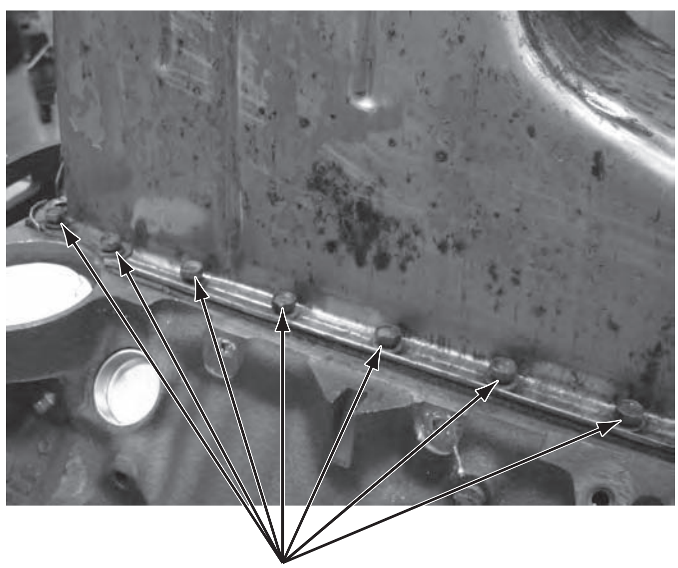


FIGURE 17.2 Leave all screws loose until each screw has been threaded into its hole. This allows the oil pan to be repositioned until all holes line up. (*Courtesy of Tim Gilles*)

- After an engine has been fully assembled, the only way for dirt to enter is if it gets past the air cleaner; cleanliness during assembly is a must. If work is stopped at any time during engine reassembly, the engine should be covered completely with a large trash bag to keep dirt out (**Figure 17.3**).
- Bolts or studs that are threaded into aluminum should be coated with antiseize compound to prevent the aluminum from oxidizing to the bolt (see Chapter 16).

Assembly Lubricants

During assembly, apply a generous amount of lubricant to all possible wear areas.

SHOP TIP

If it moves, lube it!

Assembly lubricants are used on high-load parts such as cam lobes on cam-in-block engines (**Figure 17.4**). There are assembly products that have low melting temperatures and are soluble in oil. An assembly lube with the consistency of grease at room temperature is desirable in case the engine is left sitting for a long period before it is installed in a vehicle. More information on assembly lubricants is included later in this chapter.

FIGURE 17.3 Cover the engine with a large plastic bag to keep out dirt. (*Courtesy of Tim Gilles*)

NOTE

During engine assembly, do not underestimate the importance of using substantial amounts of a suitable lubricant. After an engine has run for several minutes, the lubricant will be well distributed. However, during those first few minutes of engine operation (or attempted operation) before oil has been distributed and splashed on all of the engine surfaces, engine wear and damage can result.

Installing the Camshaft

Install the cam and make sure it turns easily in the newly installed bearings. Be careful not to nick a lobe or bearing.

SHOP TIP

- The sprocket can be installed and used as a temporary handle to turn the cam during installation.
- If the block is not installed on the engine stand, it can be stood on end to make cam installation easier on a push-rod engine.

After installing the camshaft, *check to see that it can be turned by hand.* Remove the cam and inspect the cam bearings for high spots. High spots can be removed as described in Chapter 11. If a bearing shows a 360° shiny spot, the cam is warped. A warped cam can be straightened. If the cam is not warped, be sure to find the cause of the problem. Bearings that are too tight can result in a "spun" (burned) cam bearing.

VINTAGE ENGINES

If the engine uses mushroom style lifters, they must be installed before installing the camshaft.

FIGURE 17.4 A special assembly lube is used on vintage flat tappet cam lobes. (*Courtesy of Tim Gilles*)

CASE HISTORY

An apprentice was installing camshaft bearings in an in-line six cylinder engine mounted on a universal engine stand. After all of the bearings were installed, he attempted to install the camshaft in the block. It would not go in and light was visible between part of the journal and the bearing. The apprentice checked with the machinist, who suggested removing the block from the engine stand and resting it on a workbench. After this was done, the camshaft went easily into the block. On the engine stand, the block had been sagging under its own weight.

When a heavy engine block is mounted on a universal engine stand, sometimes a camshaft cannot be installed or will not rotate easily in the new cam bearings. Remove the camshaft and check it against a flat surface to see if it is warped. If it is straight, move the block from the engine stand to a workbench and try to turn the cam again. You will be amazed to find that this often corrects the problem.

Crankshaft Installation

Several items need to be observed when preparing a crankshaft for installation, including sprocket installation and oil gallery and rear seal surface cleaning.

Woodruff Key Installation. Check the woodruff key to see that it is perfectly flat in its crankshaft groove. An incorrectly installed woodruff key can result in a cracked sprocket (**Figure 17.5**).

Crankshaft Sprocket Installation. Some crankshaft sprockets are either pressed-fit on the crankshaft snout and or slide easily into place. When the crankshaft sprocket is pressed-fit, remove the old one and install the new one

VINTAGE ENGINES

Before cam-in-block engines had roller lifters, they had flat tappets. These engines require more of an extreme pressure oil additive. Lubricate the lifters and the cam lobes (see Figure 17.4) with a special assembly lubricant used with high load parts. Molybdenum disulfide and graphite are two such assembly lubes also used in some greases and gear lubes. They should be used only between the cam lobes and lifters and should *not* be used on engine bearing surfaces. This is because the melting temperature of these lubricants is higher than the melting temperature of the engine's bearing materials.

FIGURE 17.5 Careless installation of the crank sprocket can ruin it.

FIGURE 17.6 Installing a pressed-fit crankshaft sprocket is best done before installing the crankshaft in the block. (*Courtesy of Tim Gilles*)

before installing the crankshaft in the block (**Figure 17.6**). This will prevent stress to the thrust main bearing surface when you pound the sprocket into place after the crankshaft has been installed. When the crankshaft is already in the block, pressed-fit sprocket installation is easier if the sprocket has been preheated.

The sprocket must be installed with the timing mark facing outward. The inside edge of the sprocket has a chamfer that corresponds to the fillet on the crank; if the sprocket is installed in the wrong direction, it cannot be installed all the way (**Figure 17.7**). **Figure 17.8a** and **Figure 17.8b** show the front and back of a typical crankshaft sprocket.

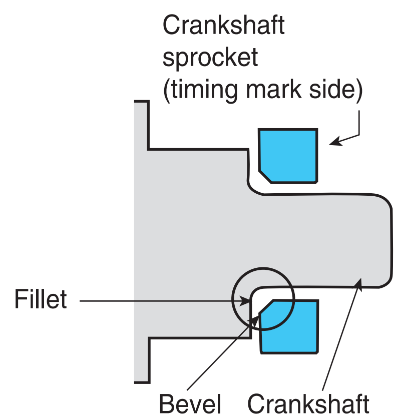


FIGURE 17.7 The inside edge of a crankshaft sprocket is beveled to clear the fillet on the crankshaft.

SHOP TIP

Be sure that all crankshaft oil passageways are clean (**Figure 17.9**). The machinist is not paid to "final" clean the crankshaft after grinding; this is the assembler's responsibility.

Be sure the crankshaft surface that the rear seal rides against is clean (**Figure 17.10**). If it is not, clean it with *very fine* emery cloth (**Figure 17.11**). Use 600-grit or finer, or use crocus cloth. Following this, do not forget to clean and lubricate this surface.

Install the Crankshaft and Bearings

Clean the main bearing bores to prevent oil clearance and heat transfer problems (**Figure 17.12**). Dirt on the surface of the bearing bore can force the bearing closer to the crankshaft, eliminating needed bearing oil clearance.

NOTE

Be especially careful to clean the recesses where the bearing locating lug will fit (**Figure 17.13**). Failure to clean this area thoroughly is often the cause of a tight crankshaft.

NOTE

Excessive bearing clearance is often discovered during an oil clearance check on a newly rebuilt engine. This can be because of dirt on the block or the main bearing parting halves (**Figure 17.14**). It takes only a small film of dirt left from the hot tank, bake oven, or shot peening to increase the oil clearance by 0.001" or more.

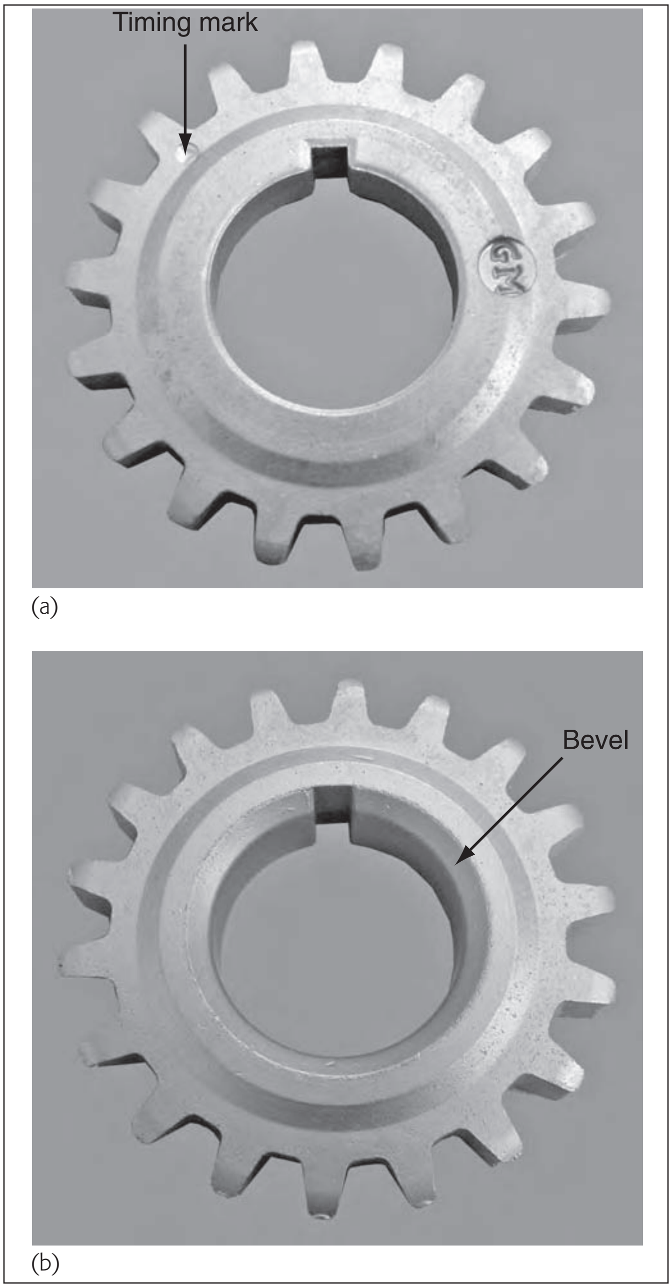


FIGURE 17.8 (a) The outside of a timing sprocket has a timing mark. (b) The inside has a bevel to clear the crank radius. (*Courtesy of Tim Gilles*)

SHOP TIP

Thoroughly clean your hands prior to handling engine bearings. Do not touch the bearing surface with your clean hands. It is a good idea to wear clean latex gloves during engine assembly (**Figure 17.15**). Acids from your skin can etch the soft surface of the bearing. Bearings are the engine's lifeline. Treat them very carefully.

FIGURE 17.9 Be certain that all crankshaft oil holes are clean.

Install the Crankshaft Bearings. Install the upper main bearings by pushing them into the main bearing bores (**Figure 17.16**).

- Be sure that the lubricating holes in the bearings line up with the corresponding oil holes in the block (**Figure 17.17**).
- Lubricate the bearings with assembly lube, but only on the surface that is *toward* the crankshaft (**Figure 17.18**).

NOTE

Do not oil the bearing backs. They are not a bearing surface, and oil impedes necessary heat transfer. Remember: "If it moves, lube it." The back of the bearing does not move.

A few main bearings have dowels or a round raised area that must fit into a hole in the block.

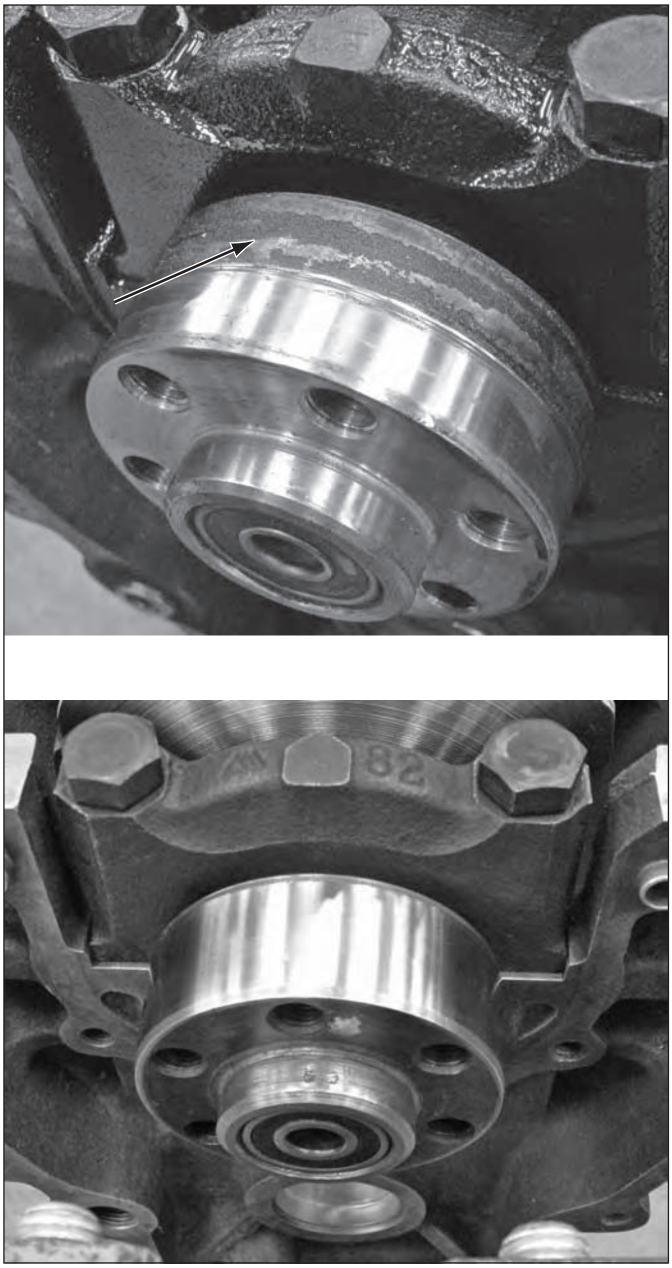


FIGURE 17.10 The top photo shows the condition of the crankshaft during engine disassembly. The lower photo is during engine assembly after crankshaft service. In addition to the polished sealing surface, you can see that the crankshaft was "knife-edged." (*Courtesy of Tim Gilles*)

Figure 17.19 shows a bearing that was torqued while it was misaligned with its hole. The result was that the crankshaft would not turn.

Lubricate Thrust Bearing Surfaces. Lubrication on thrust bearing surfaces (**Figure 17.20**) is critical to engine life. Engine oil does not form a wedge on thrust bearing surfaces like it does on bearing journal surfaces.

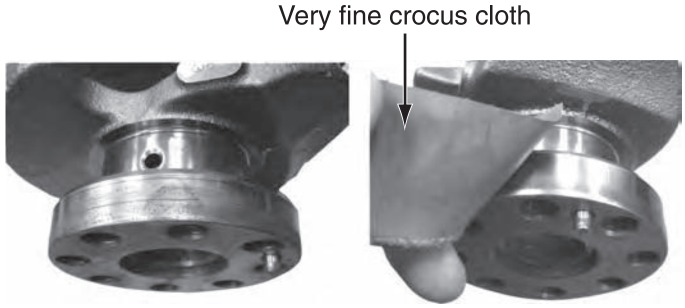


FIGURE 17.11 Clean the crankshaft rear sealing surface. (*Courtesy of Tim Gilles*)

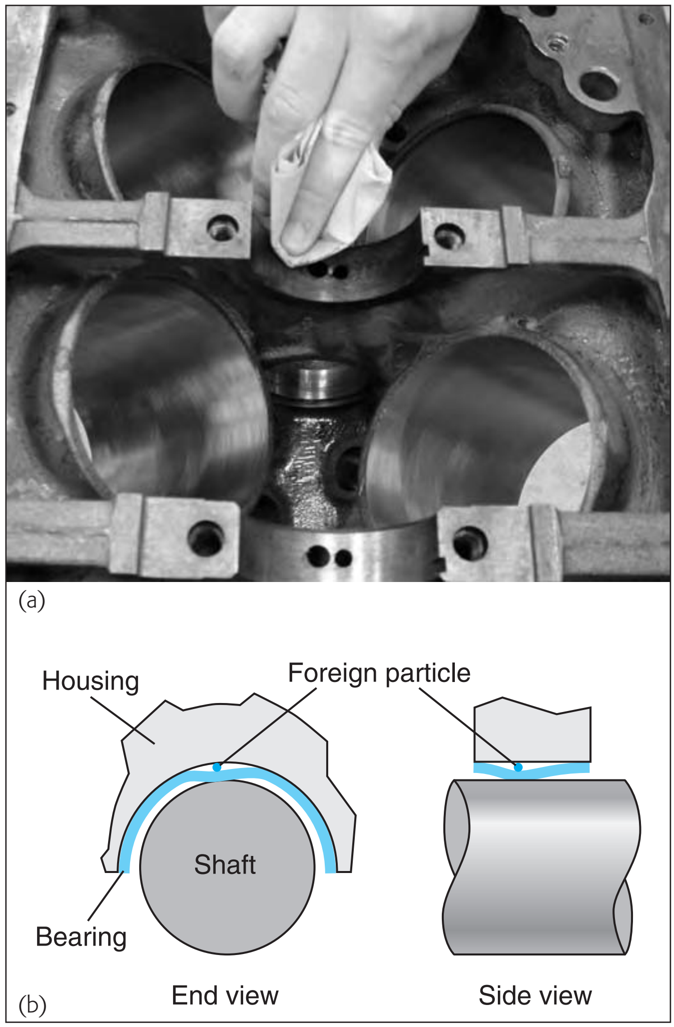


FIGURE 17.12 Clean the main bearing bores. (*Courtesy of Tim Gilles*) (b) Results of careless cleaning.

Install the Crankshaft. If the engine has a half-round rear bearing seal, install it now (see Chapter 16). A full round seal is installed after the crankshaft. Lay the crankshaft in position on the lubricated main bearings and spin it to see that it rotates easily with no main caps installed (**Figure 17.21**).

VINTAGE ENGINES

Vintage engines were produced without numerical controls and had more problems with quality control. Sometimes upper main bearing oil holes did not line up exactly with the oil holes in the block. One manufacturer provided the following recommendation for checking for an adequate oil supply in a V8 block.

"Insert into the oil hole a drill or rod of the following sizes:"

Main # 1 $= \frac{7}{64}''$	Main # 3, 5 $= \frac{9}{32}''$
Main # 2 $= \frac{9}{64}''$	Main # 4 $= \frac{5}{32}''$

FIGURE 17.13 Clean the locating lug notch. (*Courtesy of Tim Gilles*)

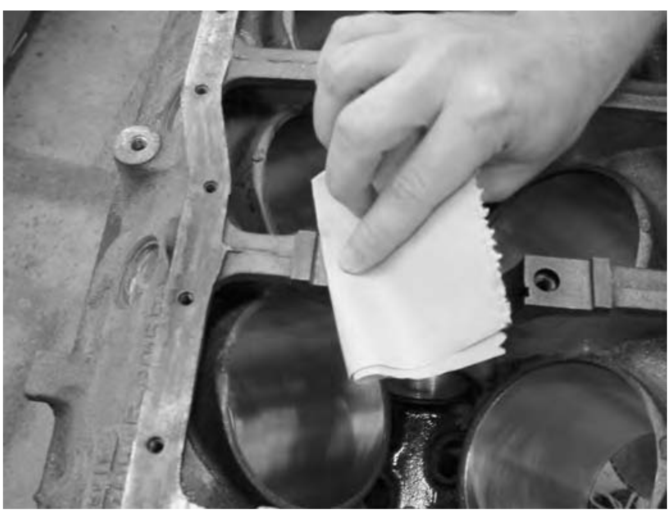


FIGURE 17.14 Clean the parting surface between the block and main cap thoroughly. (*Courtesy of Tim Gilles*)

FIGURE 17.15 Wearing gloves during engine assembly will prevent acids from your skin from etching the bearings. (*Courtesy of Tim Gilles*)

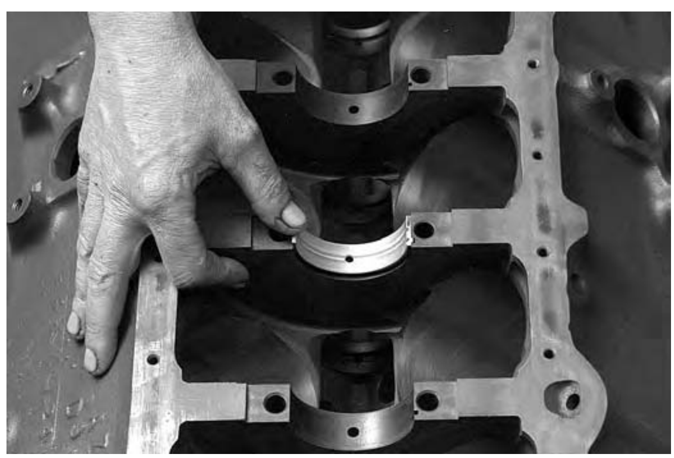


FIGURE 17.16 Snap the bearing into place. (*Courtesy of Tim Gilles*)

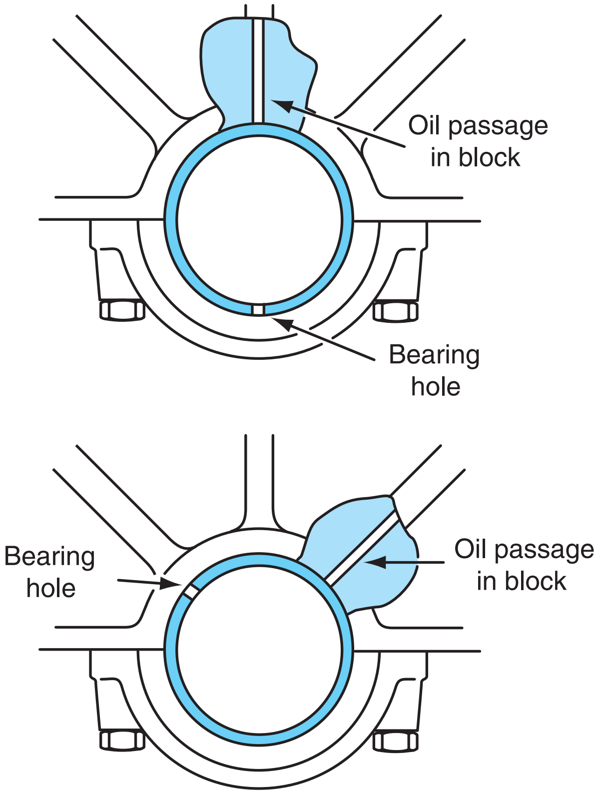


FIGURE 17.17 Installing the main bearings in the wrong positions can block the passage of oil to the crankshaft bearing journal.

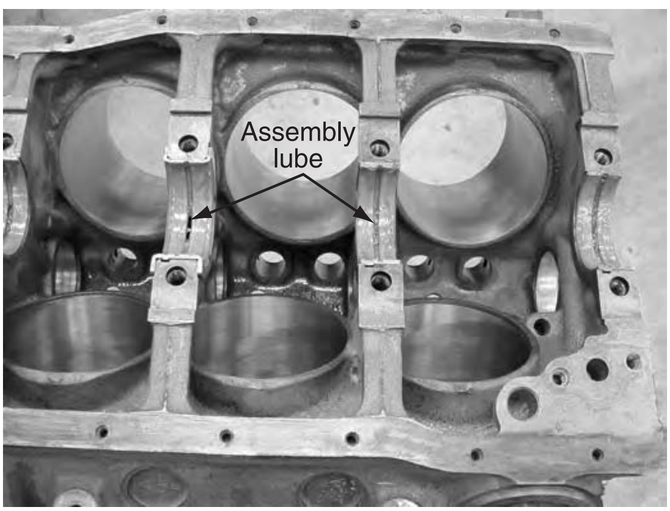


FIGURE 17.18 Apply assembly lube to the bearings (only on the side that faces the crankshaft). (*Courtesy of Tim Gilles*)

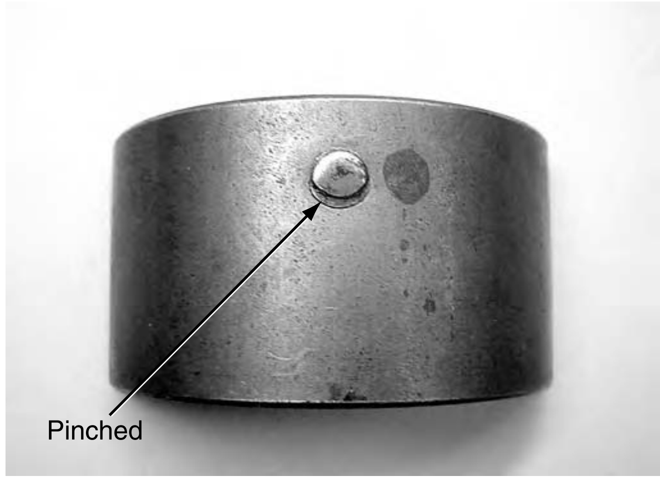


FIGURE 17.19 This main bearing was tightened while it was misaligned with its mating hole in the main bearing cap. The result was a damaged bearing. The bearing surface area on the other side was forced into contact with the main bearing journal surface, preventing the crankshaft from turning. (*Courtesy of Tim Gilles*)

FIGURE 17.20 Be certain to thoroughly lubricate the surfaces of the thrust bearings or thrust inserts. (*Courtesy of Tim Gilles*)

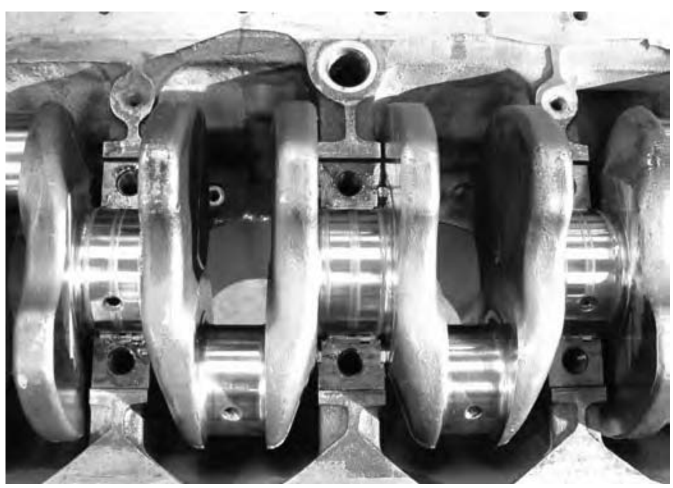


FIGURE 17.21 Install the crankshaft and check to see that it rotates easily. (*Courtesy of Tim Gilles*)

Verify Bearing Oil Clearance. Use Plastigage to check bearing oil clearance as described in Chapter 12. When using a reground crank and new bearings, check the clearance of at least one main bearing and one connecting rod bearing to make sure that the right bearings are being installed. When either the

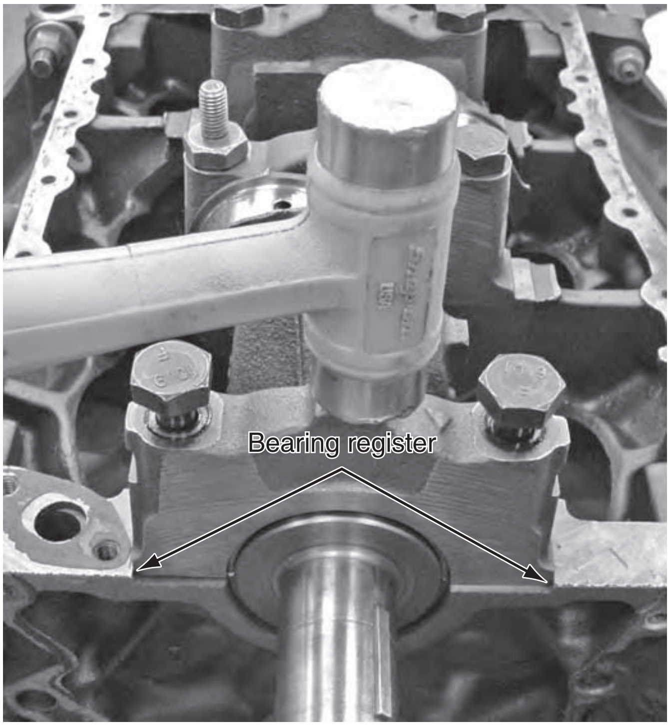


FIGURE 17.22 The block has raised registers that align the main cap. The cap fit is snug enough to require the use of a brass hammer to seat the cap to the block. Be sure the cap is facing the correct direction. (*Courtesy of Tim Gilles*)

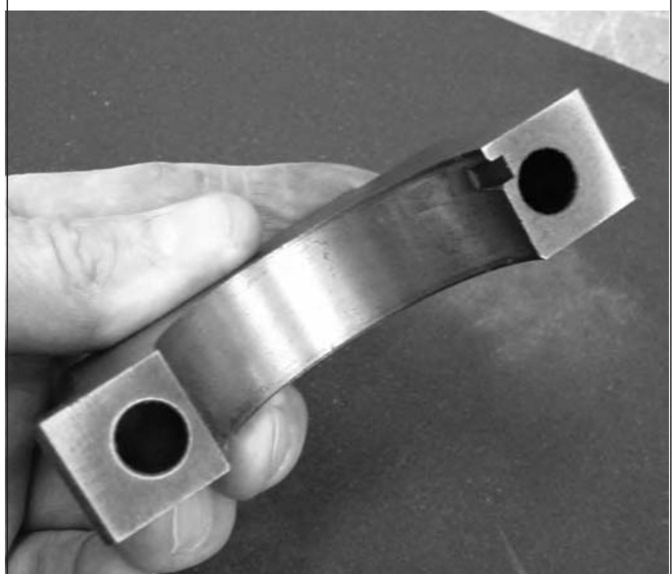
crankshaft or the bearings are being reused it is advisable to check the clearance of *every* bearing.

When installing the main caps, tap them lightly with a brass hammer so they seat within the registers (ledges) in the engine block (**Figure 17.22**).

SHOP TIP

If main bearing clearance is excessive by 0.001" or so, correct it by cleaning the parting surface of the main bearing cap. Use fine wet or dry sandpaper and a flat surface (**Figure 17.23**). It is not necessary to polish the entire parting line area. When bearing caps are machined at the factory, a relatively rough surface finish is normal.

(a)



(b)

FIGURE 17.23 Lightly clean the main cap parting surface when bearing clearance is excessive, but do not polish the entire parting area. A relatively rough OEM parting surface is normal. (*Courtesy of Tim Gilles*)

Remove the crankshaft and install the rear main seal according to the procedure described in Chapter 16.

NOTE

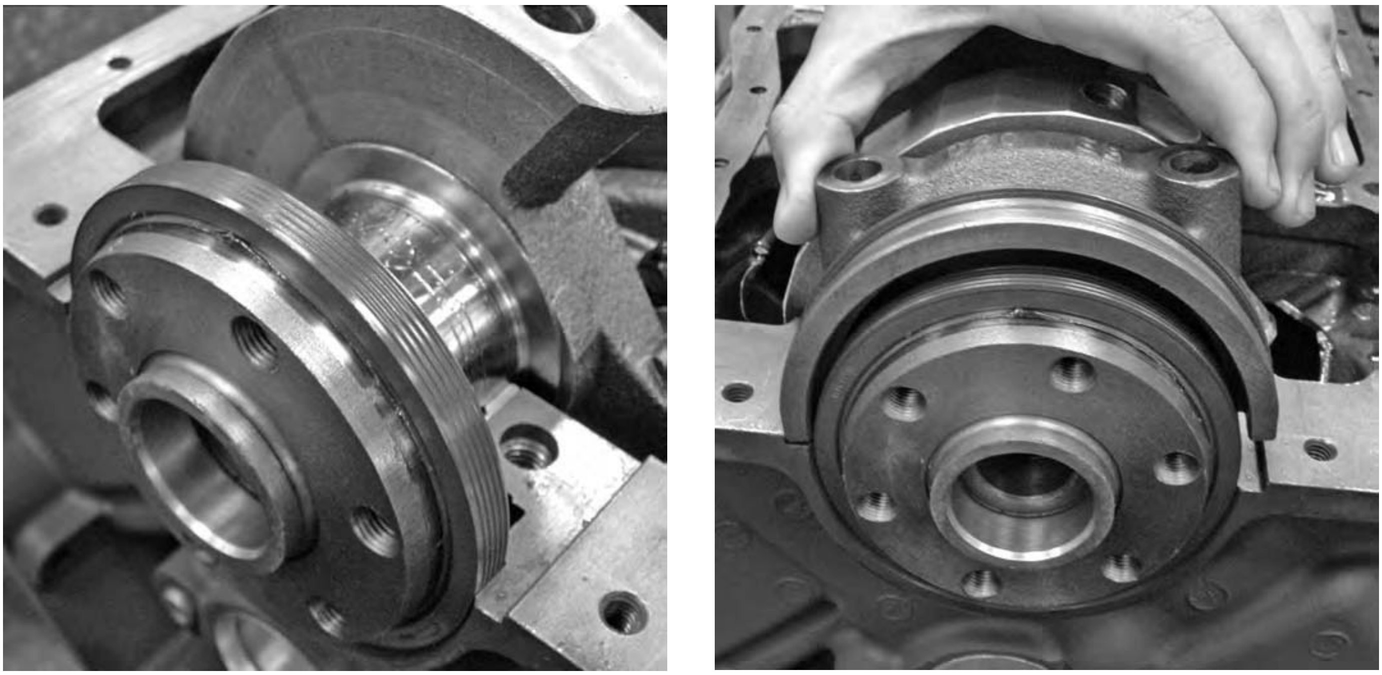
For a 5-main bearing block, the typical torque sequence is 1 4 3 2 5. Check the service specifications. At the factory, the main cap bolts are all tightened at once. Although you cannot accomplish this same feat, use the torque sequence and tighten in steps. For instance, make at least three passes of increasing torque. This will pull the caps slowly against the block and prevent the crankshaft from binding.

SHOP TIP

As you tighten *each* main cap, repeatedly check to see that the crank continues to turn easily. After final torque is achieved, you should be able to rotate the crankshaft

VINTAGE ENGINES

On older engines with rope rear main seals, the rope seal will need to be cut to fit (see Chapter 16). If the seal is cut too long, the crankshaft will be pinched, making it difficult to turn. After the rear main bearing cap is installed, rotate the crankshaft to check for increased rope seal drag. Some manufacturers provide a specification listing the maximum amount of torque (90 foot-pounds, for instance) required to turn the crankshaft using the damper bolt on an assembled engine.



(a) (b)

FIGURE 17.24 Installing a full round crankshaft seal without the need of a special tool. (*Courtesy of Tim Gilles*)

using two fingers. If not, remove the main caps to look for polished spots that indicate interference.

Some blocks have cross bolts (see Chapter 11) that will need to be installed so the main bearing bores are pulled into a round state and the crankshaft can turn freely.

SHOP TIP

Some aftermarket racing fasteners call for higher torque values. Measure the roundness of the bearing bore at the originally specified torque and at the new torque. An increase in torque of 15 to 20 foot-pounds can sometimes shorten the height of the bore by 0.001". With close bearing fits, this could result in interference.

Full round seals are installed after installing the crankshaft. If the seal is retained by the main bearing cap, install it as shown in **Figure 17.24**.

CAUTION

A few rear main seals are made of Teflon®, which must be installed dry. A Teflon seal “burns in” during the first engine startup. Small traces of oil can interfere with that process.

Align Thrust Bearing Halves

Torque all bearing caps except the thrust main. Its halves should be aligned (**Figure 17.25**) before

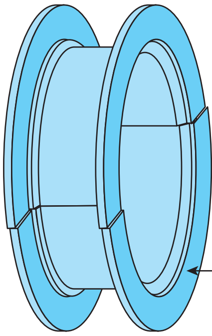


FIGURE 17.25 Misaligned thrust flanges will prevent crankshaft end play. The thrust bearing that fits in the main cap is shifted to the left in this illustration.

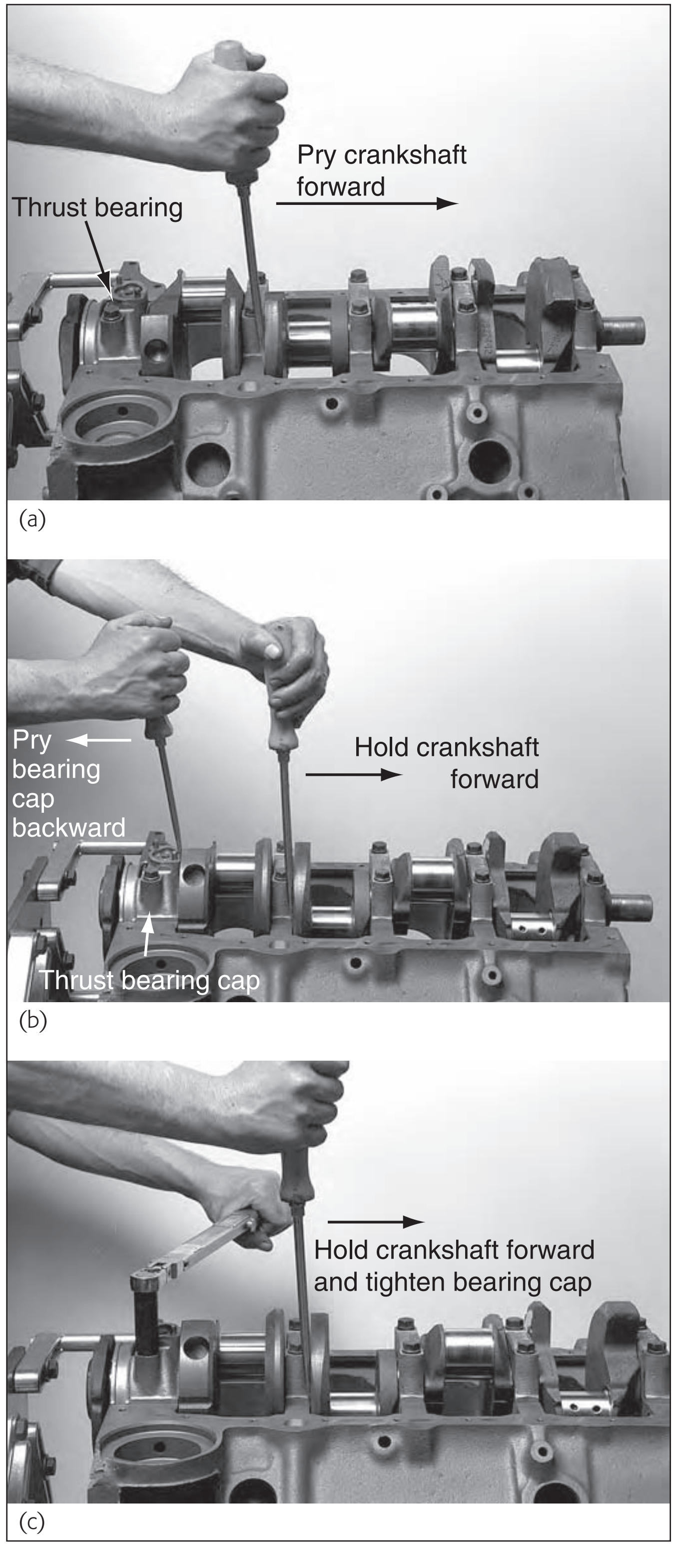


FIGURE 17.26 Align the thrust surfaces as shown.

torquing. The procedure for aligning thrust bearing halves is shown in **Figure 17.26**. After aligning the thrust halves, check crankshaft end play (**Figure 17.27**) with a feeler gauge or a dial indicator.

NOTE

End play tolerance is usually from 0.004" to 0.006" for a crankshaft with 2" to 2¾" main bearing diameters.

Install Pistons and Rings

Assemble the new or serviced pistons to the connecting rods. Be sure to install the rods on the pistons in the right direction.

Check the butt gap of the compression rings to ensure that they are within specifications. Then install them according to the instructions in the ring package with the dots facing up and the gaps properly placed. The preceding procedures are covered in detail in Chapter 13.

Install Rod Bearings

Make sure that the parting surface of the rod cap does not have any burrs or foreign material (**Figure 17.28**). An indentation on the parting surface of the rod or cap will result in a high spot surrounding it. When the cap is tightened into place, the bearing will be misaligned and the oil clearance will be excessive.

- Install the new bearing inserts in the rod and cap.
- When reusing old rod bearings, they might have lost their spread and may have to be stretched lightly to keep them in the rod while the pistons are being installed (see Chapter 12). When

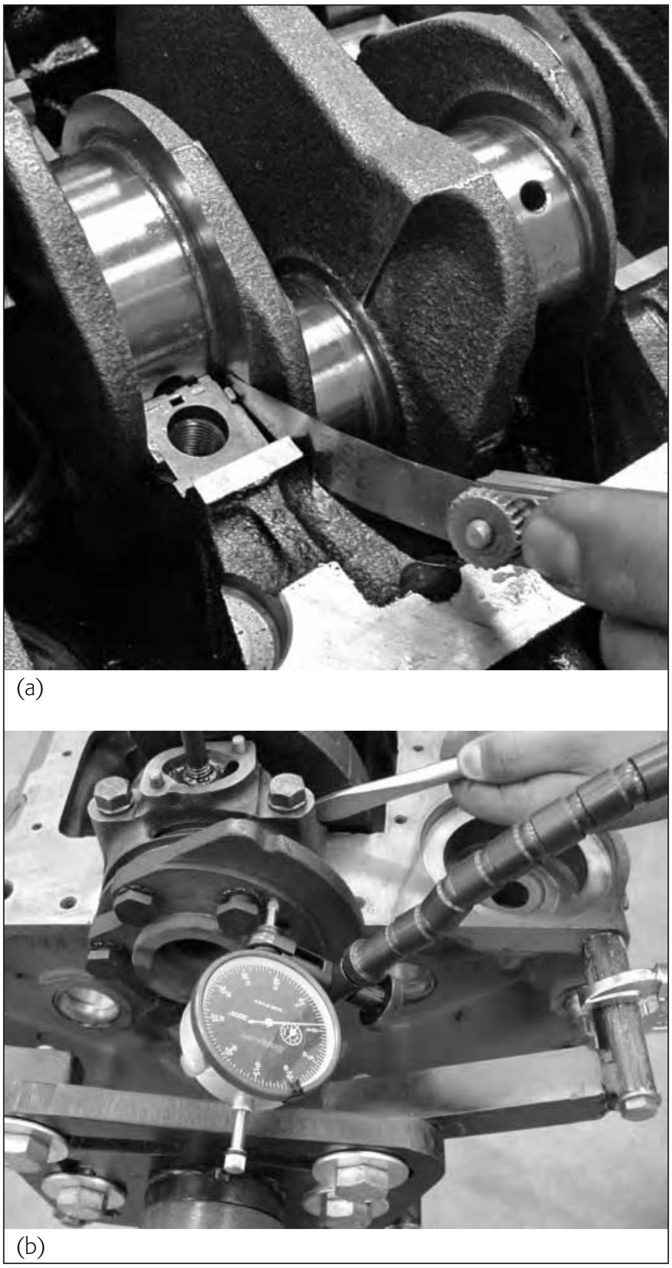


FIGURE 17.27 Two methods of checking crankshaft end play. For illustration purposes, the measurement is shown here with the cap removed using (a) a feeler gauge and (b) a dial indicator. (*Courtesy of Tim Gilles*)

installing pistons with used rod bearings, double-check each one before torquing to make sure that a bearing has not slipped out of its proper place in the rod bore.

- Make sure that the bearing locating lugs are aligned in the cap. **Figure 17.29** shows a bearing that was damaged when the bearing cap was torqued while the locating lug was not correctly seated.

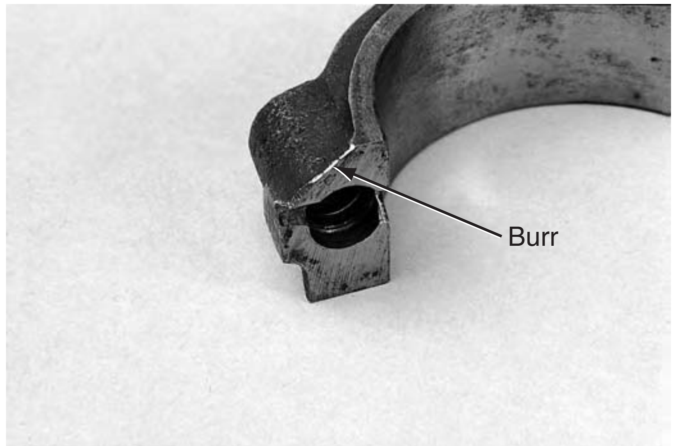


FIGURE 17.28 A raised area on the cap or rod parting surface will result in a misaligned bearing and incorrect bearing clearance.

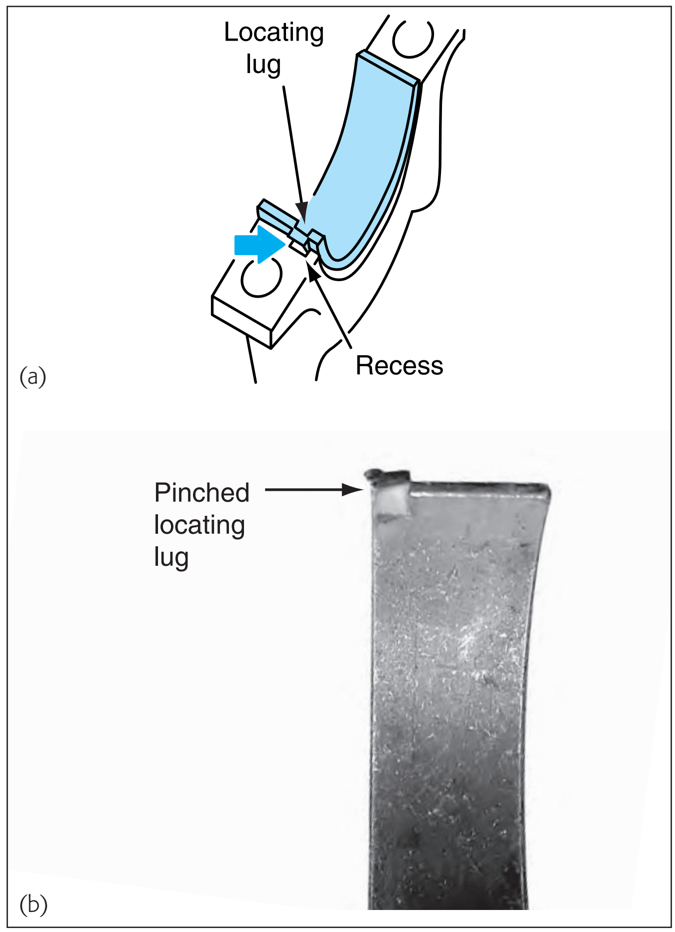


FIGURE 17.29 Make sure that the bearing locating lug is properly located in its notch before torquing the rod cap.

Install the Piston and Rod Assembly in the Block

Lubricate the rod bearings (**Figure 17.30**), piston pin (**Figure 17.31**), and piston rings before installing

FIGURE 17.30 Use assembly lube on the rod bearing surface before installing the piston assembly into the block. (*Courtesy of Tim Gilles*)

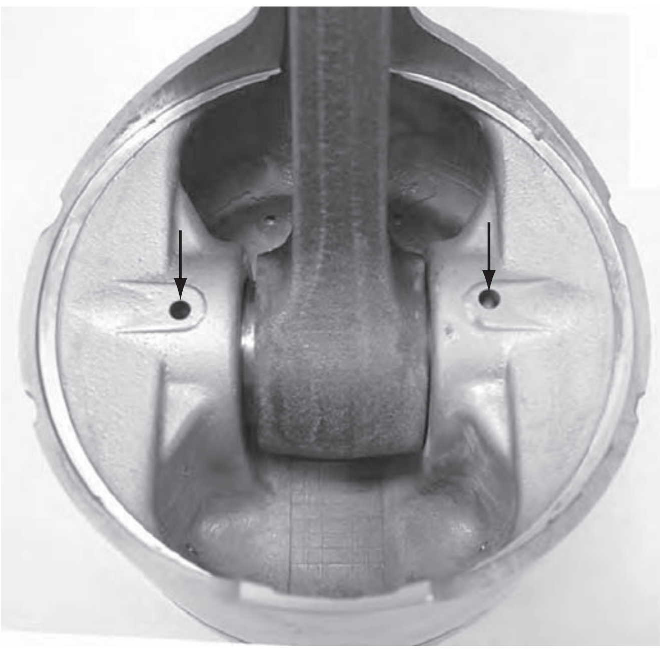


FIGURE 17.31 Lubricate the piston pin. (*Courtesy of Tim Gilles*)

FIGURE 17.32 Soak the compression rings in oil before installing them on the piston. (*Courtesy of Tim Gilles*)

FIGURE 17.33 Oil the piston, rings, and wrist pin thoroughly.

the piston-and-rod assembly in the block. Piston rings will absorb oil so soak them thoroughly to prevent wear during the initial break-in period (**Figure 17.32**). Use a suitable assembly lubricant on the connecting rod bearings. Be sure to lubricate the piston skirt thoroughly (**Figure 17.33**).

- Install a short length of fuel hose on each rod bolt to guard against nicking the crank (**Figure 17.34**).
- Use a ring compressor to compress the rings into the grooves during piston installation (**Figure 17.35**). For specific engines there are custom conical-shaped tools to install piston/ring assemblies.
- Face the notch on the top of the piston toward the front of the engine (**Figure 17.36**).

SHOP TIP

Installation of the three-piece oil ring occasionally presents some difficulty. Sometimes there is a small space between the bottom of the ring compressor and the top of the block. Try to quickly push the oil ring past the end of the ring compressor and into the cylinder bore before one of the narrow oil ring rails can spring out into this space.

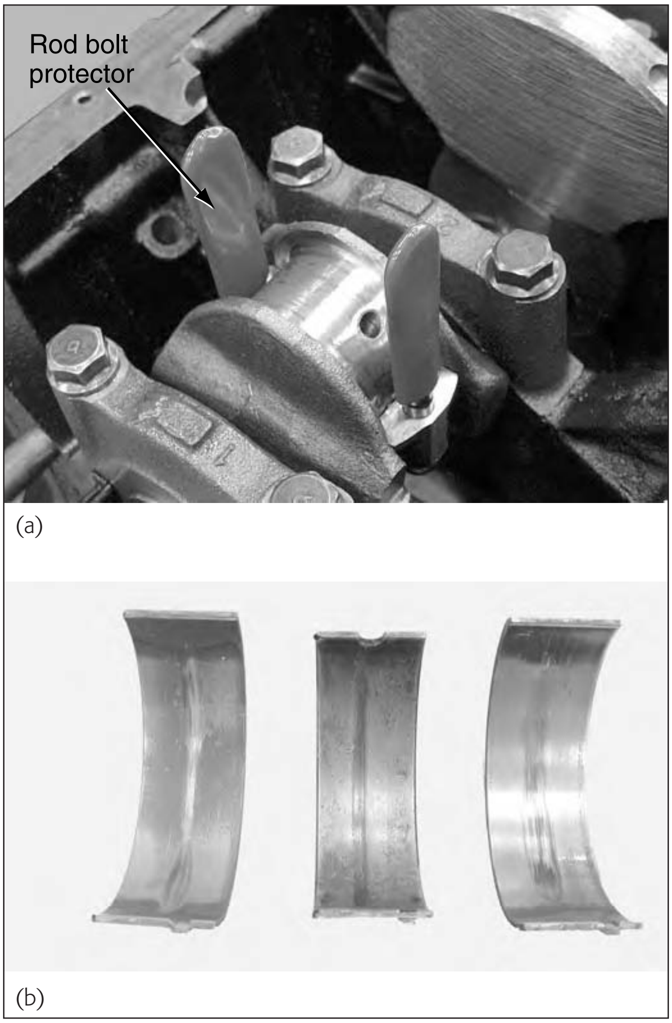


FIGURE 17.34 Protect the crankshaft. (a) Install pieces of hose or a special tool on the connecting rod bolts to protect the crankshaft from accidental nicks. (b) A nick on the rod journal will dig a groove all around the bearing insert. (*Courtesy of Tim Gilles*)

FIGURE 17.35 Different types of piston ring compressors. (*Courtesy of Tim Gilles*)

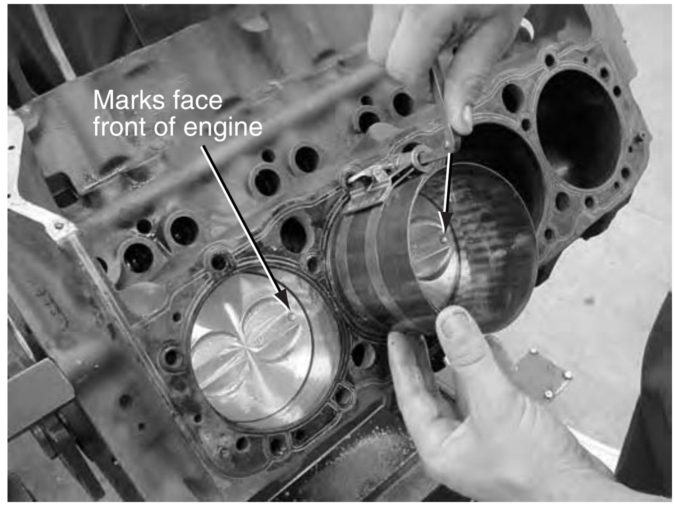


FIGURE 17.36 Install the piston-and-rod assembly in the correct direction. (*Courtesy of Tim Gilles*)

Install the Pistons. Install a ring compressor on the piston and place the piston in the appropriate cylinder bore (see Figure 17.36). Hold a rubber hammer against the top of the piston and tap the hammer lightly with the palm of your hand while holding the ring compressor firmly against the block until all the rings have entered the cylinder (**Figure 17.37**). If the piston does not go in easily, something is wrong. *Do not force* it; a ring or a ring land can be damaged.

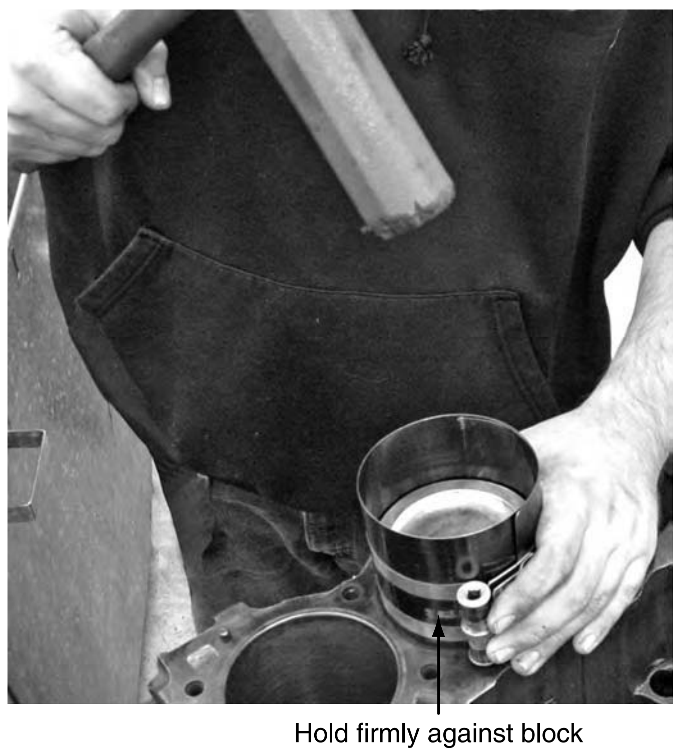


FIGURE 17.37 Install the piston-and-rod assembly using a soft mallet or piece of hardwood. Hold the ring compressor snugly against the block. (*Courtesy of Tim Gilles*)

SHOP TIP

Figure 17.38 shows oil ring rails damaged during installation. The trick to successfully installing a piston using the ring compressor is to move the piston quickly. You do not want to hit it hard, but move it quickly enough so the rails on the oil control rings do not have time to pop out.

Once all the rings are in the cylinder, the rod can be pulled down against the rod journal by hand from the crankcase side of the block. Twist the rod if necessary to align it properly with the journal. If a piston is off-center (**Figure 17.39**) and you pound it into the cylinder, the parting surface of the connecting rod can hit against the crankshaft throw, nicking it.

FIGURE 17.38 (a) This oil ring rail was damaged during piston installation. (b) This piston ring rail was damaged when a student learning to use a piston ring compressor forced it into the cylinder on a practice engine. (*Courtesy of Tim Gilles*)

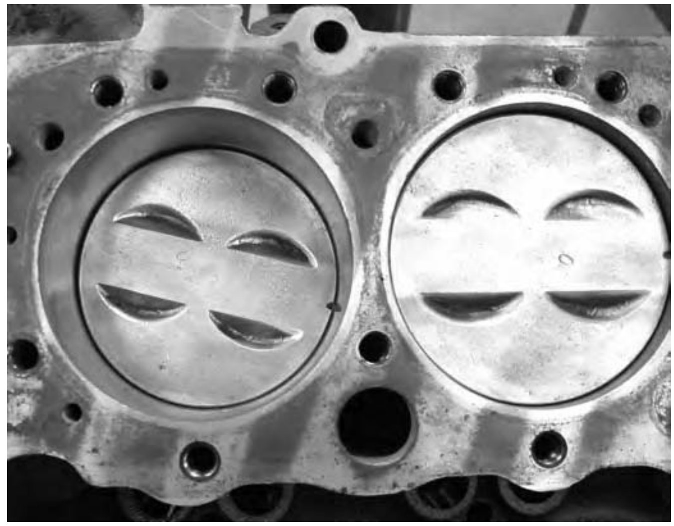


FIGURE 17.39 If the piston is off-center and you pound on it, the connecting rod parting face might be forced against the crank throw or counterweight. (*Courtesy of Tim Gilles*)

Connecting Rod Direction. Be certain that the connecting rod faces in the right direction. On some V-type engines with the notches on the piston facing forward, the left cylinder bank's rods should face the opposite direction from the right bank's (**Figure 17.40a**). If they are facing the wrong way, the rods might have been improperly installed on the pistons. Do not continue with assembly until the rods are correctly installed.

Piston Pin Offset and Spit Hole Orientation. What follows are some handy rules to refer to when dealing with piston pin offset and rod spit hole orientation. Nearly all engines are left-hand engines. A left-hand engine is one that turns counterclockwise when viewing the engine from the flywheel side. On a rear-wheel-drive vehicle, this is the orientation from the driver's seat. When a left-hand engine has oil spit holes on the connecting rods, the spit holes are to the right when the piston notches are facing forward. This provides lubrication to the working surface of the piston against the cylinder wall. When viewing the piston from the right-hand side, the piston pin will be offset to the right side of the piston (the major thrust surface).

- Remove the hoses from the rod bolts and install the rod caps. Make sure that the numbers on the rod caps correspond to the numbers on the rods and that they face in the right direction. The numbers on each rod and cap should be on the same side with the locating lugs facing each other (**Figure 17.40b**).

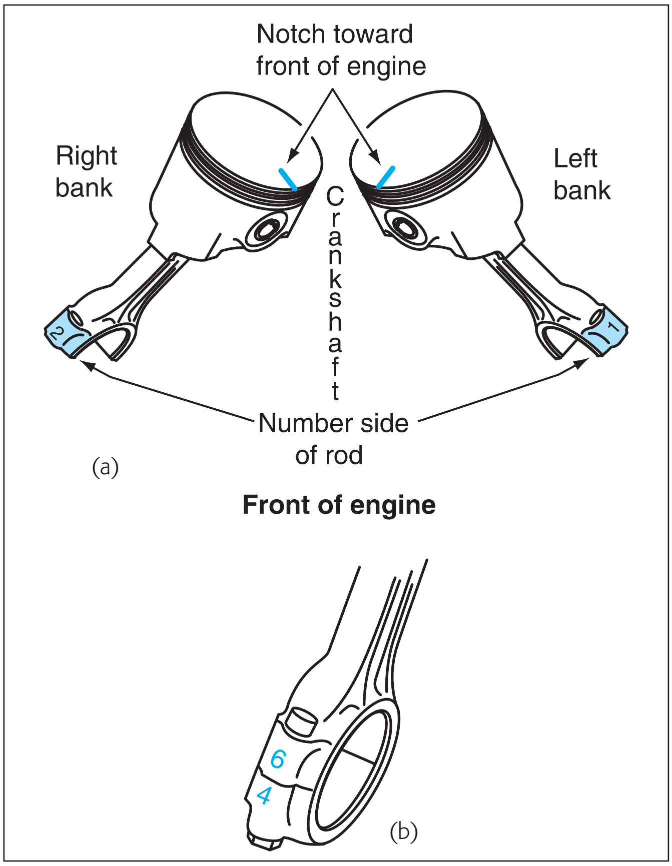


FIGURE 17.40 (a) On V-type engines, the rods are installed with their numbers facing away from the camshaft. (b) Installing the wrong bearing cap on the connecting rod can result in serious problems.

CAUTION

If you put a rod cap on backward and tighten it down, you can spring the housing, requiring replacement of the rod.

- Use Plastigage to check the bearing clearance (see Chapter 12). Using some oil, remove the Plastigage after measurement.
- Rod nuts are square and flat on the bottom side and often are curved on the top. Be sure that the flat side of each rod nut is faced against the cap. Use some thread locking compound when rod nuts are reused. Torque the nuts to specifications. In the industry, rod nuts are commonly reused without adhesives. Repeated reuse of nuts is asking for trouble. It is inexpensive insurance to replace rod nuts, especially when recommended by the engine manufacturer.

Check Installation of Rod and Bearings

After installing *each* piston, rotate the crank one complete turn to check for unacceptable drag (**Figure 17.41**).

On V-type engines, check the side clearance between the connecting rods (**Figure 17.42**) and compare it to specifications. Use the low side of the tolerance when selecting a feeler gauge. Check at two or three locations around the circumference of the rod. Variations in clearance indicate a bent or twisted rod.

Install Cylinder Heads

Be sure to install the cylinder head gaskets in the right direction (see Chapter 16). Most engines have dowels to align the heads (**Figure 17.43**).

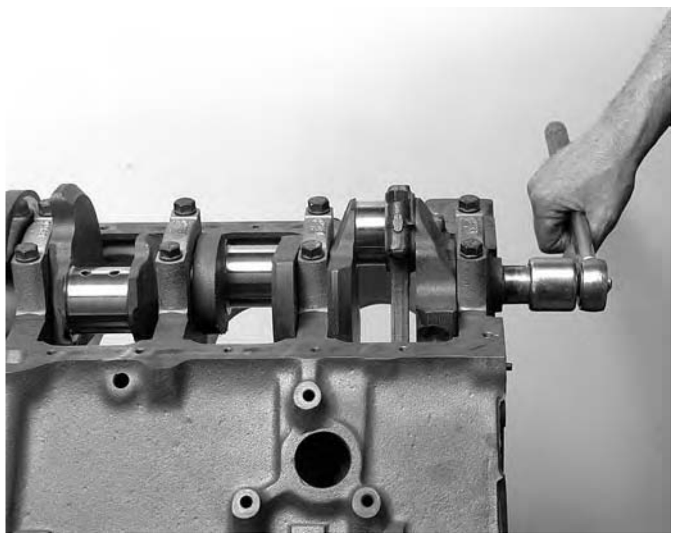


FIGURE 17.41 Rotate the crankshaft after installation of *each* piston and rod. Notice if drag becomes excessive.

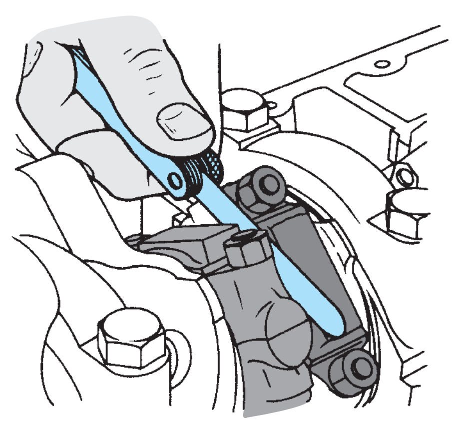


FIGURE 17.42 Checking connecting rod side clearance.

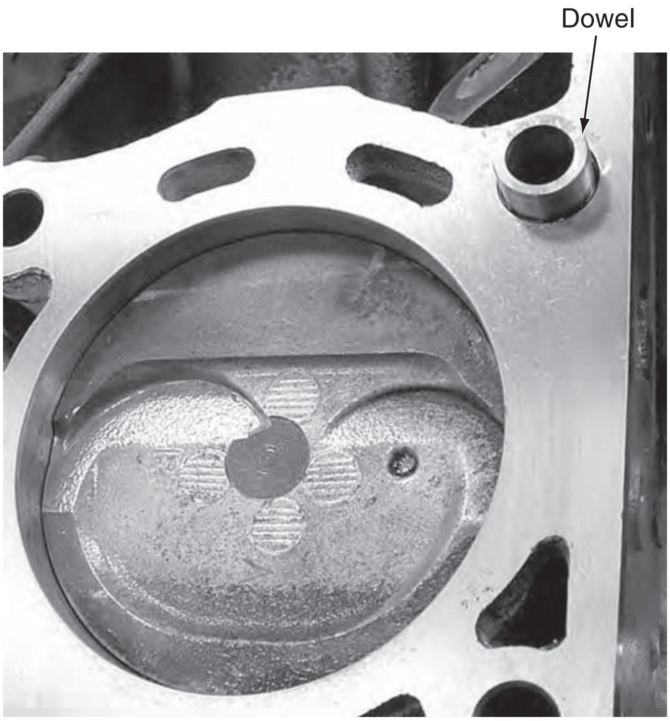


FIGURE 17.43 Most engines have dowels or grommets to align the head and head gasket to the block. (*Courtesy of Tim Gilles*)

SHOP TIP

If there are no dowels, make alignment pilots by cutting the heads off two long bolts and hacksawing screwdriver grooves in their tops (**Figure 17.44a**). These aligning studs will help protect the head gasket from damage during installation (**Figure 17.44b**) and can be removed easily after the head is installed.

Install Timing Chain and Sprockets (Pushrod Engine)

Install the chain and sprockets. Be careful to set the cam timing accurately (see Chapter 9). Before installing the timing chain, soak it in oil to ensure that the pins and bushings are thoroughly lubricated (**Figure 17.45**).

- If the sprocket was not previously installed on the crank snout, lay the timing chain and sprockets on the bench and align their marks carefully.
- Hold both sprockets into the chain while installing the crank gear.
- Turn the crankshaft until the cam sprocket aligns with its pin or key.
- Install the cam sprocket on the cam. The marks should now be in perfect alignment (**Figure 17.46**).

FIGURE 17.45 Soak a timing chain in oil before installing it. (*Courtesy of Tim Gilles*)

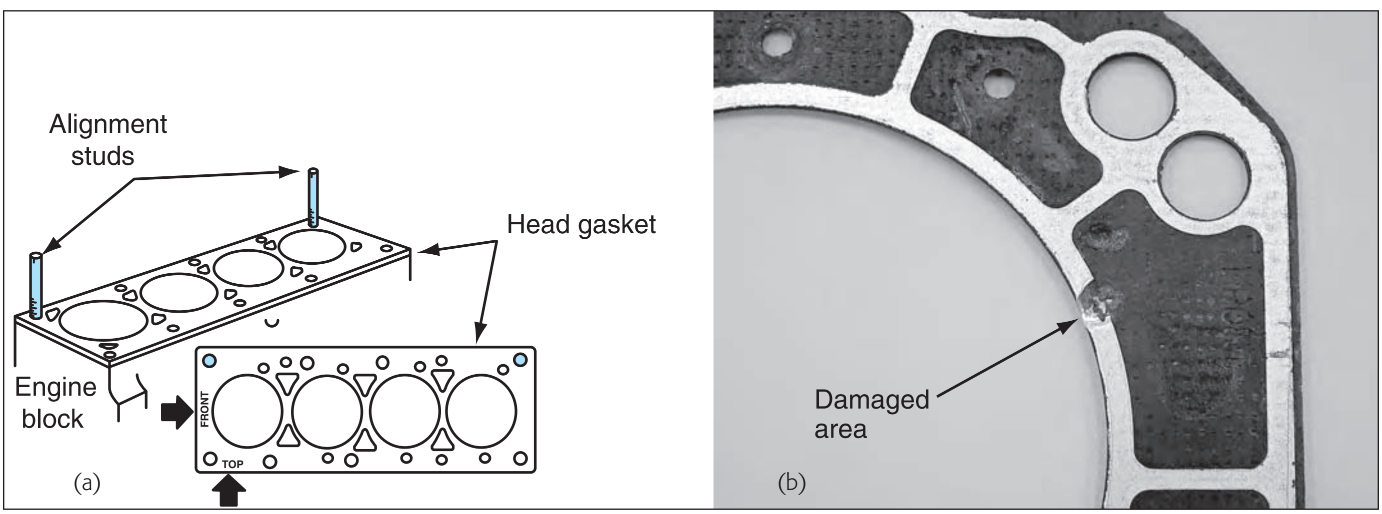


FIGURE 17.44 Aligning the head gasket and head to the block. (a) Head guide pins. (b) This head gasket was damaged when the cylinder head was dropped against it during installation. Had this gone unnoticed, certain failure would have resulted. (*Courtesy of Tim Gilles*)

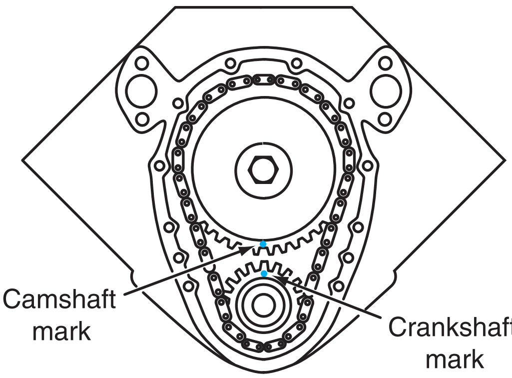


FIGURE 17.46 Install the chain and cam sprocket with the timing marks aligned according to specifications.

- Double-check cam timing by rotating the crankshaft until the marks line up again.

Install OHC Heads

Before installing overhead cam heads on the engine, the number one piston must be at TDC and the camshaft must be turned in the head until its timing mark is properly located (**Figure 17.47**). Otherwise, valves held open by the cam might be forced against pistons, bending the valves as head bolts are tightened. Refer to Chapter 9 for more complete cam timing and belt installation information.

SHOP TIP

OHC engines have an oil seal behind the timing sprocket. To make seal installation easier, loosen the front cam cap and install the seal before you install the timing sprocket (**Figure 17.48**).

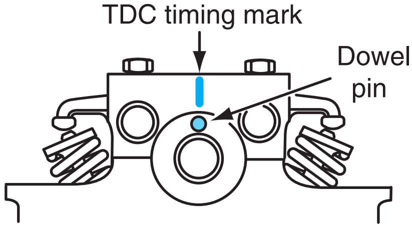


FIGURE 17.47 Position the cam correctly before installing the cylinder head, if possible. Sometimes special procedures must be followed to correctly position the camshaft(s) after installing the head(s).

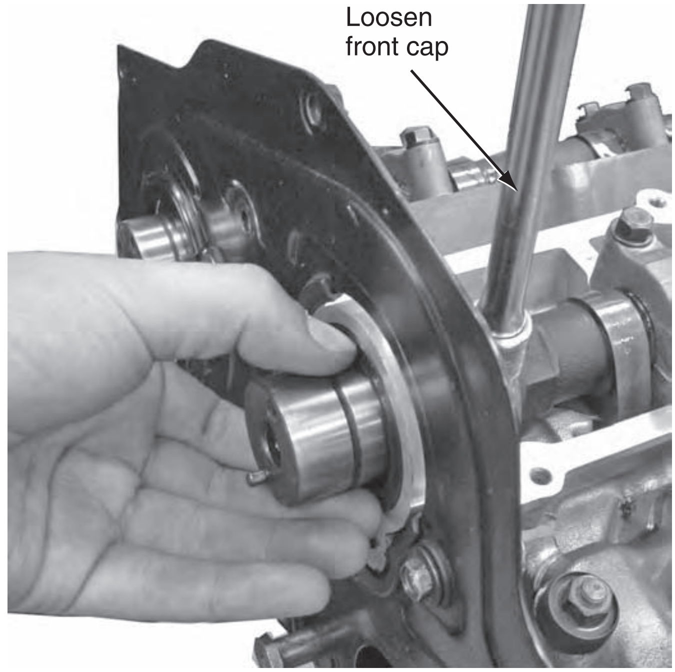


FIGURE 17.48 Overhead cam heads have a seal behind the cam sprocket. Loosen the front cam cap for easy installation of the seal. (*Courtesy of Tim Gilles*)

Set Camshaft Position. Align the TDC timing mark found on the cam sprocket with the corresponding mark on the head. Position the timing mark on the crankshaft pulley at TDC. When the cam and crank sprockets are positioned correctly, the timing chain can be installed. Be sure to check the service information for correct cam phasing information.

SHOP TIP

To double-check that the cam is actually positioned at TDC, either the number one cylinder or its companion cylinder should have its cam lobes facing as shown in **Figure 17.49**. The companion cylinder's cam lobes will face down in the valve overlap position.

Dual overhead cam engines have a separate camshaft for the intake valves and exhaust valves. The engine shown in **Figure 17.50** has timing marks visible from the *back* side of the camshaft sprockets. When the crankshaft keyway is at the 11 o'clock position, the number one cylinder is at TDC. The RFF flags on the backs of the camshaft sprockets should face each other.

FIGURE 17.49 This overhead camshaft is positioned at TDC.

On belt-driven camshafts, install the timing belt. Refer to Chapter 9 for the tensioning procedure.

Install Head Bolts

Install the heads. Before installing head bolts, make sure that all of the threads have been cleaned using a wire wheel. Any bolts with rusted shanks should be replaced with new ones.

NOTE

Do not reuse torque-to-yield bolts.

Apply sealer to any bolt that goes into a hole intersecting a water jacket (**Figure 17.51**). This will prevent pressurized coolant from migrating into the oil. A long, narrow screwdriver can be used to probe the head bolt holes to verify that they are "blind" holes (holes that have bottoms).

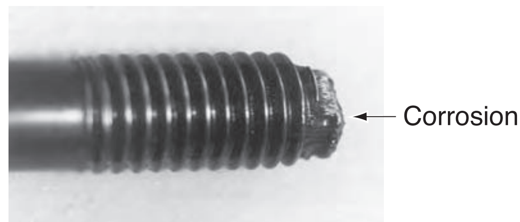


FIGURE 17.51 This head bolt extended into a water jacket. The coolant had not been maintained. (*Courtesy of Tim Gilles*)

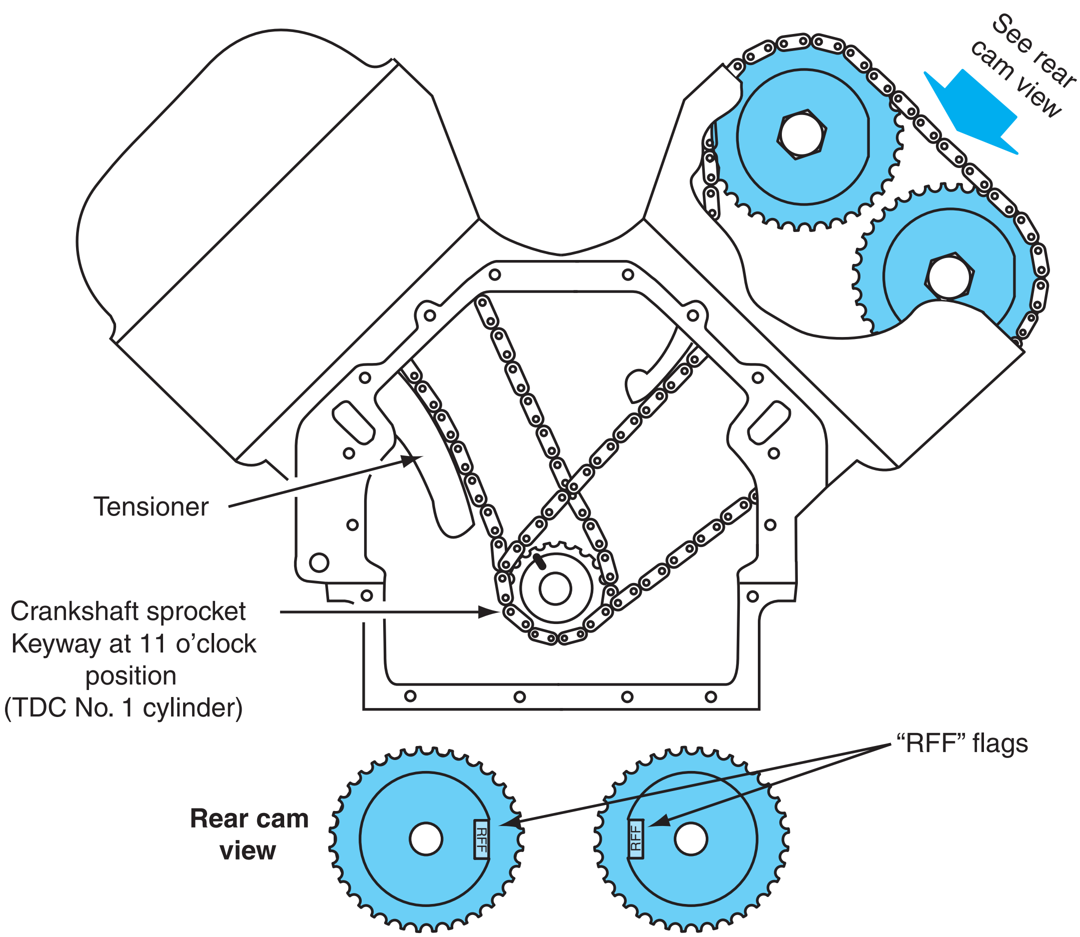


FIGURE 17.50 The cam timing marks on the DOHC engine are on the back of the sprockets.

VINTAGE ENGINES

Through most of the last half of the twentieth century, most engines in North America were pushrod engines with flat tappets. A special cam lobe lubricant was recommended for initial engine startup with these engines. One popular cam lubricant was engine oil supplement (EOS). This lubricant, and others like it, contained a high percentage of zinc dialkyldithiophosphate (ZDDP), a popular antiwear additive included in most motor oils. Phosphate additives have been found to be harmful to the life of catalytic converters, which now have a very long manufacturer warranty interval. Therefore, beginning with SM oils, ZDDP levels were reduced.

Catalytic converters began to be used to control exhaust emissions in 1973. Lead, which was used as an octane booster until that time, was banned from gasoline because it contaminated catalytic converters.

Follow the recommended bolt torque sequence and tighten the bolts to manufacturer's specifications as described in Chapter 16.

CAUTION

Using an impact wrench to tighten the retaining bolt on an OHC camshaft sprocket can sometimes result in a broken camshaft snout (**Figure 17.52**).

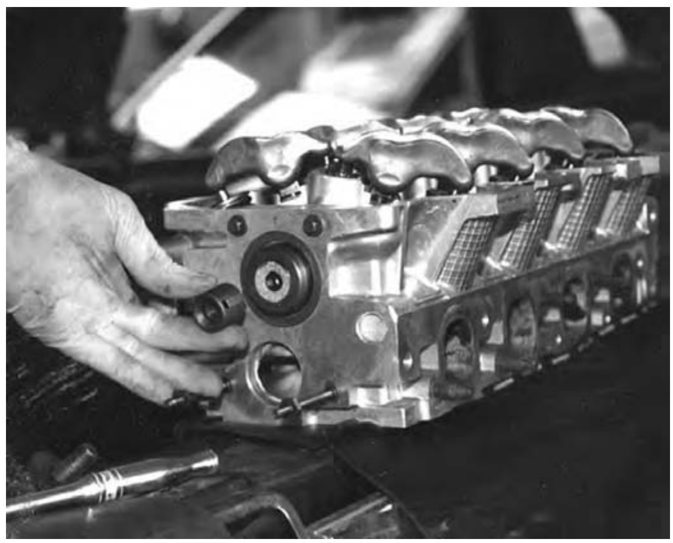


FIGURE 17.52 The front of this camshaft was broken when the bolt was tightened using an impact wrench. (*Courtesy of Tim Gilles*)

Install Valvetrain Parts

On cam-in-block engines, apply assembly lubricant to lifters to protect them against wear when the engine is first started. Install them and make sure they turn freely in their holes. A lifter that does not fit the bore snugly might indicate that the bore was oversize from the factory. Oversized replacement lifters must be ordered from the dealer (see Chapter 11).

On a few pushrod engines, lifters must be installed before cylinder heads.

NOTE

According to an AERA bulletin, it is *not* advisable to prefill lifters with oil. They will fill with the correct amount of oil as the lubrication system is pressure-primed.

NOTE

Adequate lubrication is very important to all engine parts when an engine is first started after a rebuild. Parts in the cylinder head can suffer a great deal of wear during the first few minutes of engine life if they have not been adequately lubricated during assembly. Rocker arms are particularly susceptible to problems. Always lubricate rocker arm pivots generously during engine assembly (**Figure 17.53**). **Figure 17.54** shows some severely worn rocker arms. Theoretically, parts cannot wear if they are separated by a clean oil film. Remember: "If it moves, lube it."

FIGURE 17.53 Do not forget to lubricate rocker arm pivots with assembly lube. (*Courtesy of Tim Gilles*)

Install the pushrods and rocker arms. Lubricate all wear areas thoroughly.

Install the Oil Pump

Before installing the oil pump, fill it with oil so that it will not be run while dry and will "prime" right away. Install the pump as described in Chapter 14 and make sure that the pickup screen is properly positioned so it will be about ¼" from the bottom of the oil pan.

FIGURE 17.54 Some examples of severe rocker arm wear caused by failure to lubricate the parts adequately during assembly of the cylinder head. (*Courtesy of Tim Gilles*)

Install the Timing Cover

Before installing the timing cover, install the front crankshaft seal as described in Chapter 16. Be sure to grease the artificial rubber seal lip. It will become hot and be ruined if the shaft spins against it before the lubrication system fills and oil splashes on the seal.

Timing covers are usually installed before the oil pan, because the oil pan and timing cover often share a gasket surface.

NOTE

Remember to install the woodruff key in the crankshaft keyway before installing the timing cover.

VINTAGE ENGINES

Some older pushrod engines had shaft-mounted rocker arms. The rocker shafts must be installed with the oil holes in the shaft in the proper direction; otherwise, they will not receive any oil from the lower end. Tighten the bolts closest to the center first. Then pull all the rest of the bolts slowly tight.

Some engines have an oil passage leading to the rocker shaft that passes around a rocker arm bolt. This bolt can have a reduced shank to allow for the passage of oil. Be sure that this bolt is installed in the correct hole.

VINTAGE ENGINES

Older engines with carburetors had mechanical fuel pumps, operated by an eccentric on the camshaft. Some of these had bolt-on fuel pump eccentrics (**Figure 17.55**). If you encounter one of these, remember to use an anaerobic sealer like Loctite when installing it.

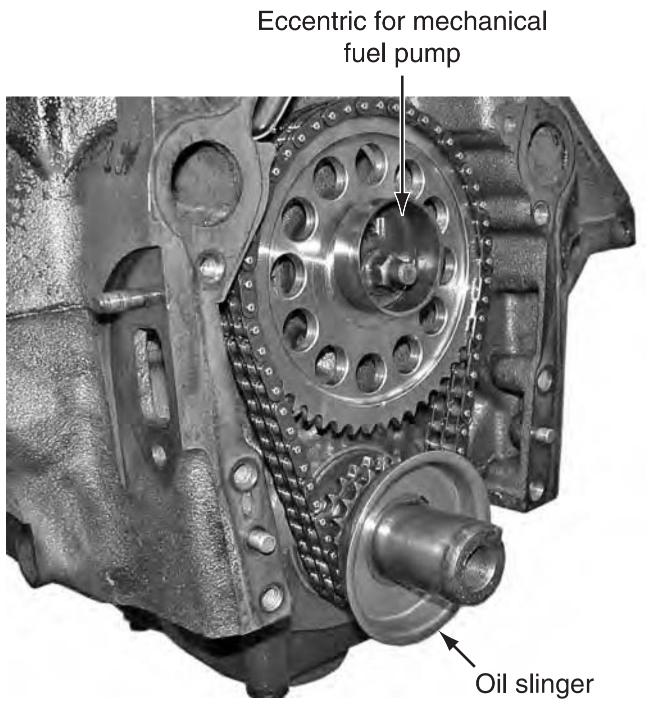


FIGURE 17.55 On vintage engines, do not forget to install the woodruff key and oil slinger before installing the timing cover. (*Courtesy of Tim Gilles*)

Oil Slinger. Engines with timing chains sometimes have an oil slinger that fits behind the vibration damper. If the engine uses one, install it before installing the timing cover (see Figure 17.55).

NOTE

If the engine has an oil slinger, it must be installed in the correct direction or it may rub and make noise. Disassembling a newly rebuilt engine to replace a backward or forgotten oil slinger is time-consuming and frustrating.

Timing Cover Alignment. Some engines do not have timing cover aligning pins. A few manufacturers have special tools for aligning their timing covers to the front seal, but these are rare. You can align the timing cover by installing the damper temporarily, using it as an aligning tool. After tightening a pair of the timing cover screws, the damper can be removed to allow the remaining screws to be tightened.

SHOP TIP

Timing cover screws are small. To prevent them from breaking, torque the screws to specification with an inch-pound torque wrench. This is usually only 50 to 60 inch-pounds.

Install the Crankshaft Damper/Pulley

The front crankshaft pulley is fitted on the crankshaft snout with either a slip fit or a press fit. A pressed-fit vibration damper can be pulled into place using a special tool. It is advisable to use the installation tool, because pounding on the damper can cause stress on the crank thrust bearing surface. If the damper must be pounded in place, it is best to stand the engine block vertically on end to support the crankshaft.

To use the installation tool, turn the threaded shaft of the tool into the threads in the front of the crankshaft. After slipping a bearing onto the shaft (**Figure 17.56a**), a nut is threaded against the bearing and tightened to pull the damper against its shoulder on the crankshaft (**Figure 17.56b**).

The damper is installed until it bottoms out against the oil slinger and the timing sprocket. Tightening the front crankshaft bolt to specified torque holds the sprocket tight against the front of the crankshaft.

SHOP TIP

If you are not sure whether the damper has been installed all the way, install the coolant pump and pulley and check

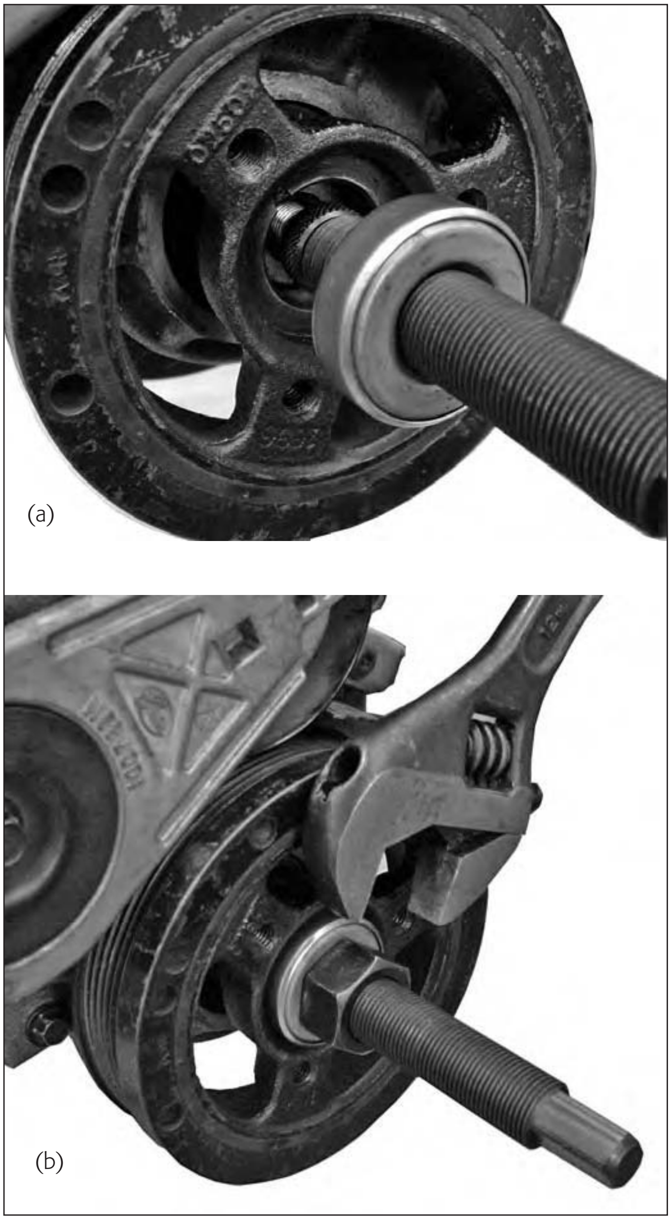


FIGURE 17.56 A damper installation tool. (a) Turn the threaded shaft of the tool into the threads in the front of the crankshaft and slide the bearing onto the shaft. (b) Thread the nut against the bearing and tighten it to pull the damper against its shoulder on the crankshaft. (*Courtesy of Tim Gilles*)

to see that the crankshaft and coolant pump pulleys are in alignment.

When a vibration damper is not pressed-fit on the crankshaft, be certain to install a large washer behind the damper retaining bolt. This will prevent the damper from coming loose. Torque the bolt, following the procedures in Chapter 9 (see related case history).

Some late-model engines require damper bolt replacement because the bolt is torque-to-yield with a preapplied sealer on the threads.

Install the Oil Pan

Careful oil pan installation is especially important. An otherwise perfect engine overhaul will appear amateurish to a customer if there is an oil leak. Replacing a pan gasket is a much more difficult repair job when the engine is in the car.

- Apply a small amount of RTV where the cork gaskets join the rubber gasket on the front of the pan. Do not use too much; the excess silicone can break off and plug the oil pump screen.
- Make sure that the pan was not dented when it was removed from the car. A dented pan that is hit by a rotating crank counterweight can sound like a rod knock.

CASE HISTORY

An apprentice technician was installing a rebuilt long block in a vehicle. When the engine was started, a loud knock was heard. The disheartened apprentice sought help from the shop owner. Further investigation showed that the oil pan had been damaged during installation of the engine. The oil pan was removed from the engine and a shiny spot was visible where the crankshaft had been making contact. After the pan was straightened and reinstalled, the engine ran fine and the vehicle was returned to the customer.

Sheet metal oil pan or valve cover bolt holes are often distorted. Straighten them by carefully flattening them with an anvil and hammer (**Figure 17.57**). Check a sheet metal oil pan to see that it is flat by putting the oil pan on a solid, flat surface (**Figure 17.58**). A flashlight inside the pan will highlight any raised areas around the perimeter.

Sometimes the same engine is used in different sizes and types of vehicles. It is not uncommon for different oil pans to be used on the same engine block. Make sure the pan used is the right

FIGURE 17.57 Flatten out sheet metal bolt holes. (*Courtesy of Tim Gilles*)

FIGURE 17.58 Check a sheet metal oil pan to see that it is flat. Place it on a solid, flat surface. Put a flashlight inside to illuminate any high spots. (*Courtesy of Tim Gilles*)

one. If the type of oil pan is changed during an engine swap, the oil pump screen must usually be changed, too.

Remember to leave all oil pan screws loose until they are all partly threaded into their holes (see Figure 17.2).

Mechanical Valve Adjustment

A few late-model engines and many earlier engines have adjustable valve clearance, also called lash. Whether the engine is an overhead valve push-rod type, an overhead cam type, or a vintage L-head, the procedure for adjusting the valve clearance is not that different. Adjust mechanical lifter valve lash by following a specified order of adjustment listed in the service information or by following the procedure described next. See Chapter 9 for more information on adjusting valves.

NOTE

The specification for lash clearance is found on the under-hood label. Be sure to note whether the spec is given in inches or millimeters.

- First, select a piston that is at TDC with its spark plug firing. At this point in the four-stroke cycle, both lifters are on the heels of the cam lobes and valve lash can be adjusted.
- To determine which piston is at TDC, rotate the crankshaft by hand until the intake and exhaust valves for any cylinder are both "rocking" (moving in opposite directions at the same time). This rocking happens during valve overlap at TDC as the intake stroke begins and the exhaust stroke ends. The valve clearance for this cylinder's companion can now be adjusted, because the *companion* cylinder is one-half turn of the camshaft away with its lobes facing away from the valves (**Figure 17.59**).

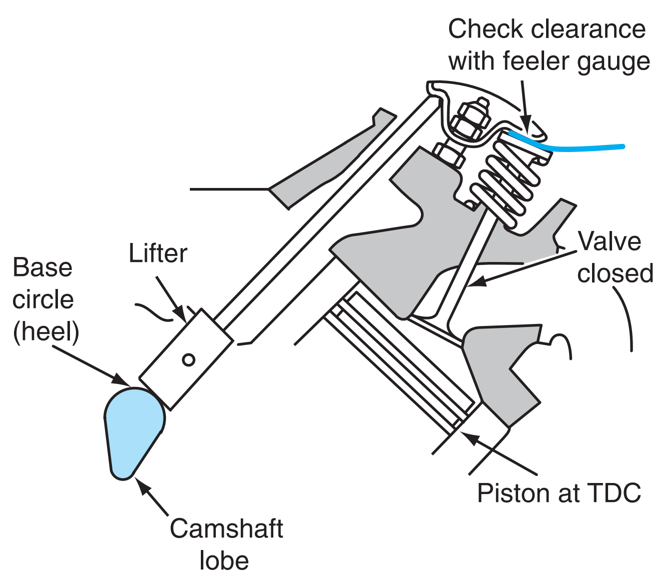


FIGURE 17.59 When a mechanical valve adjustment is required, adjust valve clearance when the lifter is on the base circle of the cam lobe and the piston is at TDC.

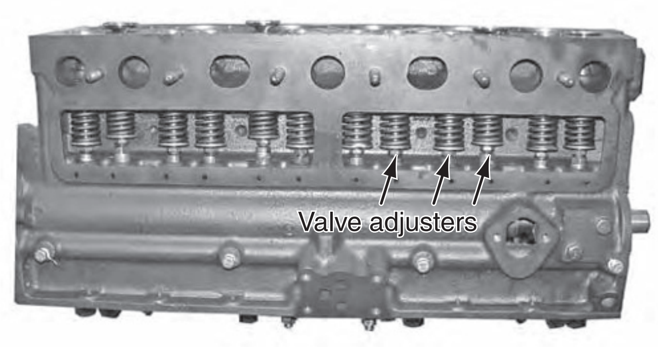


FIGURE 17.60 Typical valve adjustment on a vintage flathead engine involves the removal of access panels on the side of the block. (*Courtesy of Tim Gilles*)

- Insert a feeler gauge of the specified thickness between the rocker arm and the valve tip, and take up the clearance at the rocker adjustment screw (**Figure 17.60**).

SHOP TIP

Be very careful when measuring adjustable valve clearance. If you think the clearance is too loose, try fitting a 0.001" thicker feeler gauge into the opening. This is called the "go/no-go" method. With many modern engines, you will be able to *force* a thicker feeler gauge into the clearance space. This can result in too tight a clearance adjustment. The go/no-go method of checking valve lash can prevent problems.

Screw and Locknut Adjustment. On one cylinder head design, a feeler gauge of the specified thickness is inserted between the rocker, or cam follower, and the cam lobe while the lobe faces away. Then the clearance is adjusted (**Figure 17.61**). Two tools are needed; one loosens the locknut while the other makes the adjustment.

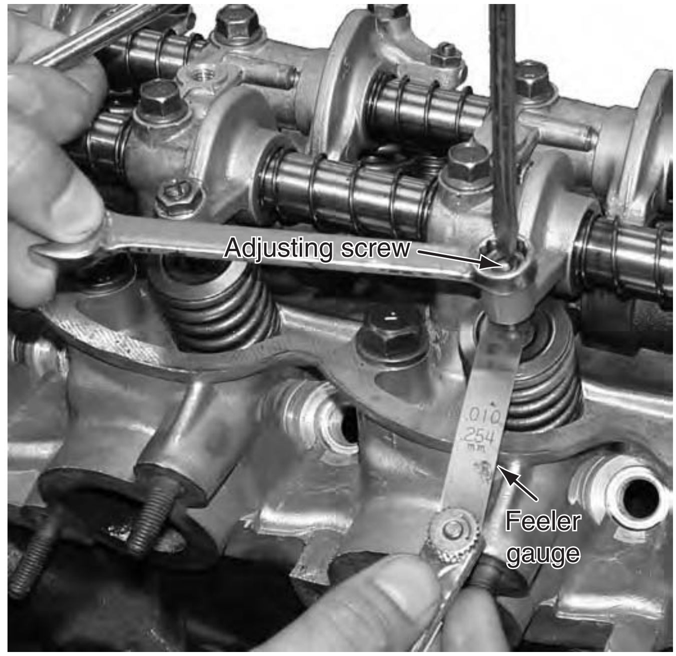


FIGURE 17.61 Typical OHC valve adjustment on a head with rocker arms. This is done while the lobe faces away from the rocker arm. (*Courtesy of Tim Gilles*)

Bucket and Shim Adjustment. On some OHC engines, the cam lobe opens the valve through an adjustable cam follower (often called a "bucket"). One type of head design uses different thicknesses of shims called lash pad adjusters (**Figure 17.62**). A shim can be removed with a blast of compressed air and a new one of the correct thickness is then installed. A special tool is available that forces a pair of buckets away from the cam so that the shims can be replaced during a valve adjustment. Chapter 8 describes this procedure and also one for performing this adjustment as part of a valve grind.

VINTAGE ENGINES

Pushrod engines with solid lifters often required periodic valve adjustment. This is best done on a hot engine, provided a hot clearance is specified. If the manual specifies H (*hot*) and no cold specification is given, readjust the clearance after the engine warms up.

Flathead engines, also called L-head engines, were popular until the early 1950s. A typical flathead like the Studebaker six cylinder engine shown in Figure 17.60 had removable covers on the side that allowed access to the valve adjusters at the bottoms of the valve stems.

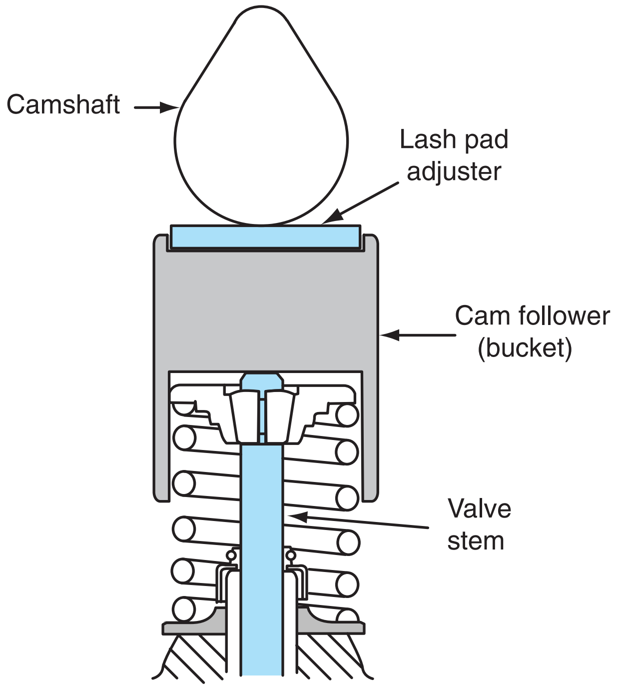


FIGURE 17.62 Some OHC engines use different thicknesses of discs to adjust valve lash.

One vintage cam follower has a tapered adjusting screw where each turn of the screw changes clearance by 0.003".

Hydraulic Lifter Lash Adjustment

It is best to adjust hydraulic lifter lash on V-type engines before the intake manifold is installed, because you will be able to see the lifters that are on the heel of the cam lobes and are positioned low in their bores (**Figure 17.63**).

Some service information lists another procedure for hydraulic lifter adjustment.

- The crank timing indicator on the damper is aligned with the TDC mark on the timing cover while a group of valves specified in the manual are adjusted.
- Then the crank is rotated one revolution and the remaining valves are adjusted.

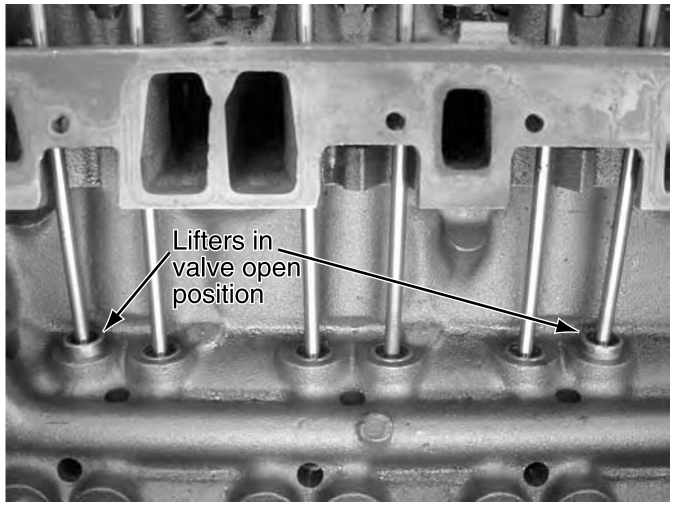


FIGURE 17.63 If hydraulic lifter lash is adjusted before installing the intake manifold, it is easy to see which lifters are on the heel of the cam. (*Courtesy of Tim Gilles*)

Install the Intake Manifold

Sometimes parts need to be installed before the intake manifold, in the valley area between the cylinder heads, for instance. **Figure 17.64** shows a cooling system pipe, core plugs, and a detonation sensor that need to be installed prior to installing the intake manifold.

Be certain nothing is accidentally left in the engine before installing the oil pan or intake manifold. **Figure 17.65** shows the result of a careless engine assembly where a shop towel was left inside the engine.

Chapter 16 describes the precautions to take when sealing an intake manifold. Torque the

VINTAGE ENGINES

Vintage pushrod engines had a specified amount of hydraulic lifter preload to obtain a correct adjustment. The correct hydraulic lifter adjustment is obtained by depressing the lifter's plunger into the lifter bore for a specified number of turns. Check the valve lash specifications in the service information and tighten the rocker arm adjusting nut while feeling the pushrod to check for clearance. Chapter 9 describes the procedure for adjusting hydraulic lifters in detail.

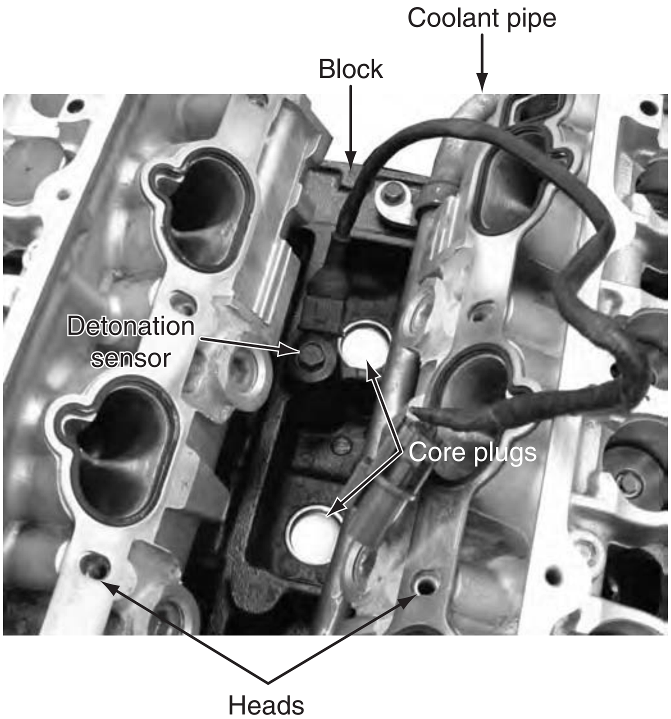


FIGURE 17.64 Before installing the intake manifold, other items sometimes need to be installed. On this engine installation of these parts is easier before installing cylinder heads also. (*Courtesy of Tim Gilles*)

manifold according to specifications found in the service information (**Figure 17.66**). Be sure to follow the torque sequence.

Install the Thermostat

Install the thermostat with the temperature sensor facing into the block. If the thermostat is installed the other way, the engine will overheat (see Chapter 15). Always install the correct temperature thermostat.

FIGURE 17.65 A shop towel left inside the engine resulted in engine failure. This is what remains of the connecting rod and piston pin. (*Courtesy of Tim Gilles*)

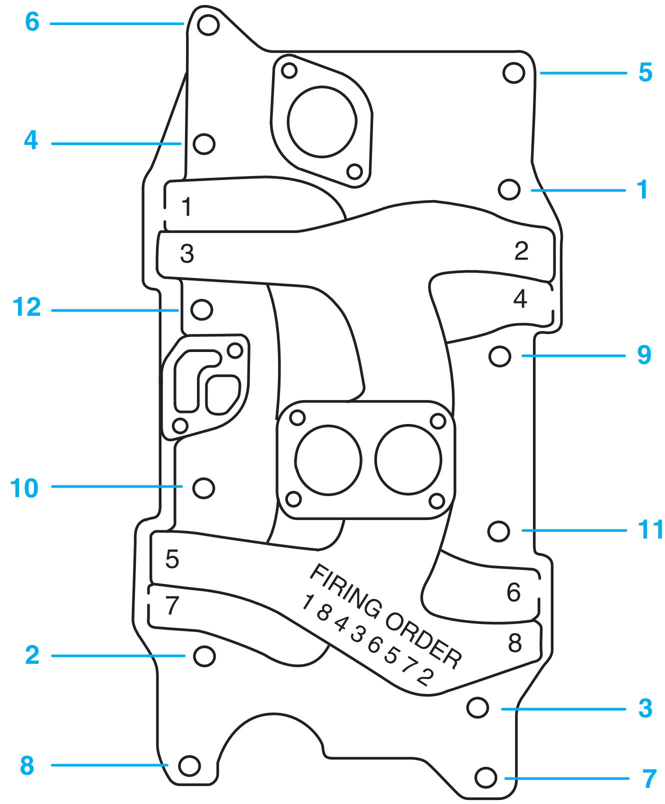


FIGURE 17.66 Intake manifold torque sequence. Notice the firing order and cylinder numbers cast on the manifold of this vintage engine with a carburetor.

CASE HISTORY

An apprentice was finishing the installation of a rebuilt engine by installing the thermostat and all of the belts and hoses. After the engine was started, he took the car on a test drive. After a very short distance, the engine overheated. Further investigation by the shop foreman showed that the thermostat had been installed backwards. With the temperature sensing bulb facing toward the radiator, the thermostat could not sense the heated coolant in the block. Correctly installing the thermostat corrected the overheating problem.

COMPLETION OF ASSEMBLY

A good paint job is an important part of a professional engine rebuild (**Figure 17.67**). It is easier to paint the engine after it is completely assembled. Exhaust manifolds should not be painted, so paint the engine before they are installed.

VINTAGE ENGINES

When engines had cast iron heads and blocks, in frost-free areas of the country, many people would neglect their cooling systems and not use coolant. Today's engines have aluminum parts and must use coolant with anticorrosion additives. Aluminum water outlet housings are not very durable when used with water alone. An iron water outlet is a better choice, unless the head is made of aluminum.

VINTAGE ENGINES

Engines with carburetors had mechanical fuel pumps. To install one of these on the engine, first rotate the crankshaft until the fuel pump eccentric is at its lowest position in relationship to the pump. Otherwise it can be difficult to install the pump. If there is a spacer plate beneath the fuel pump, be sure it is in place. Tightening a pump against the block without this spacer in place will overstretch the fuel pump diaphragm, ruining it.

FIGURE 17.67 A good paint job is an important part of a professional engine rebuild and adds to the customer's perception of high-quality work. (*Courtesy of Tim Gilles*)

SHOP TIP

Apply a thin layer of grease to exhaust gasket surfaces. This makes it easier to remove paint from these areas. Screw old spark plugs into the plug holes during painting.

- Spray one light coat of paint. This is called a **tack coat**. Wait until it becomes tacky to the touch.
- Spray the second coat. Spraying the second coat after the first coat becomes tacky will prevent runs and promote better paint coverage.

NOTE

When painting a small part, be sure to use a large enough piece of paper beneath the part (**Figure 17.68a**). Using too small a piece of paper (**Figure 17.68b**) results in overspray getting on a floor or workbench—a sure way to make an employer unhappy.

Spin Testing

High-volume engine rebuilders use a **run-in stand** to **spin test** rebuilt engines following assembly. The engine is rotated at 500–600 rpm by a machine while the lubrication system has oil pressure. Major problems can be spotted using this test before a defective engine leaves the rebuilder. One of the advantages of a long block over a short block

(a) RIGHT (b) WRONG

FIGURE 17.68 (a) When painting small parts, be sure to use a large enough piece of paper beneath the parts. (b) Too small a piece of paper beneath the part results in overspray on the ground—a sure way to make your boss unhappy. (*Courtesy of Tim Gilles*)

is that certain tests and adjustments are possible during spin testing.

- Compression and oil pressure can be checked.
- Cam, rod, and main bearings can be visually checked for excessive bearing oil leakage.
- Valve adjustment can be performed.
- Lifter rotation can be checked.

With the oil pan and valve covers installed, oil leaks can be pinpointed. Some rebuilders choose to spin test the engine for a longer period to verify that oil pressure does not decrease when the oil heats up during the test. The oil is not artificially heated but as the engine spins, shearing of the oil results in the conversion of mechanical energy to heat.

Rebuilders who use a dynamometer (see Figure 10.81) for spin testing break in the engine at 10% load. When running an engine on a dyno at high rpm, a remote control should be used so the operator will not be injured if an engine part should fail.

Install Exhaust Manifold(s)

Some in-line engines use a combined intake and exhaust manifold gasket. After the block assembly is painted, install the exhaust manifold(s).

- Check the service information for an exhaust torque sequence. If one is not specified, tighten the bolts in the center of the manifold first to prevent cracking it (see Chapter 16).
- If there are dowel holes in the exhaust manifold that align with dowels in the cylinder head, make sure that these holes are larger than the dowels. If the dowels do not have enough clearance because of the buildup of foreign material, the manifold will not be able to expand properly and might crack.
- Tighten the individual manifold-to-engine bolts first.
- Then tighten the bolts where the two parts meet.

Install Flywheel or Flexplate

Many engines have a thin, steel plate installed between the engine and transmission housing (**Figure 17.69**). Part of this plate covers parts of the clutch or torque converter housing. First-time engine installers sometimes forget to install this part before installing the flywheel or flexplate.

- Reinstall the engine sling as described in Chapter 4.
- Raise the engine into the air on a suitable lift, and remove the engine stand mounting head.
- Set the assembled engine on the floor and support it with blocks of wood while attaching the flywheel (on standard transmission vehicles). Be sure to use the right flywheel bolts and lock washers. These bolts have very thin heads and the lock washers are thin. If normal bolts or washers are used, they can cause interference with the clutch disc or the torque converter.
- If the engine has a single-piece rear main seal, sealer may be needed on the flywheel bolts (see Chapter 16).

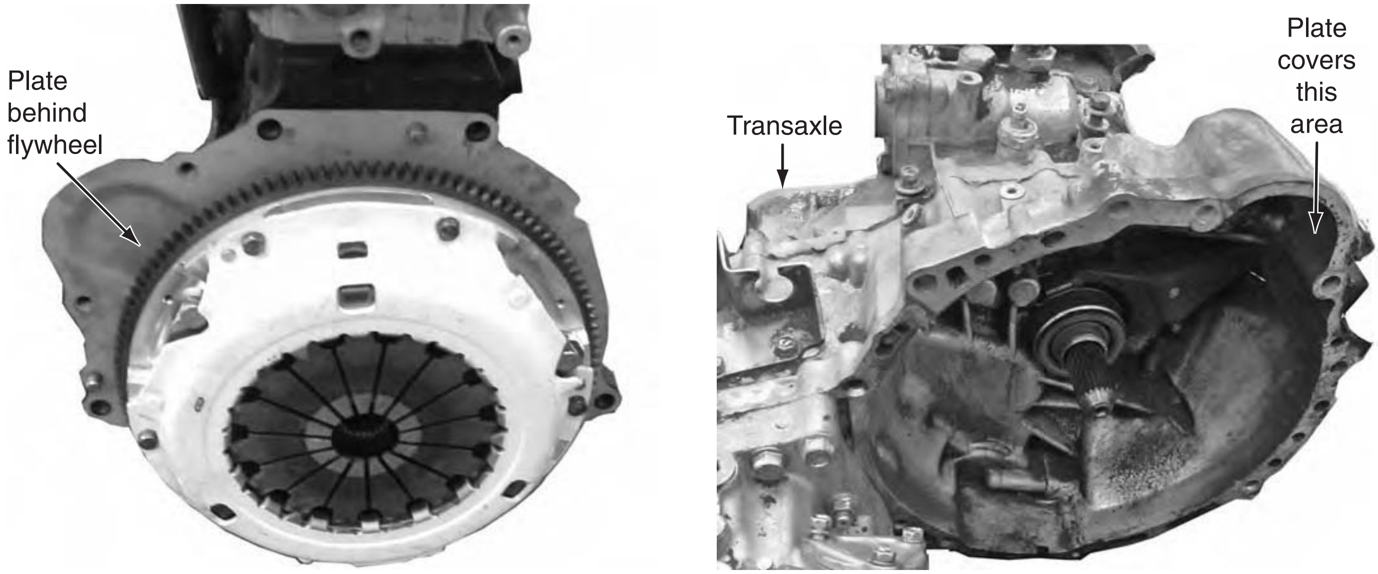


FIGURE 17.69 Do not forget to install the plate between the engine and the flywheel. (*Courtesy of Tim Gilles*)

- Make sure that the bolts are properly torqued in the correct sequence. If a torque specification is not available, use the bolt torque chart in the appendix at the back of this book to determine the correct torque.

Install Clutch Parts

If the vehicle has a manual transmission, install the clutch. Parts of a clutch assembly are shown in **Figure 17.70**. Clutch operation is not discussed here.

- Check to see that the pilot bushing or bearing for the transmission input shaft is installed at the rear of the crankshaft and in good condition (**Figure 17.71**). If the bushing must be removed, use a puller (**Figure 17.72**). On vehicles with pilot bearings, a trick that sometimes works is to pack the cavity behind the bearing with grease, and then insert the largest bolt that will fit into

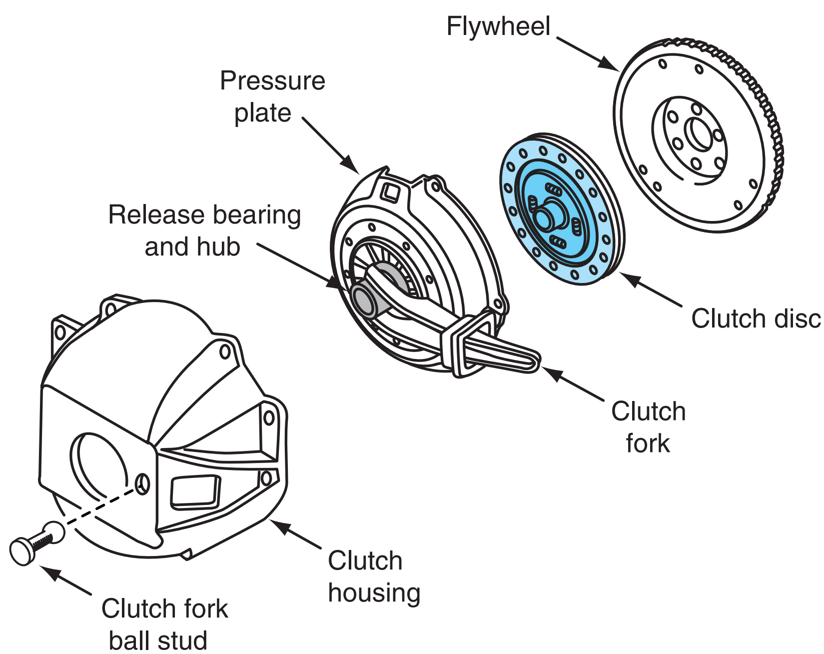


FIGURE 17.70 Parts of the clutch assembly.

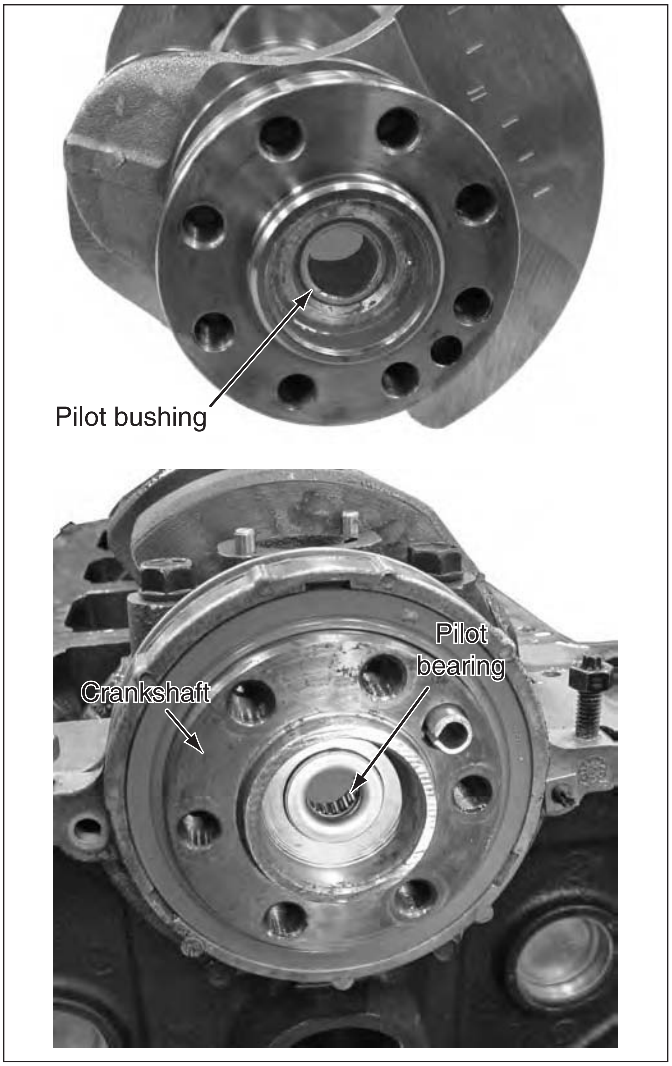


FIGURE 17.71 Check the pilot bushing or bearing. These are commonly replaced when a new clutch is installed. (*Courtesy of Tim Gilles*)

the I.D. of the bearing. Pounding on the bolt forces the bearing from the hole.

- Use a clutch aligning tool to align the clutch disc to the pilot while you attach the disc and clutch pressure plate to the flywheel. Injection molded plastic clutch pilots are available for each make of vehicle. One is shown in use in **Figure 17.73**.
- Be careful to install the disc in the right direction. There should be a marking on it that says "flywheel side."

NOTE

When installing the flywheel, be sure to torque to specifications. Uneven or excessive tightening can distort the rear seal surface on the crankshaft, resulting in an oil leak. Sometimes tightening procedures involve several torquing steps.

FIGURE 17.72 A pilot bushing puller. Sometimes the puller must be disassembled (center photo) so the jaws can fit into the hole in the pilot bushing. (*Courtesy of Tim Gilles*)

Install Torque Converter

If the vehicle has an automatic transmission, before installing the torque converter, it is a good practice to replace the front pump seal (see Chapter 16). If the transmission was removed from the vehicle along with the engine, reinstall it on the engine now.

Be certain that the torque converter is correctly engaged with the transmission front pump gear (**Figure 17.74**). It will drop deeper into the transmission, and the drive lugs on the converter should be felt engaging the transmission pump gear (**Figure 17.75**). Failure to install the converter correctly can damage the transmission pump (**Figure 17.76a**). **Figure 17.76b** shows a view looking into a torque converter. When a torque converter is installed into an automatic transmission, at least three areas must align with other members: the pump drive, the stator support splines, and the input shaft splines. Some lockup torque converters have an additional splined area for another small input shaft.

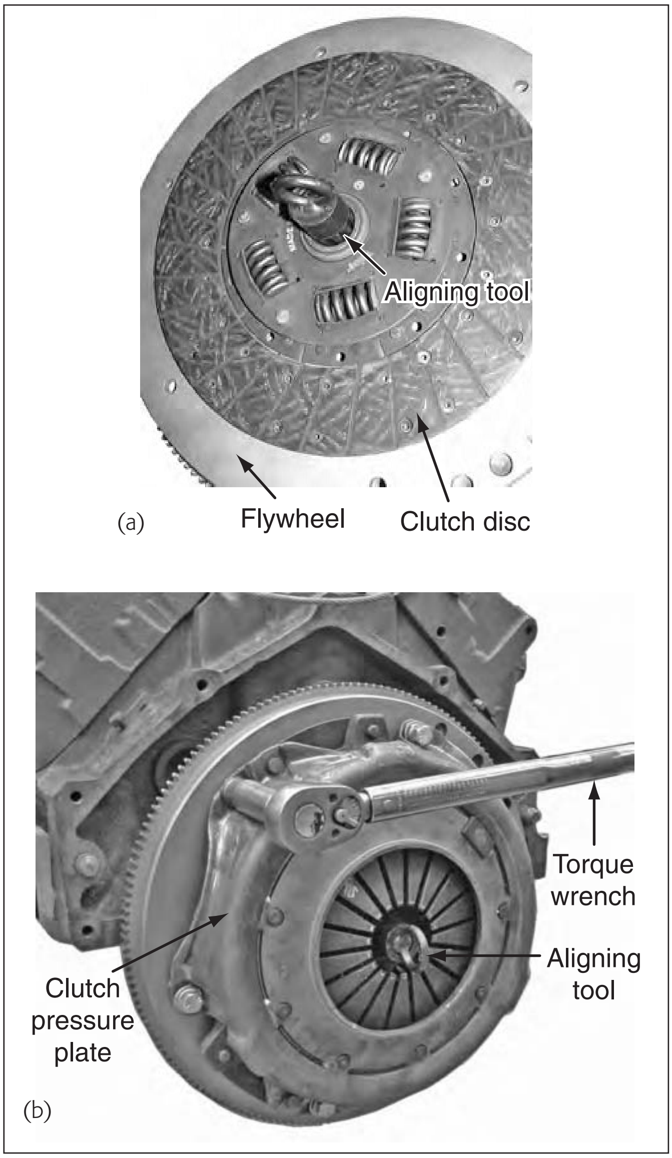


FIGURE 17.73 Clutch installation. (a) Align the clutch disc with an aligning tool. (b) Torque the pressure plate to specifications. (*Courtesy of Tim Gilles*)

CASE HISTORY

An apprentice was bolting an automatic transmission to a rebuilt engine. There was a gap of about ⅜" between the engine and transmission. He installed two bolts through the transmission into the back of the engine and began to tighten them, forcing the engine and transmission together. The result was a cracked transmission housing (Figure 17.77).

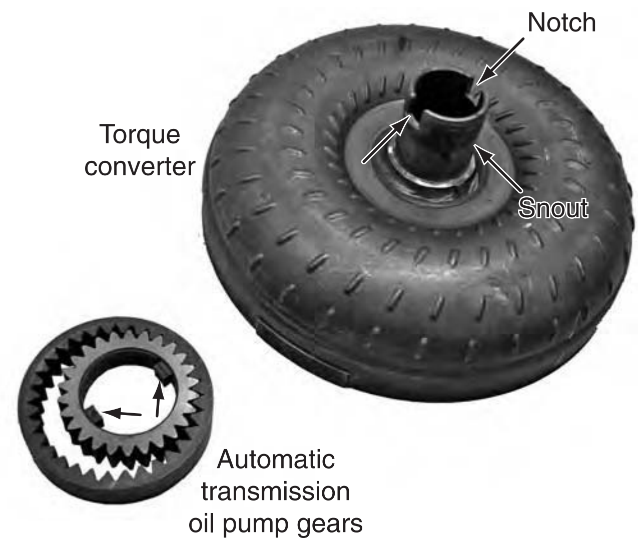


FIGURE 17.74 The torque converter drives the automatic transmission oil pump. During engine installation the notches on the converter must be aligned with the tabs on the gear. (*Courtesy of Tim Gilles*)

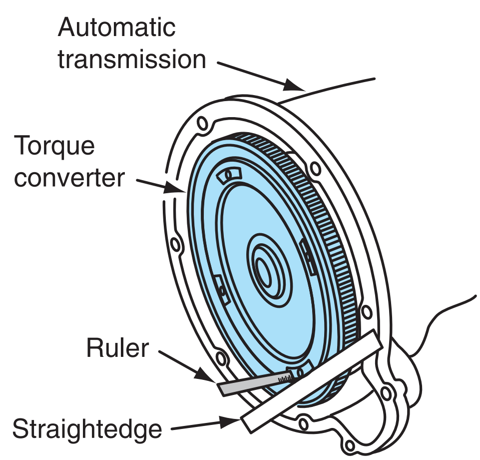


FIGURE 17.75 Be certain to verify that the converter is installed all the way into the transmission housing.

Install Engine Mounts

Many technicians like to install the engine mount bolts loosely on the block during engine installation so that the mounts can be more easily aligned with the frame mount brackets. A *rolling head prybar* (**Figure 17.78**) is handy when aligning mounts. Use the pointed end to line up the mount bolt holes before installing the mount bolts. Make sure the mounts are in like-new condition if reused.

ENGINE INSTALLATION

Install the engine in the vehicle. Be sure to use fender covers. Be especially careful when using a chainfall. The chain can nick the car's paint.

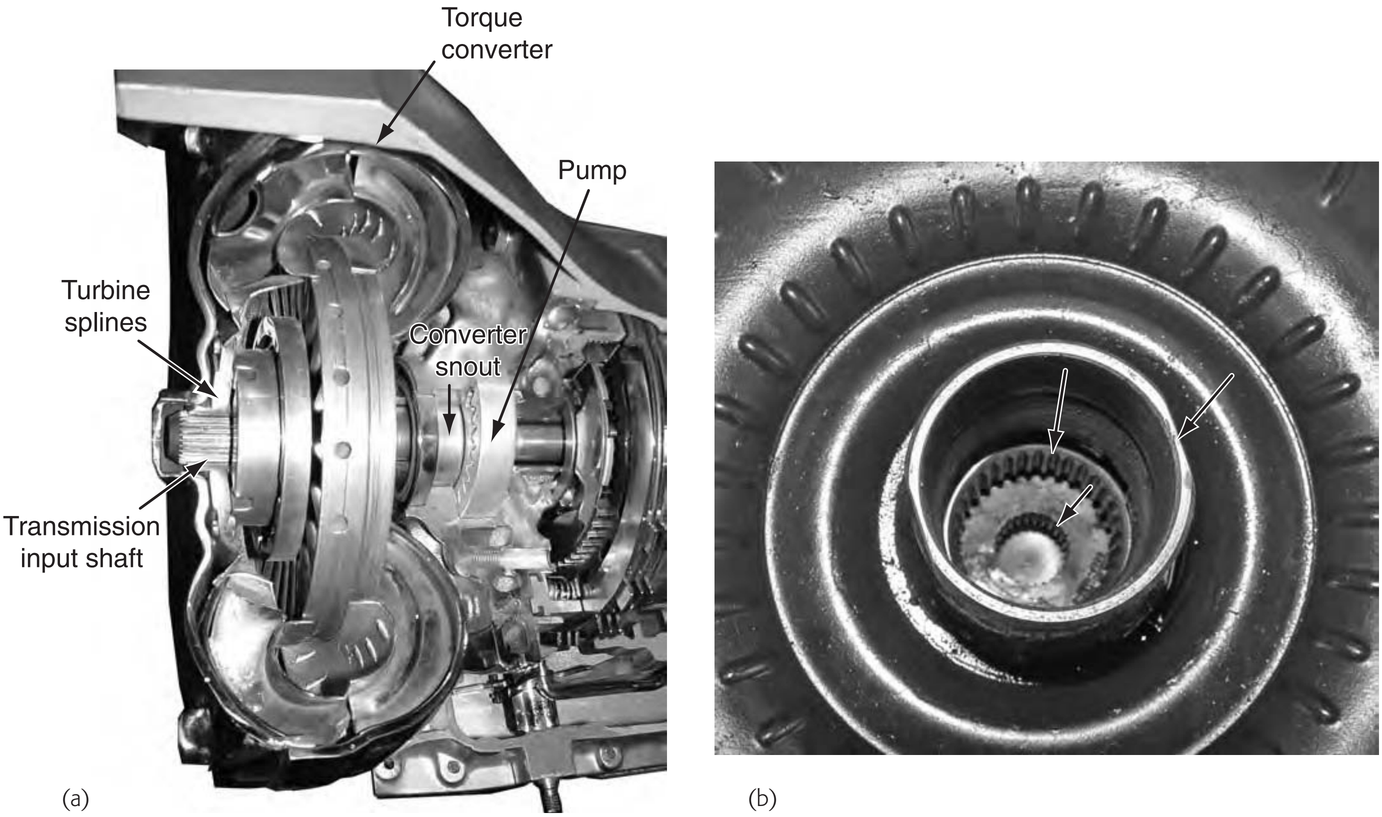


FIGURE 17.76 (a) Cutaway showing the relationship between the torque converter and pump. Also notice how the input shaft intersects the converter's turbine splines. (b) Three areas that must slide onto or into other members during torque converter installation into an automatic transmission transaxle. (*Courtesy of Tim Gilles*)

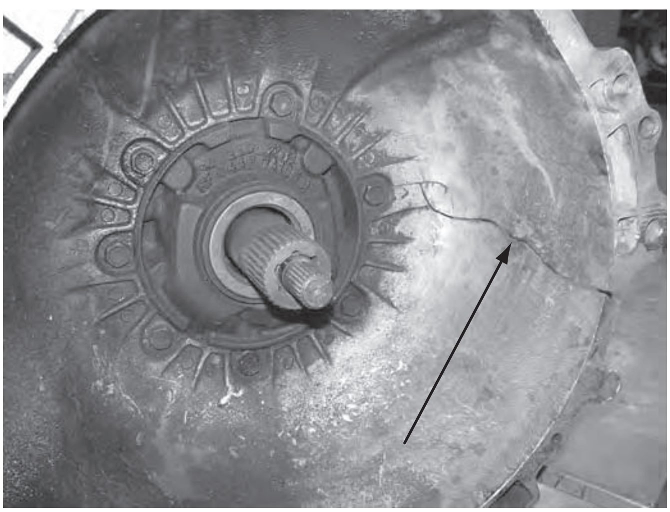


FIGURE 17.77 This transmission housing was cracked when an apprentice forced the transmission against the engine by tightening the bolts. (*Courtesy of Tim Gilles*)

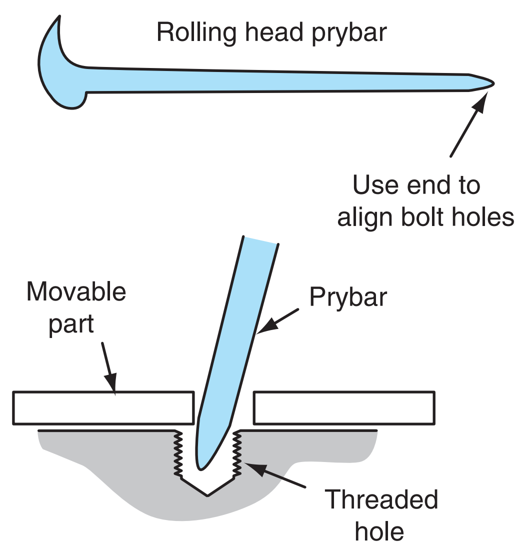


FIGURE 17.78 A rolling head prybar is helpful when aligning engine mounts.

If the transmission was not removed from the vehicle, use a floor jack or a transmission jack under the transmission to help align it with the engine. Guide pins will be especially helpful when a manual transmission is still in the vehicle (**Figure 17.79**). This is usually the case when a heavy truck transmission is involved.

The clutch or converter housing is aligned to the engine by dowels or bushings (**Figure 17.80**). Be certain these are not missing or damaged. Dirt or

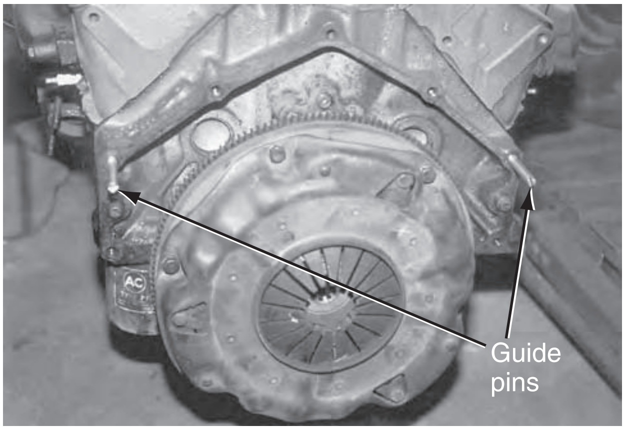


FIGURE 17.79 Guide pins to aid in transmission housing installation. (*Courtesy of Tim Gilles*)

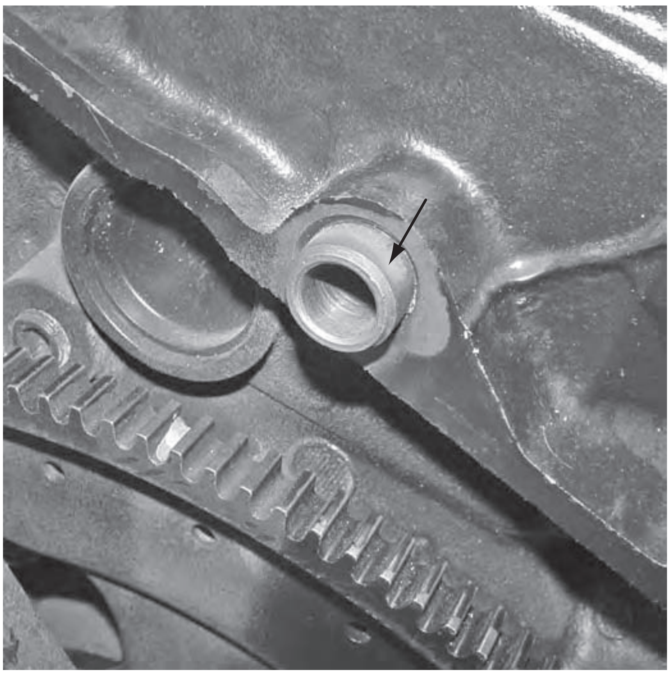


FIGURE 17.80 This bushing is one of two that aligns the engine and transmission. Be certain it is present and in good condition. (*Courtesy of Tim Gilles*)

imperfections in the surface area of contact between the engine and the transmission can result in vibration. Some vehicles have the starter motor mounted to the transmission. If an alignment bushing is missing, the starter motor pinion gear might not align correctly with the starter ring gear on the flywheel or flexplate. This will prevent the starter motor from being installed because the plate between the engine and transmission is not aligned. Loosening the transmission housing bolts will allow the plate to move so the starter can be installed. Some problems can result from this solution, however. A broken flexplate can result if the engine and transmission are not precisely aligned. This can also prevent the starter pinion gear from continuing to run at the same depth on the starter ring gear as the flexplate rotates.

CAUTION

Do not use engine mount bolts to pull a V-type engine into place. Use shims if necessary to fill any gaps between the mount and block (**Figure 17.81**). The AERA reports numerous cases of block distortion and scuffed pistons in cylinders near mounts that were forced tight.

Connect Accessories. Install all previously disconnected parts.

With automatic transmissions, bolt the torque converter to the flexplate (**Figure 17.82**). Align the converter with the factory marks or with marks made during disassembly. Some converters have drain plugs that must align with holes in the flexplate.

NOTE

The Automatic Transmission Rebuilders Association (ATRA) recommends that there be at least 1⁄16" clearance between the flexplate and converter to allow for converter expansion; 1⁄8" is preferred and 3⁄16" is the maximum.

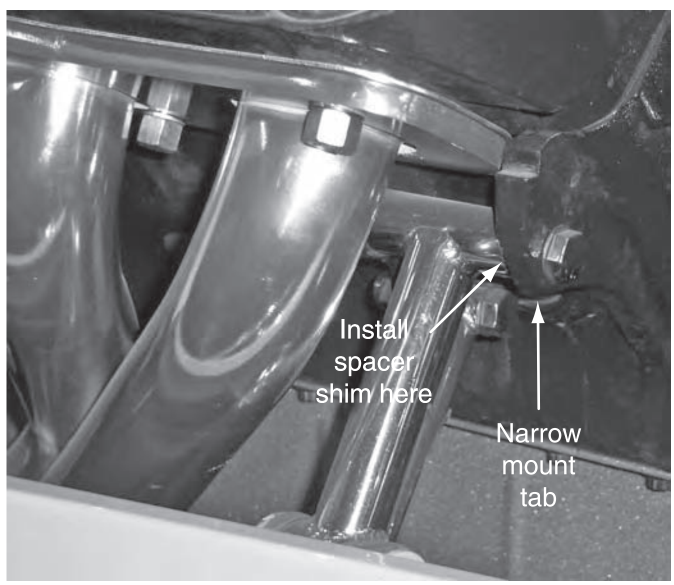


FIGURE 17.81 This Chrysler block has a narrow, cast tab for attachment to the engine mount. Number two cylinder is located behind this tab. Forcing the tab to align with the mount can result in distortion to the number two cylinder bore and piston scuffing. (*Courtesy of Tim Gilles*)

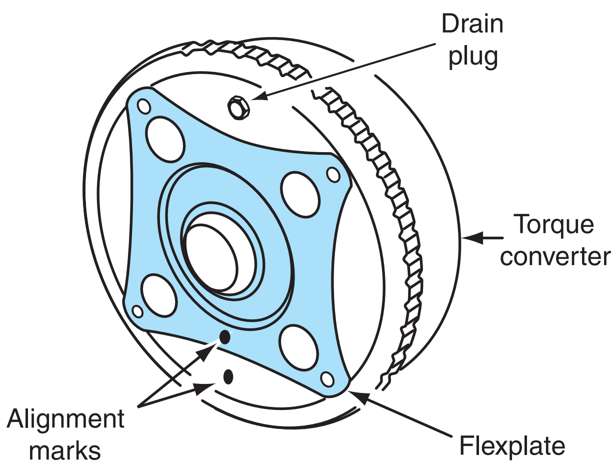


FIGURE 17.82 Be certain that the flexplate and converter are properly aligned.

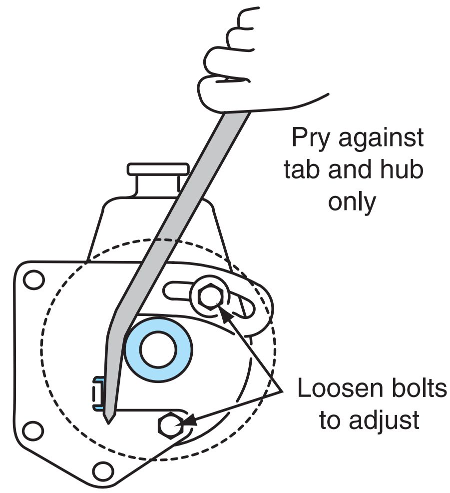


FIGURE 17.83 When tightening the power steering belt, pry only in the designated area to avoid damage.

- Attach the exhaust pipes using new nuts. Brass nuts are preferable, if they are available.
- Install all pulleys, accessories, and belts. If the engine has V-belts, use a belt tension gauge to adjust belt tension. Manufacturers usually provide a suitable place to pry on the pump housing (**Figure 17.83**). When adjusting power steering belt tension, be careful not to pry against the sheet metal portion of the pump; the pump may be damaged.
- Install the radiator, radiator hoses, and heater hoses. Then fill the system with the appropriate coolant.
- Reattach all electrical wires and vacuum lines.

Install Fuel System Components

Install the fuel injection rails, hoses, and electrical connectors. If you replace hose clamps, be sure that they are of the full round type used with high-pressure fuel injection systems, not the kind used with carburetors or cooling systems.

Prime the Lubrication System

Install the sending units for temperature and oil pressure. After installing the oil filter, add oil to the crankcase and prime the system. Lubrication system priming is discussed in detail in Chapter 14.

VINTAGE ENGINES

Until the mid-1980s, many North American vehicles had carburetors. Some engines came with different carburetors, so you always want to save the old gasket to compare with the new one. The small-block Chevrolet, for instance, had 28 different carburetor gaskets available for its many manifestations.

The *small block* Chevrolet was first produced as a 265-cubic-inch version in 1955. In 1957, it became a 283. In 1962, its bore and stroke were increased and it became a 327. In the mid-1960s, the 302 (5 liter) and 350 (5.7 liter) were introduced. Later engines included the 305, 307, and 400-cubic-inch versions. The last year of what later became known as the Generation One Small Block was 1992. Generation Two engines, built until 1997, were based on the earlier design but had aluminum heads and other refinements.

VINTAGE ENGINES

The mechanical fuel pump diaphragm used with a carburetor accumulates particles of dirt. Before a rebuilt engine is started, the carburetor is usually dry so the fuel pump diaphragm moves farther than normal, breaking dirt off the diaphragm and clogging the fuel system. To prevent this, prefill the carburetor or pump some fuel out of the line from the pump before connecting it to the carburetor.

Priming Crankshaft-Driven Oil Pumps. On engines with crankshaft-driven oil pumps, use a pressure primer (see Chapter 14) or remove all spark plugs and crank the engine. Continue cranking until oil is distributed throughout the engine or until the gauge has registered oil pressure for 30 seconds. It is much easier on the engine to prime the system first than to start the engine and wait for the pump to prime itself while the engine runs without oil. It is also a good idea to fill the oil pump housing with a low melting point assembly lubricant during engine assembly so the oil pump can begin pumping as soon as the engine is cranked.

Install Valve Covers

When oil is apparent at the rocker arms, the engine is primed and the valve covers can be installed. It is easier to position the engine at TDC on number one before installing the valve covers, so do that first. When installing the valve covers on V-type engines, be certain that the breather and oil filler openings are on the correct sides of the engine. If all the valve cover screws cannot be screwed in easily by hand, try installing the valve cover in the opposite direction.

IGNITION SYSTEM INSTALLATION AND TIMING

There are two predominant ignition system designs: distributor and distributorless. Most new engines no longer have distributors, but there are still many that do. Some engines with a distributor must be precisely timed after installation.

VINTAGE ENGINES

When pushrod engines had distributors, it was common practice to prime distributor driven oil pumps, with the distributor removed, by driving the oil pump with a drill. If you do this, remember that not all distributors are clockwise rotating so be sure to use a drill that turns in the same direction that the distributor normally rotates. On earlier small-block GM engines, pressure will not be sufficient to pump oil to the rocker arms unless the distributor shaft is installed in a distributor housing. Check the lubrication diagram in the service manual to see if oil travels around the distributor housing in the engine being primed.

A pushrod engine lubrication system cannot be primed by driving the oil pump unless there is a gear on the bottom of the distributor (see Figure 9.4). Otherwise the oil pump has a gear that is in constant mesh with the distributor drive gear on the camshaft.

VINTAGE ENGINES

All older engines were equipped with ignition distributors with adjustable ignition timing. Before installing a distributor, first align the timing mark on the crankshaft pulley with the TDC mark on the timing cover (**Figure 17.84**). Some engines have a timing mark located on the flywheel, visible through a small opening in the top of the transmission housing (**Figure 17.85**). When the marks are aligned, either the number one cylinder or its companion cylinder is at the top of its compression stroke. The spark plug should be ready to fire. If the distributor is installed 180° off, backfiring will occur and the engine will not run.

To be sure that the number one cylinder is on its compression stroke, observe the rocker arms to see if they are both moving. Rotate the crankshaft until the rocker arms for the companion cylinder to number one are both moving at TDC. Align the timing mark and install the distributor with its rotor pointing to the number one spark plug wire in the distributor cap.

The distributor might not drop down all the way into the block. The engine can be cranked or turned by hand until the distributor and oil pump are aligned (see Chapter 14). When they are aligned, the distributor will drop the last ¼" or so until it is flush with the block.

Timing the distributor with the engine stopped is referred to as **static timing**. Make sure that the spark plug wires are correctly installed on the distributor cap. They must be installed in the right firing order and in the direction of the distributor's rotation. **Figure 17.86** shows a distributor with counterclockwise rotation and a firing order of 1 5 4 2 6 3 7 8. Check the book! The firing order for a 302 (5-liter) Ford can be either 1 5 4 2 6 3 7 8 or 1 3 7 2 6 5 4 8, depending on the model year or application.

Ignitions before the mid-1970s often had mechanical contact points that triggered the ignition system. Ignition timing was advanced according to engine speed or load by mechanical and/or vacuum advance mechanisms. These systems evolved, first with electronic systems that replaced the contact points with a transistor and ignition module. Later systems have timing advance controlled by inputs to the PCM (the vehicle's main computer).

The following describes how to install and time a distributor with ignition points.

On most engines, the distributor and oil pump rotate in the same direction the vacuum advance points toward the distributor. **Figure 17.87** shows two distributors that turn in opposite directions. When a distributor has mechanical spark advance, another way to check for direction of rotation is to "snap" the rotor in one direction while the distributor shaft is held stationary. The rotor will be spring-loaded only in the direction of distributor rotation.

To determine the ignition timing point, turn the distributor in its direction of normal rotation until the points just begin to open. This is when the spark will occur. With the ignition system on and a test light connected to the distributor side of the coil and to ground, rotate the distributor slightly in the direction it normally rotates until the light goes off. Then slowly turn the distributor in the opposite direction until the points open and the test light comes on, indicating ignition.

Electronic ignition distributors are timed in the following way. The electronic ignition pulse occurs when the armature pole, or trigger, lines up with the magnetic pickup in the distributor (**Figure 17.88**).

(*Continued*)

VINTAGE ENGINES (CONTINUED)

The tooth on the armature must align perfectly with the pickup, or an error in timing will result. Align the timing mark on the crankshaft at the number of degrees of advance specified in the service literature. Then rotate the distributor to position the trigger. In Figure 17.88 a magnetic pulse generator ignition system is shown. Other types of distributors are timed in a similar manner.

After reviewing the previous section on static timing, carry out the following procedure. On either type of ignition system, the ignition system can be static timed by causing the ignition system to make a spark.

- Align the timing indicator at the crank pulley to the desired timing specification.
- Install the distributor with the rotor pointing to the number one plug cable.
- Rotate the distributor body in the direction of normal distributor rotation until the rubbing block, or pole piece, is between cylinder number one and the cylinder that fires before it in the firing order.
- Hold the spark plug end of the number one plug cable near a bare metal spot on the block.
- With the ignition switch on, rotate the distributor slowly in the direction opposite to its normal rotation. When the spark occurs, the distributor is properly timed. Be sure to turn off the ignition.
- Tighten the distributor hold-down.

The timing should now be set closely enough so that the engine will start.

If the idle speed is not controlled by the computer, the engine idle will be off if the timing is wrong. If the timing is retarded, the idle will be too low. If the timing is advanced, the idle will be too high. Remember this before changing the idle adjustment screw.

FIGURE 17.84 A typical ignition timing mark on a pre-OBDII engine. (*Courtesy of Tim Gilles*)

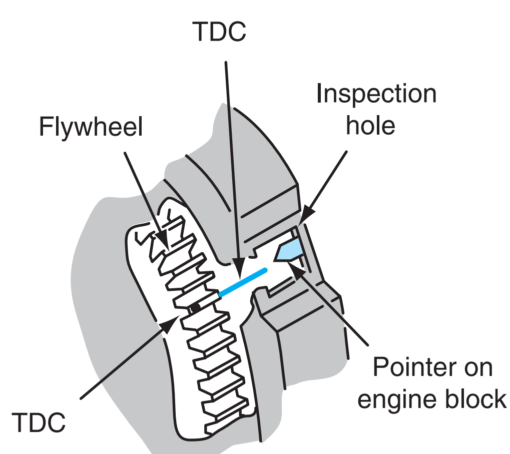


FIGURE 17.85 Some older engines had the timing mark located on the flywheel.

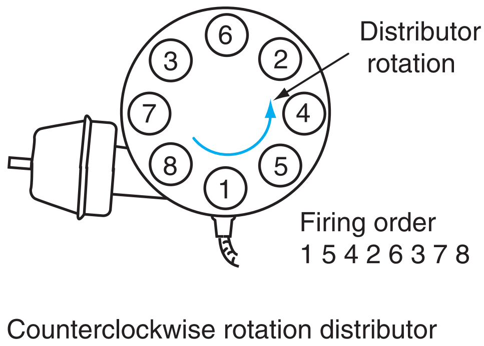


FIGURE 17.86 On engines with distributors, make sure that the spark plug cables are in the right order and position.

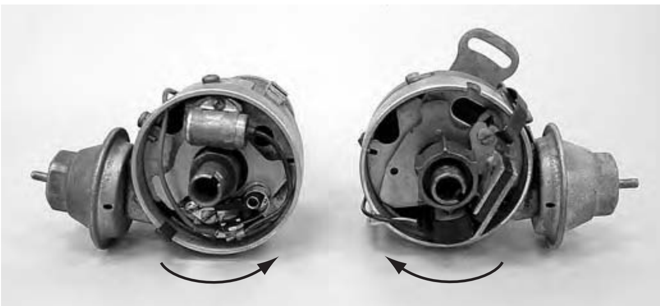


FIGURE 17.87 These vintage distributors rotate in opposite directions; the one on the left turns counterclockwise. (*Courtesy of Tim Gilles*)

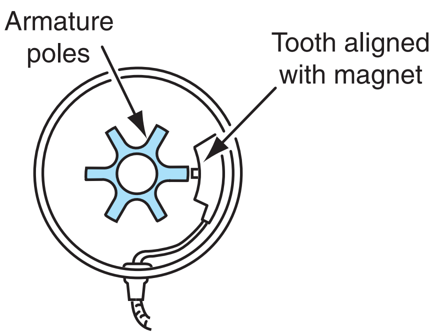


FIGURE 17.88 Timing a magnetic pulse generator distributor. This one is from a six cylinder vehicle.

FIGURE 17.89 This engine uses a distributorless ignition system with individual coils located at each spark plug. (*Courtesy of Tim Gilles*)

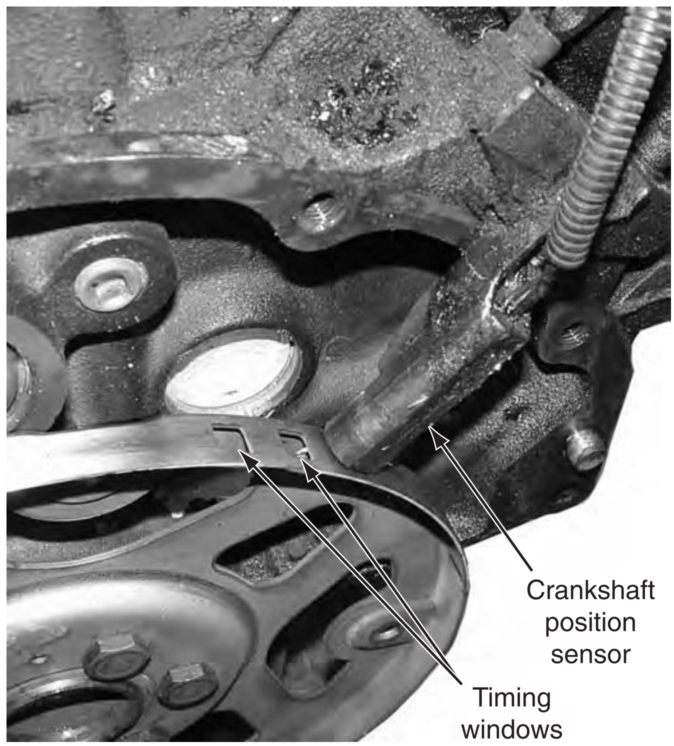


FIGURE 17.90 The crankshaft position sensor "reads" the holes in this flexplate to determine the position of the crankshaft so the computer can control the timing. (*Courtesy of Tim Gilles*)

Distributorless Ignitions

Distributorless, or direct ignition systems, are common on newer vehicles. With these ignition systems, each cylinder will have its own coil (**Figure 17.89**), or sometimes two cylinders share a coil. An electronic ignition module, often located under the coil assembly, is connected to the vehicle computer and controls the firing order and ignition advance. A crankshaft position sensor (**Figure 17.90**) tells the computer where the crankshaft is located and the computer adjusts the spark timing accordingly. Many engines since the mid-1990s have had camshaft position sensors, also called cam angle sensors, as well (**Figure 17.91**). These are used primarily for misfire detection, variable valve timing, and timing sequential fuel (port) injectors.

FIGURE 17.91 This camshaft position sensor for a pushrod engine is installed in a hole at the back of the engine above the camshaft. (*Courtesy of Tim Gilles*)

ENGINE STARTING AND BREAK-IN

The first few minutes of an engine's operation are critical to its long life. A new part might look smooth to the naked eye. Compared to a used, worn-in part, however, it is rough. Moving parts are continuously separated by a film of oil; only the peaks on rough surfaces touch. If this contact occurs without scuffing (welding), the parts will wear into each other.

During break-in of a new engine, temperatures must be controlled so that the oil film will not become too thin or the clearances become too small. Heavy engine loads should also be avoided.

SAFETY NOTE

Before starting the engine, make sure that everything has been reconnected properly. Block the front wheels and apply the parking brake. If the transmission linkage was disturbed during the repair, it is possible that the car might start in gear.

CAUTION

Most manufacturers and the AERA discourage the use of *any* starting fluid. If timing, fuel, and compression are correct, starting fluid should not be needed. Excess starting fluid can cause an explosion and can damage pistons, piston rings, or gaskets. If you insist on using starting fluid, use a little instead of a lot and do *not* spray it into the engine when it is cranking or running.

After starting the engine, make sure that the engine has oil pressure and that the coolant temperature does not climb too high. Check for oil leaks. If any adjustments are needed, the engine should be shut off immediately.

Reinstall the hood. Squeeze the top radiator hose to see if it is hard (indicating a full cooling system).

SAFETY NOTE

Do not open the radiator cap unless the hose collapses when squeezed. Escaping coolant will boil when the pressure is released. Someone could be burned, and coolant will be wasted.

Road Test and Break-In

SAFETY NOTE

Before a test drive, double-check all hose connections and fluid levels. With the key off, push the accelerator to wide-open throttle (WOT). Be certain there are no binds or obstructions in the accelerator linkage. When released, the throttle pedal should return quickly to the idle position.

VINTAGE ENGINES

Sometimes, it is difficult to get fuel from the gas tank to a mechanical fuel pump on a carbureted vehicle. Try jacking up the rear of the car or hooking up a temporary electric fuel pump at the fuel hose on the carburetor to help prime the vehicle's mechanical fuel pump.

VINTAGE ENGINES

On cam-in-block engines with flat tappets, it is especially important that the engine starts immediately to avoid excessive loading between the cam lobes and the lifters. Start the engine and run it at 1500–2000 rpm for about 20 minutes to allow the cam and lifters to begin to wear into each other. If the engine does not start after 30 seconds of cranking, stop and verify the ignition timing and fuel. Idling should be avoided during this period to prevent cam and lifter failure and because during idle less oil is thrown off the connecting rod journals onto the cylinder walls, cam, and other parts that need this critical lubrication.

After the initial 20-minute period, allow the engine to idle. Setting ignition timing correctly is essential on engines where the computer does not control it. Ignition timing is checked using a timing light.

- Just a few degrees of late timing can lower power output and cause overheating.
- Advanced timing can result in damaging abnormal combustion. Also, for every 3° of extra ignition advance, a gasoline octane increase of about four numbers is required to avoid spark knock.

VINTAGE ENGINES

On older pushrod engines it was common practice to adjust valve lash with the engine idling. This was effective in locating and silencing hard-to-find valve clearance noises. Clearance fine-tuning can be done at low idle speed by inserting a feeler gauge and adjusting the screw until a slight drag is felt. Check the condition of the feeler gauge, because it can be pounded out of shape easily.

This procedure can be messy because of the oil that is being supplied to the rocker arms. During adjustment with the engine running, engine oil can run onto a hot exhaust manifold where it might catch fire. Oil will ignite when it reaches its flash point much like diesel oil self-ignites when heated under high compression. Try to minimize oil spillage.

Be sure there are no loose parts that could cause a rattle. Many late-model cars have knock (detonation) sensors that will react to the frequency of the vibration of spark knock, retarding spark timing (see Chapter 3). A knock sensor can be triggered by such things as the rattle of a bad fuel pump, a loose valve adjustment, or a muffler vibrating against the frame. When the sensor retards timing, the engine idle on pre-OBD II cars will drop and performance will be erratic.

Piston rings are lapped during manufacture and will conform to the cylinder walls in a very short time. You can use the following procedure during your test drive to help seat the new piston rings. Drive the vehicle on the freeway in high gear. Accelerate from 45 mph to 55 mph and coast back to 45 mph at least ten times. This helps to seat the rings under pressure and vacuum conditions. The deceleration (vacuum) phase also draws extra oil onto the cylinder walls to prevent scuffing. Tell your customer to drive easily, with no high rpm, during the first 500 miles.

FINAL INSPECTION AND CLEANING

After all break-in procedures are completed, double-check for oil leaks. Make certain that all wires and lines have been correctly reinstalled, and that all warning lights or gauges are operating properly.

VINTAGE ENGINES

Engines with carburetors were susceptible to vapor lock. In today's fuel injected engines, gasoline is supplied under higher pressure and excess fuel circulates back to the fuel tank on returnable fuel systems. Some new vehicles use returnless fuel systems to reduce potential hydrocarbon emissions when heated fuel from the engine compartment is returned to the fuel tank.

To avoid **vapor lock**, be sure all fuel lines are positioned at least ½" from any heat source and fuel filters are positioned where they can be cooled by air. A common cause of vapor lock is when a fuel line runs too close to an exhaust manifold or pipe. Vapor lock occurs when fuel vaporizes in a line and a bubble blocks fuel flow. Pump pressure will then cause the bubble to contract each time the pump pulses. When the line cools and the bubble condenses, the problem disappears.

Customer Relations

The vehicle should be clean when it is returned to the owner. Grease on the fenders, steering wheel, seats, or carpet will contribute to a poor first impression of the job. A customer who is favorably impressed will be the best source of free advertisement.

The customer should use the following break-in procedures suggested by Clevite Engine Parts:

1. Do not allow excessive engine idle for the first 3 hours of rebuilt engine operation.
2. Keep in the normal rpm range at about 75% load for the first 2 to 3 hours.
3. Engine speed should be varied as much as possible.
4. Full load or high-speed operation should be limited to less than 2 to 3 minutes at a time.
5. After high load operation, allow the engine to return to a stable operating temperature by running at light load before shutting it off.

Ask your customer to return after 500 miles for an oil and filter change. A phone call reminder is good public relations and will provide a chance to check up on any complaints. A 500-mile inspection checklist is shown in **Figure 17.92**.

Oil consumption on an overhauled engine with cast iron rings might not stabilize until all parts have broken in (seated). The customer should not be concerned until the vehicle has been driven at least 4000 miles. Instruct the customer to check the oil frequently.

500-Mile Inspection

Following an engine rebuild, check the following items:

- Check oil level.
- Check for oil leaks.
- Change oil and filter.
- Check coolant level.
- Pressure test cooling system.
- Inspect hoses and retighten hose clamps.
- Retorque all exposed fasteners.
- Check tension of belts(s).
- Adjust valves as required.
- Retorque all head bolts as required.

FIGURE 17.92 A 500-mile inspection checklist.

VINTAGE ENGINES

Certain procedures were common at the 500-mile service on vintage engines. These engines often required retorquing of the head gasket, and mechanical valve lifter readjustment was often done after the valves have seated. After a head retorque, valve adjustments might also change on pushrod engines, but this should not affect OHC valve lash. On a V-type engine with an iron intake manifold, the manifold can be retorqued when hot to help guard against air leaks.

Key Terms

assembly lubricants
run-in stand
spin test
static timing
tack coat
vapor lock

Study Questions

1. What should be done to threaded holes in the block before reassembling the engine?
2. Why is the crank pried forward and backward before torquing the thrust main bearing cap?
3. What should be installed on the rod bolts to protect the crank against accidental nicks during piston installation?
4. Why should the crank be rotated after installing each piston?
5. What procedure can be performed to its companion when a cylinder's valves are both rocking during valve overlap?
6. Would an oil pump mounted inside the crankcase usually use a gasket on its outlet?
7. If the block does not have aligning pins for the timing cover, how can the cover be aligned?
8. What service is performed on distorted stamped-steel oil-pan and valve-cover screw holes?
9. When painting, how can you protect machined areas you do not want paint to stick to?
10. When tightening the exhaust manifold bolts, which ones are tightened first: inside or outside?
11. In automatic transmission cars, which seal should be replaced while the engine is out?
12. A rolling head prybar is handy for aligning what part?
13. The engine should be run at 1500–2000 rpm for _____ minutes when first started after a rebuild.
14. How are the rings broken in during a test drive?
15. The first service and checkup is recommended at _____ miles after an engine rebuild.

ASE-Style Review Questions

1. Two technicians are discussing crankshaft bearing installation. Technician A says that upper and lower main bearing inserts are always interchangeable. Technician B says to lubricate the backsides of the bearing inserts before installing them. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. An OHC cylinder head is being installed on an engine. Technician A says that some OHC cylinder heads cannot be installed if the camshaft is not positioned correctly at TDC. Technician B says that valves can be bent if the correct procedures are not followed. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. Technician A says that a broken flexplate can result if an alignment bushing is missing and the engine and transmission are not in alignment. Technician B says that forcing an engine into alignment with its mounts can result in a distorted cylinder bore. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. Each of the following can result in reduced crankshaft bearing oil clearance EXCEPT:
   a. Dirt on the surface of the bearing bore
   b. Dirt in the recess where the bearing locating lug fits
   c. Dirt on the block or the main bearing parting halves
   d. A nick on the surface of the bearing bore

5. Following an installation of a rebuilt engine, a technician breaks in the engine by accelerating from 45 mph to 55 mph and coasting back to 45 mph several times. During this process, which of the following is/are true?
   a. Rings are pushed against the cylinder walls under pressure conditions.
   b. Rings are pushed against the cylinder walls under vacuum conditions.
   c. Oil is drawn onto the cylinder walls during deceleration to prevent scuffing.
   d. All of the above
   e. None of the above

6. Which of the following is/are true about rebuilt engine warranties?
   a. If a problem with the engine is the fault of the technician, the rebuilder is not liable for the cost of the repair.
   b. A fuel system problem can void the warranty.
   c. Engine overheating can void the warranty.
   d. Any of the above
   e. None of the above

7. A recently rebuilt engine has several burned pistons. Technician A says that pistons can burn or seize in the cylinder due to an intake manifold air leak. Technician B says that too rich an air-fuel mixture is a likely cause of this problem. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Two technicians are discussing engine installation. Technician A says to install two of the bolts and pull the engine and transmission together by slowly tightening them. Technician B says that the engine mount bolts on one side of the engine must be torqued before installing the mount on the other side of the engine. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. An engine failed because it was overheated. Technician A says that a coolant temperature sensor could be defective. Technician B says that the fan relay could be defective. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Which of the following is the best answer?
    a. It is best to install the crankshaft sprocket onto the crankshaft after the crankshaft has been installed in the block.
    b. When starting an engine with starting fluid, if the engine does not start, spray three more squirts into the air intake while you crank the engine.
    c. Pry on the sheet metal power steering pump housing to adjust the belt tension.
    d. On a pre-OBD II engine, when ignition timing is retarded, idle speed will be lower.

Appendix

Sample ASE Machinist Test Questions and Answers

CYLINDER HEAD SPECIALIST QUESTIONS

1. All of the following could be used for cleaning aluminum cylinder heads *except:*
   a. a caustic base
   b. carburetor cleaner
   c. solvent
   d. bake oven

   The best answer is A. Caustic bases can damage aluminum. The other methods of cleaning are all acceptable.

2. Valve stem height is not enough. Machinist A says that replacing the valve seat will correct it. Machinist B says that replacing the valve will correct it. Who is right?
   a. Machinist A
   b. Machinist B
   c. Both A and B
   d. Neither A nor B

   The best answer is D. Neither of the options will correct the seat height problem. Normally, valve seat height will *increase* as the seat or valve wears or is ground.

3. The following stem tip height measurements are taken on one cylinder head:

1.808"	1.822"
1.814"	1.815"
1.812"	1.810"
1.818"	1.848"

   Which of the following should be done?
   a. replace the seat on the valve with the 1.848 reading
   b. replace the seat on the valve with the 1.808 reading
   c. replace all the valve seats
   d. shim the valve springs

   The best answer is A. The stem tip height in that answer is 0.040" more than the least worn of the others.

4. An engine has a broken rocker arm. Machinist A says that a likely cause is insufficient valve-to-piston clearance. Machinist B says that a likely cause is a defective valve guide seal. Who is right?
   a. Machinist A
   b. Machinist B
   c. Both A and B
   d. Neither A nor B

   The best answer is A. The valve could have collided with the piston (due to a broken timing chain or belt, or a weak or broken valve spring). A bad valve guide seal is an unlikely cause.

5. Each of the following should be done when rebuilding an OHC head *except:*
   a. check the deck height before and after surfacing
   b. check the rocker arm ratio
   c. adjust the valve lash before installing the head
   d. set the cam timing at the TDC position before installing the head

The correct “wrong” answer is B. All of the other answers are correct.

6. An OHC cylinder head with hydraulic lash adjusters is being reinstalled on the engine. Machinist A says to fill the lash adjusters with oil. Machinist B says to adjust the valve clearance before installing the head. Who is right?
   a. Machinist A
   b. Machinist B
   c. Both A and B
   d. Neither A nor B

   The best answer is A. This type of adjuster takes a very long time to fill with oil after the engine is first started. Answer B is incorrect. Hydraulic adjusters automatically adjust.

7. A head is being disassembled. One exhaust valve is gray in color. Machinist A says that this indicates low compression in that cylinder. Machinist B says that the cylinder has a leaky guide seal. Who is right?
   a. Machinist A
   b. Machinist B
   b. Both A and B
   c. Neither A nor B

   The best answer is A. Normal color of exhaust valves is brown. A gray-white color indicates a valve running too cool, such as when compression is low. A leaky valve guide seal will cause oil buildup on the neck area of the valve.

8. A head has a scuffed valve stem. What is the most probable cause?
   a. Too little valve stem to guide clearance
   b. A bad valve guide seal
   c. Poor cooling system maintenance

   The best answer is A. Scuffed (welded) valve stems can result from too tight a fit after a guide is repaired. Err on the side of looseness.

9. How much should the interference fit be on a valve seat ring for an aluminum head?
   a. 0.001"　　b. 0.002"
   c. 0.004"　　d. 0.007"

   The best answer is D. Aluminum head seat interference is 0.006"–0.010".

10. How much interference should a cast iron valve seat ring have?
    a. 0.001"　　b. 0.002"
    c. 0.006"　　d. 0.008"

    The best answer is C. Cast iron valve seat ring interference is 0.003"–0.006".

11. Which of the following would be a correct stem-to-guide clearance measurement for a replacement valve guide?
    a. 0.0015"　　b. 0.004"
    c. 0.0005"　　d. 0.015"

    The best answer is A. Typical stem-to-guide clearance specifications run from 0.001" to 0.0035".

12. Which of the following would be a correct interference measurement for a replacement valve guide?
    a. 0.0015"　　b. 0.004"
    c. 0.0005"　　d. 0.015"

    The best answer is A. Typical guide-to-head interference specifications run from 0.001" to 0.002".

13. A new valve guide has been installed. The specification for valve clearance is from 0.002" to 0.0035". What is the smallest reamer that should be used if the new valve stem measures 0.3415"?
    a. 0.342"　　b. 0.343"
    c. 0.344"　　d. 0.345"

    The best answer is C. This is the closest size reamer to the minimum size specification of 0.3435".

14. Guides are being removed from an aluminum head. Machinist A says to counterbore the guide before driving it out. Machinist B says preheating the head can help to make removal easier. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Both machinists are correct.

15. After knurling and reaming a valve guide, how should the guide be cleaned? Machinist A says to blow out the guide using a high volume of compressed air. Machinist B says that the guide should be cleaned with a brush. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Both machinists are correct.

16. When rusted valve springs are found, what should be done?
    a. Shot peen them
    b. Soak them in acid
    c. Throw them away
    d. Test them against manufacturer's specs

    The best answer is C. Springs that are rusted are ruined.

17. During an initial inspection of a cast iron head, a damaged thread is found. What should be done?
    a. Clean the head and check for cracks
    b. Repair the head only after all other machining has been done
    c. Fix the thread before repairing any other parts
    d. Scrap the head

    The best answer is A. Before attempting any repairs to the head, it should be cleaned and checked for cracks to see if it is worth repairing.

18. Which of the following are true when pinning a crack? Machinist A says to use ceramic sealer. Machinist B says to tighten the tapered plugs only lightly. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Both machinists are correct.

19. What is the repair of choice for cast iron combustion chamber cracks?
    a. Interlocking threaded pins
    b. Welding
    c. Peening
    d. Cast iron combustion chambers are not repairable

    The best answer is A. Pinning the head provides a good inexpensive repair without changing metallurgy.

20. Machinist A says that a pressure test should be done at normal engine operating temperature. Machinist B says that a pressure test can be used to check for cracks. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is B. A crack will tend to leak when the engine is cold, before parts expand.

21. Machinist A says that the pressure test checks for *cracks.* Machinist B says that the pressure test checks for *leaks.* Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Both answers are correct.

22. A V8 engine has had 0.030" removed from its surface during head surfacing. Machinist A says to surface the intake manifold. Machinist B says to use a shim with the head gasket. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Either answer is correct.

23. A head with an 87 cc combustion chamber volume is replaced with a 78 cc combustion chamber head. Which of the following is the result?
    a. Increased displacement
    b. Decreased displacement
    c. Increased compression ratio
    d. Decreased compression ratio

    The best answer is C. A smaller combustion chamber has a higher compression ratio.

24. A head has a small crack in a valve seat. What is the recommended repair? Machinist A says to counterbore the head and replace the seat with an insert. Machinist B says to use interlocking pins to repair the seat and then grind the seat. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is A. If the crack does not go into a water jacket, the procedure mentioned will provide a good repair.

25. When a valve is opened, its rocker arm hits the top of the valve guide. Machinist A says that the guide has been installed too high. Machinist B says that the valve spring is weak. Who is right?
    a. Machinist A
    b. Machinist B

c. Both A and B
d. Neither A nor B

The best answer is A. The top of a universal guide might not have been cut off properly after installation.

26. Machinist A says that all positive guide seals have a Teflon® insert. Machinist B says that a positive seal should contact the retainer. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is D. Neither answer is correct. Some positive seals do not have Teflon inserts. The positive seal will be damaged if the valve retainer contacts it.

27. A vintage automobile that was designed to be run on leaded gas is run on unleaded gas. Machinist A says that the result can be excessive valve seat wear. Machinist B says that installing replaceable hard seats will prevent seat and valve wear in these engines. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both machinists are correct.

28. Two machinists are discussing rebuilding procedures for engines that will use propane fuel. Machinist A says that excessive valve and seat wear on propane engines can be avoided by installing hard seats. Machinist B says that valve rotators should be used on the exhaust valves. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is A. Propane is a dry gas so wear on valve seats results. Valve rotators should not be used with dry gas engines.

29. A rocker arm stud has pulled loose from a head. Machinist A says that the hole can be tapped for installation of a threaded stud. Machinist B says that the hole can be reamed for an oversize stud. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both answers are correct.

30. Two machinists are discussing valve stem tip height measurement. Machinist A says tip height should be measured on heads that have nonadjustable rocker arms. Machinist B says that tip height should be measured on heads with mechanical rocker arm adjustment. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Although valve stem tip height is more important with nonadjustable rockers, it is important with adjustable ones, too.

31. Which of the following should be checked on an OHC head? Machinist A says to check the bolt torque specification for the timing sprocket. Machinist B says to check the condition of the surface where the seal rides on the front of camshaft. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both answers are correct.

32. An OHC head has excessive cam journal clearance. Machinist A says this could result in low oil pressure at highway speeds. Machinist B says this could cause a knocking sound. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is B. Low oil pressure would only be likely at idle. When the engine turns faster, the pump would probably have the ability to fill the larger void of the excessive clearance.

33. Machinist A says that interference fit for cam bearings in a pushrod engine should be 0.0002". Machinist B says that cam bearings are usually chamfered on the O.D. Who is right?
a. Machinist A
b. Machinist B

c. Both A and B
d. Neither A nor B

The best answer is B. Cam bearing interference fit is about 0.002–0.003", not 0.0002".

34. A pushrod is being checked for straightness on a flat surface. Machinist A says to use a micrometer. Machinist B says to use a dial indicator. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is D. Bent pushrods would be visible to the eye when rolled on a flat surface. If any measuring instrument were to be used it would be a feeler gauge.

35. Machinist A says that excessive shimming of valve springs could cause coil spring bind. Machinist B says that shims are installed on aluminum heads to protect the spring pad from wear. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Both answers are correct.

36. When removing oil gallery plugs from a cast iron head, which of the following should be done? Machinist A says to heat the plug with a torch and apply paraffin wax. Machinist B says to drill the plug and remove it with a screw extractor. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Although A is the most correct answer, B would also work.

37. A cast iron head is being checked for cracks using dry magnetic particle inspection. Machinist A says that after the initial test, you should turn the magnet on the head 90° and recheck. Machinist B says to apply the iron powder before applying the magnet to the head. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is A. Turning the magnet 90° changes the magnetic field and can help locate cracks. Powder is not applied until after the magnet is attached to the head.

38. A valve seat is being ground. Machinist A says to use a 30° stone to move the seating area higher on the valve face. Machinist B says to use a 60° stone to move the seat area lower on the valve face. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is D. Each of the above would have the opposite effect of that stated.

39. A stepped guide is being removed from a head. Machinist A says to press it out from the combustion chamber side of the head. Machinist B says to reinstall the guide from the valve cover side. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Both are correct. A stepped guide would be larger in diameter on the valve cover side of the head so it must be removed and installed accordingly.

40. Unless otherwise specified, valves are reusable if the margin exceeds:
    a. 1⁄16"   b. 1⁄32"
    c. 1⁄64"   d. 3⁄64"

    The best answer is B. The common industry standard for valve margins is 1⁄32".

41. Following grinding of a valve seat, a valve is found to be recessed too much into the head. Which is the best means of correction?
    a. Regrind the 30° angle
    b. Regrind the 60° angle
    c. Regrind the 45° angle
    d. Replace the valve seat with an insert

    The best answer is D. The seat will have to be replaced if the stem tip height and valve spring height are to be correct.

42. A camshaft still will not turn into the block after the installation of two sets of cam bearings.

Machinist A says that a probable cause would be that the cam journals are too large. Machinist B says that the cam bores are misaligned. Who is right?

a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is B. Misaligned cam bores could cause the cam not to turn.

43. Three valve springs have tension readings below specifications. What should be done?

a. Shim the springs with 0.060" shims
b. Replace the three springs
c. Heat the springs and quench them in oil

The best answer is B. The springs should be replaced.

44. An OHC head is warped on the camshaft side. Machinist A says to straighten the head, line bore the cam towers, and surface the combustion chamber side of the head. Machinist B says to line bore the cam towers and surface the combustion chamber side of the head. Who is right?

a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both procedures are possible, depending on the design of the head.

CYLINDER BLOCK SPECIALIST QUESTIONS

1. Which of the following is the best grit stone to be used for moly rings?

a. 280 b. 100
c. 150 d. 80

The best answer is A, 280 grit. Moly requires a relatively fine surface finish compared to ordinary cast iron rings.

2. Which of the following describes the process known as plateau honing?

a. Medium stone first, then coarse
b. Fine stone first, then coarse
c. Coarse stone first, then fine

The best answer is C. Plateau honing is when a coarse stone is used, followed by a fine stone for about a minute.

3. What is the recommended allowance for honing after boring?

a. 0.0005" b. 0.001"
c. 0.003" d. 0.005"

The best answer is C. Boring leaves microscopic cracks and burrs in the cylinder wall that are often about 0.002" deep. Honing removes these imperfections.

4. What is the recommended piston pin fit?

a. 0.0008"–0.0012" b. 0.008"–0.012"
c. 0.0001"–0.0002" d. 0.001"–0.002"

The best answer is A. Piston pin interference fit is about 0.001".

5. Which of the following is a correct interference fit for a cylinder sleeve?

a. 0.0001"
b. 0.003"
c. bore the hole the same size as the sleeve

The best answer is B. The recommended interference fit for a cylinder sleeve is 0.0005" per inch of bore diameter.

6. When referring to the grit of honing stones, the lower the number:

a. the finer the grit
b. the coarser the grit
c. the number has nothing to do with the grit

The best answer is B. Lower numbers are used to define coarser/rougher stones.

7. Following honing, a cylinder block is ready to be cleaned. Machinist A says to use hot soapy water and a bristle brush. Machinist B says to use petroleum-based cleaning solvent. Who is right?

a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is A. Cleaning solvent tends to drive the grit further into the cast iron of the bore.

8. When centering a boring bar prior to boring a block to accept a sleeve: Machinist A says to center the bar at the top of the cylinder above the ring ridge. Machinist B says to center the bar in the bottom of the bore. Who is right?

a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is B. To maintain factory alignment, the boring bar is centered in the unworn area at the bottom of the cylinder.

9. Two machinists are discussing cylinder head surfacing. Machinist A says that more metal can be removed in one pass with a mill. Machinist B says that the grinder leaves a better surface finish on an iron head. Who is right?
   a. Machinist A
   b. Machinist B
   c. Both A and B
   d. Neither A nor B

   The best answer is C. Both of these answers are correct.

10. Torque-to-yield head bolts are being installed. Machinist A says to measure the thread before reusing the bolt. Machinist B says to use antiseize on them. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is D. Neither of these answers is correct. Torque-to-yield bolts might be longer after they are stretched, but measuring the thread will not tell you this because the thread has not reached its failure point so it will not be distorted. Using antiseize on the bolts will result in overstretching them to the point of failure.

11. Torque plates are used:
    a. to keep the deck from distorting
    b. to prestress the block
    c. to ensure correct tension on torque-to-yield fasteners

    The best answer is A. The purpose of torque (deck) plates is to keep the cylinders free from distortion during honing. Keeping the deck in proper alignment ensures this.

12. A piston ring is being checked for a worn ring groove. Machinist A says to check a piston for side clearance using a new ring and a feeler gauge. Machinist B says that if the groove is worn excessively, use a tapered ring. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is A. Ring side clearance in excess of 0.006" can result in a broken ring. The ring groove can be remachined and a spacer installed above it when the top ring groove on an expensive piston is worn.

13. Machinist A says that for longer stone life, lubricating oil is used when honing. Machinist B says that honing oil is used for cooling. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is C. Both answers are correct.

14. If a crankshaft with a standard journal diameter of 2.225" is ground 0.020" undersize, what size will it measure?
    a. 2.205"
    b. 2.025"
    c. 2.215"

    The correct answer is A.

15. Machinist A says that cam bearings are pressed-fit to their journals. Machinist B says that cam bearings are pressed-fit to their bores. Who is right?
    a. Machinist A
    b. Machinist B
    c. Both A and B
    d. Neither A nor B

    The best answer is B. Cam bearings are pressed-fit into the block. Journals require normal bearing oil clearance.

16. When checking piston-to-cylinder wall clearance, which of the following is the wrong solution?
    a. Use a feeler gauge at the ring lands
    b. Use a feeler gauge on the thrust side of the skirt
    c. Use a dial indicator and a micrometer
    d. Use inside and outside micrometers

    The best answer is A. Using any of the other methods of measurement would work.

17. When inspecting a piston, its diameter can be measured at any of the following *except* at the:

a. top of the skirt
b. middle of the skirt
c. bottom of the skirt
d. ring lands

The best answer is D. The diameter of a piston at its ring lands is considerably smaller than on the skirt.

18. An engine has excess rod bearing side clearance. Machinist A says that this can cause low oil pressure. Machinist B says that this could cause high oil consumption. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is D. Rod bearing side clearance does not affect oil pressure or oil consumption.

19. Machinist A says to check pin-to-piston clearance with a feeler gauge. Machinist B says to check pin-to-piston clearance with Plastigage. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is D. Neither of the answers describes a correct method of measuring piston-to-pin clearance.

20. Rods are being resized. Machinist A says that V-type rods should be sized in pairs. Machinist B says to flip the rods and switch positions often during honing. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. V-type rods are best sized in pairs because they are narrower than in-line rods so it is more difficult to hold them in alignment during honing (without a power stroker). Rods are flipped during honing to keep the stones true and so that imperfections in the stone are not translated to the rod bore.

21. An engine has full-floating piston pins. Machinist A says that full-floating pins are free-floating in the piston. Machinist B says that full floating pins are free-floating in the connecting rod. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. A full-floating pin is free to move in both the rod and the piston.

22. Machinist A says that crankshaft oil holes must be cleaned after grinding. Machinist B says that before a crankshaft is polished, the crankshaft gear or sprocket must be removed. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is A. The crankshaft must be thoroughly cleaned following grinding. The sprocket or gear need not be removed before polishing.

23. Which of the following is/are related to the internal balance of an engine?
a. The flywheel
b. The damper
c. The balance shaft(s)
d. All of the above

The best answer is D. All of the answers relate to engine balance.

24. A crankshaft measures 0.012" runout with a dial indicator. How much is it bent?
a. 0.006"
b. 0.012"
c. 0.024"

The best answer is A. If the crankshaft is bent 0.006" then a dial indicator needle will deflect a total of 0.012".

25. A flangeless crankshaft has a groove worn into the surface where its seal rides. Machinist A says that this can be corrected by repositioning the seal. Machinist B says this can be corrected by installing a sleeve. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both answers are correct.

26. Machinist A says that a broken crankshaft could be caused by a defective vibration damper. Machinist B says that when one journal has lost

its hardness, this could be due to a burned rod bearing. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both answers are correct.

27. Two machinists are trying to determine the identification of a crankshaft. Machinist A says to find its casting number. Machinist B says to measure the main and rod journals. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both machinists are correct.

28. Which of the following is not an acceptable method of measuring main bearing bores?
a. Dial bore gauge
b. Inside micrometer
c. Snap gauge and micrometer

The correct answer is C. A snap (telescoping) gauge is not accurate enough for this measurement.

29. To test after a crack repair, which is the best method?
a. Pressure test
b. Magnaflux®
c. Dye penetrant

The best answer is A. The other test methods listed will highlight the crack even after it is repaired.

30. Line honing has been done too far into a block. Machinist A says the engine could have piston-to-cylinder head clearance problems. Machinist B says that the cam timing will retard. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The correct answer is C. Both answers are correct.

31. There is a groove in the deck of a block between the cylinders. What is the most probable cause?
a. A blown head gasket
b. An incorrectly adjusted carbide cutter on the surfacer
c. Lack of cooling system maintenance
d. None of the above

The correct answer is A. Running an engine with a blown head gasket can result in erosion of the deck surface between the cylinders.

32. A sleeve is being installed in a block. Machinist A says to leave a step in the bottom of the bore to help retain the sleeve. Machinist B says to install the sleeve before boring the other cylinders. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both answers are correct.

33. A crankshaft thrust face is damaged. Machinist A says to weld and refinish it to its original size. Machinist B says to grind for an oversized thrust bearing. Who is right?
a. Machinist A
b. Machinist B
c. Both A and B
d. Neither A nor B

The best answer is C. Both answers are correct.

English-Metric Conversion Chart

CONVERSION FACTORS

Unit	To Unit	Multiply By
LENGTH		
Millimeters	Inches	.03937
Inches	Millimeters	25.4
Meters	Feet	3.28084
Feet	Meters	.3048
Kilometers	Miles	.62137
Miles	Kilometers	1.60935
AREA		
Square Centimeters	Square Inches	.155
Square Inches	Square Centimeters	6.45159
VOLUME		
Cubic Centimeters	Cubic Inches	.06103
Cubic Inches	Cubic Centimeters	16.38703
Liters	Cubic Inches	61.025
Cubic Inches	Liters	.01639
Liters	Quarts	1.05672
Quarts	Liters	.94633
Liters	Pints	2.11344
Pints	Liters	.47317
Liters	Ounces	33.81497
Ounces	Liters	.02957

Unit	To Unit	Multiply By
WEIGHT		
Grams	Ounces	.03527
Ounces	Grams	28.34953
Kilograms	Pounds	2.20462
Pounds	Kilograms	.45359
WORK		
Centimeter Kilograms	Inch-Pounds	.8676
Inch-Pounds	Centimeter Kilograms	1.15262
Meter Kilograms	Foot-Pounds	7.23301
Foot-Pounds	Newton Meters	1.3558
PRESSURE		
Kilograms/ Sq. Centimeter	Pounds/Sq. Inch	14.22334
Pounds/Sq. Inch	Kilograms/Sq. Centimeter	.07031
Bar	Pounds/Sq. Inch	14.504
Pounds/Sq. Inch	Bar	.06895
Atmosphere	Pounds/Sq. Inch	14.696
Pounds/Sq. Inch	Atmosphere	.06805
TEMPERATURE		
Centigrade Degrees	Fahrenheit Degrees	$(C° \times 9/5) + 32$
Fahrenheit Degrees	Centrigrade Degrees	$(F° - 32) \times 5/9$

Inches	Decimals	MM
1/64	.016	.397
1/32	.031	.794
3/64	.047	1.191
1/16	.063	1.588
5/64	.078	1.984
3/32	.094	2.381
7/64	.109	2.778
1/8	.125	3.175
9/64	.141	3.572
5/32	.156	3.969
11/64	.172	4.366
3/16	.188	4.763
13/64	.203	5.159
7/32	.219	5.556
15/64	.234	5.953
1/4	.250	6.350
17/64	.266	6.747
9/32	.281	7.144
19/64	.297	7.541
5/16	.313	7.938
21/64	.328	8.334
11/32	.344	8.731
23/64	.359	9.128
3/8	.375	9.525
25/64	.391	9.922
13/32	.406	10.319
27/64	.422	10.716
7/16	.438	11.113
29/64	.453	11.509
15/32	.469	11.906
31/64	.484	12.303
1/2	.500	12.700

Inches	Decimals	MM
33/64	.516	13.097
17/32	.531	13.494
35/64	.547	13.891
9/16	.563	14.288
37/64	.578	14.684
19/32	.594	15.081
39/64	.609	15.478
5/8	.625	15.875
41/64	.641	16.272
21/32	.656	16.669
43/64	.672	17.066
11/16	.687	17.463
45/64	.703	17.859
23/32	.719	18.256
47/64	.734	18.653
3/4	.750	19.050
49/64	.766	19.447
25/32	.781	19.844
51/64	.797	20.241
13/16	.813	20.638
53/64	.828	21.034
27/32	.844	21.431
55/64	.859	21.828
7/8	.875	22.225
57/64	.891	22.622
29/32	.906	23.019
59/64	.922	23.416
15/16	.938	23.813
61/64	.953	24.209
31/32	.969	24.606
63/64	.984	25.003

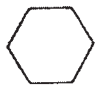
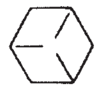
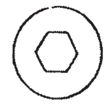
FIGURE A.1 English-metric conversion chart.

Size Conversion Chart

Fractions	Decimal In.	Metric MM.	Fractions	Decimal In.	Metric MM.
1/64	.015625	.39688	33/64	.515625	13.09687
1/32	.03125	.79375	17/32	.53125	13.49375
3/64	.046875	1.19062	35/64	.546875	13.89062
1/16	.0625	1.58750	9/16	.5625	14.28750
5/64	.078125	1.98437	37/64	.578125	14.68437
3/32	.09375	2.38125	19/32	.59375	15.08125
7/64	.109375	2.77812	39/64	.609375	15.47812
1/8	.125	3.1750	5/8	.625	15.87500
9/64	.140625	3.57187	41/64	.640625	16.27187
5/32	.15625	3.96875	21/32	.65625	16.66875
11/64	.171875	4.36562	43/64	.671875	17.06562
3/16	.1875	4.76250	11/16	.6875	17.46250
13/64	.203125	5.15937	45/64	.703125	17.85937
7/32	.21875	5.55625	23/32	.71875	18.25625
15/64	.234375	5.95312	47/64	.734375	18.65312
1/4	.250	6.35000	3/4	.750	19.05000
17/64	.265625	6.74687	49/64	.765625	19.44687
9/32	.28125	7.14375	25/32	.78125	19.84375
19/64	.296875	7.54062	51/64	.796875	20.24062
5/16	.3125	7.93750	13/16	.8125	20.63750
21/64	.328125	8.33437	53/64	.828125	21.03437
11/32	.34375	8.73125	27/32	.84375	21.43125
23/64	.359375	9.12812	55/64	.859375	21.82812
3/8	.375	9.52500	7/8	.875	22.22500
25/64	.390625	9.92187	57/64	.890625	22.62187
13/32	.40625	10.31875	29/32	.90625	23.01875
27/64	.421875	10.71562	59/64	.921875	23.41562
7/16	.4375	11.11250	15/16	.9375	23.81250
29/64	.453125	11.50937	61/64	.953125	24.20937
15/32	.46875	11.90625	31/32	.96875	24.60625
31/64	.484375	12.30312	63/64	.984375	25.00312
1/2	.500	12.70000	1	1.00	25.40000

FIGURE A.2 Size conversion chart.

General Torque Specifications Chart for Inch Standard Fasteners
(When SAE 10 oil is used as a lubricant)

Material	SAE 2 Mild Steel		SAE 5		SAE 8	Socket Head Cap Screws
Minimum Tensile P.S.I. Strength	74,000	60,000	120,000	105,000	150,000	160,000
Proof P.S.I. Load	55,000	33,000	85,000	74,000	120,000	136,000
Steel Grade Symbols						
Bolt Diameter Inches	Torque: pound-foot					
¼	7	—	10	—	14	16
5/16	14	—	21	—	30	33
⅜	24	—	37	—	52	59
7/16	39	—	60	—	84	95
½	59	—	90	—	128	145
9/16	85	—	130	—	184	210
⅝	117	—	180	—	255	290
¾	205	—	320	—	450	510
⅞	—	200	515	—	730	825
1	—	300	775	—	1090	1235
1⅛	—	425	—	955	1545	1750
1¼	—	600	—	1345	2180	2000

**NOTE: Use only when manufacturer's specifications are not available. These values are for stiff metal-to-metal joints and are based on 90% of proof load. Do not use for gasketed joints or joints of soft materials.

FIGURE A.3 General torque specifications chart (when SAE 10 oil is used as a lubricant). (*Courtesy of Snap-on Tools Company*)

General Torque Specifications Chart for I.S.O.* Metric Fasteners**
(When SAE 10 oil is used as a lubricant)

Minimum Tensile Strength	**kg/mm²**	40		50		60			80	100	120
	P.S.I.	56,900		71,100		85,340			113,800	142,200	170,700
Proof Load	**kg/mm²**	22.6	29.1	28.2	36.4	33.9	43.7	47.5	58.2	79.2	95.0
	P.S.I.	32,150	41,390	40,110	51,770	48,220	62,160	67,560	82,780	112,650	135,130
Property Class		4.6	4.8	5.6	5.8	6.6	6.8	6.9	8.8	10.9	12.9
Bolt Diameter		**Torque**				☐ **kilogram centimetre** ☐ **kilogram metre**					
metric	**inch**										
6mm	**.236**	49	63	61	79	74	95	103	126	172	206
8mm	**.315**	119	153	148	191	178	230	250	306	417	500
10mm	**.394**	235	303	294	379	353	455	495	606	8.2	10
12mm	**.472**	411	529	427	662	616	7.9	8.6	10.5	14	17
14mm	**.551**	654	8.4	8.2	10.5	10	12	13	17	23	27
16mm	**.630**	10	13	12	16	15	20	21	26	36	43
18mm	**.709**	14	18	17	23	21	27	30	36	49	59
22mm	**.866**	27	35	34	44	41	52	57	70	95	114

*I.S.O. = International Standardization Organization.
**NOTE: Use only when manufacturer's specifications are not available. These values are for stiff metal-to-metal joints and are based on 90% of proof load. Do not use for gasketed joints or joints of soft materials.

FIGURE A.4 General torque specifications chart for I.S.O. metric fasteners (when SAE 10 oil is used as a lubricant). (*Courtesy of Snap-on Tools Company*)

GARRETT TURBOCHARGER TROUBLESHOOTING

Engine lacks power	Black exhaust smoke	Excessive engine oil consumption	Blue exhaust smoke	Turbocharger noisey	Cyclic sound from turbocharger	Oil leak from compressor seal	Oil leak from turbine seal	CAUSE	REMEDY
●	●	●	●			●		Clogged air filter element	Replace element according to engine manufacturers recommendations
	●	●	●	●	●	●		Obstructed air intake duct to turbo compressor	Remove obstruction or replace damaged parts as required
●	●			●				Obstructed air outlet duct from compressor to intake manifold	Remove obstruction or replace damaged parts as required
●	●			●				Obstructed intake manifold	Refer to engine manufacturers manual & remove obstruction
				●				Air leak in duct from air cleaner to compressor	Correct leak by replacing seals or tightening fasteners as required
●	●	●	●	●				Air leak in duct from compressor to intake manifold	Correct leak by replacing seals or tightening fasteners as required
●	●	●	●	●				Air leak at intake manifold to engine joint	Refer to engine manufacturers manual & replace gaskets or tighten fasteners as required
●	●	●	●	●		●		Obstruction in exhaust manifold	Refer to engine manufacturers manual & remove obstruction
●	●					●		Obstruction in muffler or exhaust stack	Remove obstruction or replace faulty components as required
●	●			●		●		Gas leak in exhaust manifold to engine joint	Refer to engine manufacturers manual & replace gaskets or tighten fasteners as required
●	●			●		●		Gas leak in turbine inlet to exhaust manifold joint	Replace gasket or tighten fasteners as required
				●				Gas leak in ducting after the turbine outlet	Refer to engine manufacturers manual & repair leak
		●	●			●	●	Obstructed turbocharger oil drain line	Remove obstruction or replace line as required
		●	●			●	●	Obstructed engine crankcase vent	Refer to engine manufacturers manual, clear obstruction
		●	●			●	●	Turbocharger center housing sludged or coked	Change engine oil & oil filter, overhaul or replace turbo as required
●	●							Fuel injection pump or fuel injectors incorrectly adjusted	Refer to engine manufacturers manual — replace or adjust faulty component(s) as required
●	●							Engine camshaft timing incorrect	Refer to engine manufacturers manual & replace worn parts
●	●	●	●			●	●	Worn engine piston rings or liners (blowby)	Refer to engine manufacturers manual & repair engine as required
●	●	●	●			●	●	Internal engine problem (valves, pistons)	Refer to engine manufacturers manual & repair engine as required
●	●	●	●	●	●	●	●	Dirt caked on compressor wheel and/or diffuser vanes	Clean using a Non-Caustic cleaner & Soft Brush. Find & correct source of unfiltered air & change engine oil & oil filter
●	●	●	●	●		●	●	Damaged turbocharger	Analyze failed turbocharger, find & correct cause of failure, overhaul or replace turbocharger as required

FIGURE A.5 Turbocharger troubleshooting chart. (*Courtesy of Honeywell International Inc.*)

Metric Conversion Chart

METRIC CONVERSION: lb. ft. to N•m

The chart below can be used to convert pound foot to newton metre. The left hand column lists pound foot in multiples of 10 and the numbers at the top of the columns list the second digit. Thus 36 pound foot is found by following the 30 pound foot line to the right to "6" and the conversion is 49 N•m

lb. ft.	0	1	2	3	4	5	6	7	8	9
	N•m	N•m	N•m	N•m	N•m	N•m	N•m	N•m	N•m	N•m
0	0	1.36	2.7	4.1	5.4	6.8	8.1	9.5	10.9	12.2
10	13.6	14.9	16.3	17.6	19.0	20.3	21.7	23.1	24.4	25.8
20*	27	28	30	31	33	34	35	37	38	39
30	41	42	43	45	46	47	49	50	52	53
40	54	56	57	58	60	61	62	64	65	66
50	68	69	71	72	73	75	76	77	79	80
60	81	83	84	85	87	88	90	91	92	94
70	95	96	98	99	100	102	103	104	106	107
80	109	110	111	113	114	115	117	118	119	121
90	122	123	125	126	127	129	130	132	133	134
100	136	137	138	140	141	142	144	145	146	148

* Above 20 lb. ft. the converted N•m readings are rounded to the nearest N•m.

METRIC CONVERSION: kg•cm to N•m

The chart below can be used to convert kilogram centimetre to newton metre. The left hand column lists kg•cm in multiples of 10 and the numbers at the top of the columns list the second digit. Thus 72 kg•cm is found by following the 70 kg•cm line to the right to "2" and the conversion is 7.1 N•m.

kg. cm.	0	1	2	3	4	5	6	7	8	9
	N•m	N•m	N•m	N•m	N•m	N•m	N•m	N•m	N•m	N•m
0	0	.098	.20	.29	.39	.49	.59	.69	.78	.88
10	.98	1.08	1.18	1.27	1.37	1.47	1.57	1.67	1.76	1.86
20	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.8
30	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
40	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
50	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8
60	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8
70	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8
80	7.9	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7
90	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7
100	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7

One oz. in. = 28.35 gms. in.
One lb. in. = 1.152 kg•cm
One lb. ft. = .138 kg•m

One kg•cm = .8679 lb. in.
One kg•cm = 7.233 lb. ft.
One N•cm = .0885 lb. in.
One N•m = .7375 lb. ft.

FIGURE A.6 Metric conversion chart. (*Courtesy of Snap-on Tools Company*)

Torque Table Variations

To compensate for these surface variations, this simple formula may be used to approximate the required torque:

$$T = FDC \div 12$$

T = Torque in foot lbs.
F = Friction Factor (torque coefficient)
D = Cap Screw diameter in inches
C = Cap Screw tension required in lbs.
70% of min. tensile strength shown on the torque value chart

FRICTION FACTOR (F) FOR VARIOUS SURFACES		PERCENT OF TORQUE CHANGE REQUIRED
Dry-unplated steel	.20	Use std. torque value shown
Cadmium plating	.15	Reduce std. torque 25%
Zinc plating	.21	Increase std. torque 10%
Aluminum	.15	Reduce std. torque 25%
Stainless steel	.30	Increase torque 50%
Resistoplate TF		Use std. torque value

Lubricants and Threaded Fasteners

Lubricants, when used on the threads of either "blind" or tapped holes, hex nuts, or on the cap screw itself may increase the effect of the applied torque. This is because the lubricant may reduce the thread friction and allow more of the applied torque to develop tension or clamping force, since less of the torque applied to the assembly goes toward overcoming friction.

The random use of thread lubricants frequently causes screw failures and fastener breakdowns. The reduced amount of friction in the fastener assembly and the torque applied may produce far greater tension than is recommended. In many cases the applied torque will actually result in screw tension that exceeds the strength of the fastener used, and the fastener may fail.

The uncontrolled use of a lubricant is a potential cause of assemblies being overloaded and, therefore, subject to failure unless torque corrections are made.

TORQUE REDUCTIONS REQUIRED FOR VARIOUS LUBRICANTS

LUBRICANT	TORQUE REDUCTION REQUIRED FROM 'DRY' TORQUE: SUPERTANIUM CAP SCREWS WITH NUT	ALL OTHER CAP SCREWS
Premier Thread Lubricant	-20%–30%	20%–45%
Premier ETP	-20%–30%	20%–40%
Never-Seize	-20%–30%	20%–45%
Premier Thread-Eze	-20%–30%	20%–40%
Moly-Cote (Molybdenum Disulphide)	-20%–30%	20%–45%
Heavy Oils	-20%–30%	20%–40%
Graphite	-20%–30%	20%–30%
White Lead	-20%–30%	20%–20%

FIGURE A.7 Torque table variations when lubricants are used. Note that the amount of torque reduction on this chart is when compared to dry torque specifications. (*Courtesy of Lawson Products, Inc.*)

Sealers and Adhesives

AUTOMOTIVE AFTERMARKET Product Name	Product No.	FUNCTION
Lock N' Seal	21 (blue)	LOCKING Medium strength for locking and sealing screws, nuts, threaded fasteners. Removable.
Stud N' Bearing Mount	22 (red)	LOCKING High strength. Studs, bearings, bushings, sleeves.
Wick N' Lock	290 (green)	LOCKING Wicking action for locking pre-assembled screws and threaded fasteners.
PST Pipe Sealant with Teflon	92 (white)	SEALING Pipe threads, threaded fittings (hydraulic, air, oil, refrigerant).
Gasket Eliminator	524 (orange)	REPLACE GASKETS Rigid parts. Replaces all kinds of cut gaskets except for high temperature use.
RTV Silicone	525	REPLACE GASKETS Flexible parts.
Gasket Sealant (Hardening Type)	526	SEAL/REPAIR GASKETS Permanent.
Gasket Sealant (Non-hardening Type)	527	SEAL/REPAIR GASKETS Removable
Gasket Adhesive	528	HOLD GASKETS IN PLACE
Stud N' Bearing Mount	22 (red)	RETAINING High strength for studs, bearings, bushings.
Sleeve Retainer	27 (green)	RETAINING Internal engine parts to 400° F.
SuperBonder Adhesive	494 (clear)	BONDING–FAST Instant bonding of metal, rubber, vinyl, ceramics, and most plastics.
Rear View Mirror Adhesive	33 (clear)	BONDING Rear view mirrors only.
Fast Cure Epoxy 445	445 (gray)	BONDING–GENERAL Fast curing epoxy in pre-measured mixer cups of general repairs on most materials–no clearance limit.
NEAT Epoxy Adhesive	446 (clear)	BONDING–GENERAL Fast curing epoxy in pre-measured mixer cups of general repairs on most materials–no clearance limit.
General Purpose Epoxy 453	453 (clear)	BONDING–GENERAL For general purpose, gap filling use. In pre-measured mixer cups.
Anti-Seize Compound	767	LUBRICATION High performance lubricant. Withstands temperature range of -65°F. to +2000°F., moisture, salt and corrosive conditions.
Safety Solvent	755	CLEANER Super-safe, effective degreaser and cleaner. Non-flammable.
Klean N' Prime	25	SPEED CURE Of Loctite anaerobic products.

FIGURE A.8 Sealers and adhesives. (*Courtesy of Henkel Corporation*)

Cam selection chart

Cam Duration at .050 Cam Lift (in crank shaft degrees):	Combination Street and Drags:	Competition Drag Racing:	Oval Track Racing:
Up to 230 Degrees:	Good idle & torque. Heavy car w/small engine or w/auto.	(Not normally used)	High torque. Heavy car w/small engine & low compression
230 to 250 Degrees:	Combination street & drags. Middleweight car w/small engine. Heavyweight car w/large engine.	(Not Normally used)	Heavy cars w/small engine. Hobby classes.
250 to 260 Degrees:	Marginal street. Middleweight car w/large engine.	High torque Super stock. Heavyweight car w/big engine or middleweight car w/small engine.	Stocks, modified & sportsmen. Short track.
260 to 270 Degrees:	Super street. Light car w/ large engine.	Super stock w/large disp. or H.P. engine.	Light car w/big engine. Short & long track. Wide power range. Short track G.N.
270 to 285 Degrees:	(Never used)	Gasser/Heavy fuel classes. Super charged gas. Sprints.	Super, long track. Super speedways. Light car w/big engine. Super modifieds.
285 to 300 Degrees:	(Never used)	Pro stock. Light car w/large engine. Gasser dragster, Altered Funny car/Super-charged fuel.	(Not normally used)

■ A general recommendation for choosing a replacement cam for a relatively stock street engine or one with computerized engine controls would be to choose a cam that has no more than 220 degrees of duration (measured at .050 in. lift). This type of cam works best between 1500 and 5000 rpm and should not upset manifold vacuum at idle (which might adversely affect operation of the engine's sensors and engine performance).

■ Cams with durations in the 230 to 260 degree range work best in engines built to run in the 2500 to 6000 rpm range where mid-range power is more important than low speed torque. And for high speed engines where the power range is 3500 rpm and up, durations above 260 degrees perform best.

FIGURE A.9 Cam selection chart. (*Courtesy of Federal-Mogul Corporation*)

Glossary

A

ABDS—Accessory belt drive system. The belt, pulleys, tensioner, bearings, and belt-driven accessories make up the accessory belt drive system.
Adiabatic—A physics term meaning occurring without a gain or loss of heat.
Aerobic—A sealer that cures in the presence of air.
Aftermarket—Automobile parts that are made by other than original equipment manufacturers.
Agitation—Moving a liquid so that it cleans better.
Alloy—A substance that is a combination of two or more metals.
Anaerobic—A sealer that cures without air.
Antidrainback Valve—A valve in a horizontally mounted oil filter that prevents it from draining when the engine is off.
API—American Petroleum Institute.
Arcing Brushes—When a brush skips off the commutator of a motor armature, it causes a spark that burns away at the commutator.
Assembly Lubricant—A special lubricant with extreme pressure characteristics that will remain on the surface of a part that is stored.
ATF—Automatic transmission fluid.

B

Back-Cut Valve—A valve with two or more angles cut on its face to improve airflow.
Backfire—When an air-fuel mixture explodes in the exhaust system.
Backlash—Clearance between gears.
Backpressure—Exhaust system pressure resulting from too much exhaust flow for a given cross-sectional opening.
BDC—Bottom dead center. When the piston is as low as it can travel in the cylinder.
Bearing Crush—The end of the bearing sticks out of the bore. When it is tightened against the bearing on the other side it is held from spinning.
Bearing Locating Lug or Tang—The notch found on the backside of a bearing that locates it in its bore.
Bearing Spread—The bearing is distorted slightly so that it will remain in the bearing bore during engine assembly.
Bellmouth Wear—Valve guide wear that is more pronounced in cylinder heads with rocker arms.
Big Block—A physically larger version of a manufacturer's engine block design.
Bimetal Engine—An engine with a cast iron block and aluminum head.
Black Light Testing—A black light tester is used for finding oil leaks. A fluorescent dye is added to the oil.
Block Check Tester—A tester that has a liquid that changes color when exposed to exhaust gas. It sniffs the air above a radiator's coolant.
Blowby—Combustion gases that leak past the piston rings.
Blowdown—A term describing the part of the power stroke between the time the exhaust valve opens and the piston arrives at BDC.
Blow-Off Valve—A valve, also known as a BOV, that prevents turbo surge by dumping boost pressure when the throttle is closed quickly.
BMEP—Brake mean effective pressure.
Bob Weights—Weights attached to the connecting rod throws when balancing an engine to simulate rotating and reciprocating weight.
Boost Differential—When there is more pressure in a turbocharger turbine than the compressor, or vice versa.
Boost Pressure—The amount of pressure that a turbocharger or supercharger puts into the intake manifold.
Boost Threshold—The point at which boost starts.
Boundary Lubrication—When the oil film partially breaks down.
British Imperial (U.S.) System—The standard system of measurement used for many years in the United States and England.
Bucket—A name for the part of an overhead cam head that fits between the valve and the cam lobe.
Butterfly Valve—A round plate that controls airflow; for example, the throttle plate in the fuel system.
Bypass Oil Filter—An oil filter that filters a smaller amount of oil than a full-flow filter, sometimes used as an auxiliary filter.
Bypass Valve—An oil filter valve that allows oil to bypass the filter when the engine oil is too thick or too much oil is being supplied to the filter.

C

CAFÉ—Corporate Average Fuel Economy. A government standard used to charge a gas guzzler tax on autos that are inefficient.
Caliper—A measuring tool for making outside or inside measurements.
Cam Ground Piston Skirt—The piston is oval when it is cold and becomes more round as it heats up.
Cavitation—The formation of air bubbles in coolant, often caused by coolant boiling, air in the coolant, a suction restriction, overpumping, or vibration of the cylinder walls during combustion.
CFM—Cubic feet per minute.
Chamfer—To bevel or cut off the edge of a sharp surface.
Chlorinated Hydrocarbon—A cleaner for carburetors.
Chlorinated Solvents A solvent that has chlorine atoms. Chlorinated solvents are harmful to the environment and their use is usually restricted.
Choke Bore—When the bottom of the bore is larger than the top.
Clamping Force—When two parts are tightened together the stretch of the fastener results in clamping force.
Closed PCV System—A PCV system that uses filtered intake air supplied through a hose from the air cleaner.
Companion Cylinders—Two different pistons in an engine that are in the same position as they go up and down.
Compression Ratio—The difference in volume in the cylinder when the piston is at the bottom compared to when it is at the top.
Compressor Bypass Valve—A relief valve on the intake side of a turbocharger that is quieter than a blow-off valve, dumping its pressure back into the fresh air intake instead of into the atmosphere.
Crankcase—The lower area of the cylinder block surrounded by the oil pan.
Cranking Vacuum Test—A test of an engine's condition that is done with a vacuum gauge while the engine cranks.
Crocus Cloth—Used for very fine polishing, it is 1200-grit jeweler's rouge abrasive on a cloth backing.
Cross Fluid Contamination—When oil and coolant mix due to an internal leak.
Crosshatching—A criss-cross finish that is desirable when honing cylinder walls.
Curtain Area—When valve lift reaches 25% of the diameter of the head of the valve, this equals the curtain area; further valve lift will not flow more air.
Custom Engine Rebuild—When a complete engine is disassembled and rebuilt.
Cylinder Sleeve—A replacement cylinder liner used to repair a damaged bore.

D

Decking a Block—When the head gasket surface of a block is remachined.
Deglazing—Removing the glaze in the ring belt area of the cylinder.
Detonation Sensor—The sensor that senses abnormal combustion. Also called a knock sensor.
Diffuser—The part of the turbocharger compressor cover where the air exits.
Displacement—The volume of a cylinder.
Dry Start—A term that describes the period of time after engine startup when oil has not yet been supplied to engine bearings.
Duration—The length of time in crankshaft degrees that a valve remains open.
Duty Cycle—A rating for air compressors.
Dynamometer—A brake device for loading the engine and measuring torque and horsepower.

E

Eccentricity—The taper or drop in wall thickness of a bearing shell above its parting line.
Edge Loading—When a lifter becomes concave, it wears the sides of a cam lobe.
EDM—Electrical discharge machining.
EGR—Exhaust gas recirculation.
Elastic Limit—The point at which a bolt that is being stretched will fail.
Electrical Discharge Machine (EDM)—A machine used for eroding broken fasteners.
End Thrust—Fore or aft force on a shaft.
EPDM—Ethylene propylenediene monomer. A synthetic rubber used in many belts and hoses. It has excellent long-life properties and is resistant to heat and ozone.
Externally Balanced—When a crankshaft does not have enough material on its counterweights, external balancing is provided on the vibration damper and flywheel or torque converter.

F

Ferrous—Iron and steel.
Fillet Radius—The curved area on the sides of a crankshaft journal.
Firing Order—The order in which the cylinders have their power strokes.
Flare—A sealing angle or bubble formed at the end of a piece of tubing.
Flare Nut—A hollow nut that surrounds a piece of tubing.
Flash Point—The lowest point at which a liquid will give off flammable vapors.

Flat Crankshaft—A V8 crankshaft with the rod throws spaced 180° apart, located only at the top (0°) and bottom (180°) of the crankshaft.
Flat Rate Manual—A manual that lists the estimated times for specific repair jobs; also called Parts and Time Guide.
Foot-Pounds—The standard method of measuring torque.
Freewheeling Engine—An engine that will not have a valve contact a piston if the timing chain or belt breaks.
Full-Floating Pin—A piston pin that floats in the rod and the piston. Lock rings keep it from coming out of the piston.
Full-Flow Oil Filter—An oil filter designed to filter all of the oil most of the time.

G

Gauge Block—A tool used to calibrate a measuring instrument.
Glazed—A smooth, shiny area where the piston rings ride against the cylinder wall.
Greasesweep—A material used to soak up spills.
Ground Straps—Straps that are found between the engine and the bulkhead or firewall of the vehicle. They ground the car's body to the engine.

H

Harmonic Balancer—Another name for the vibration damper that is found on the front of the crankshaft.
Heli-Arc/TIG Welding—A welding process for welding aluminum that uses an inert gas shield.
HEPA Vacuum—A special vacuum for asbestos.
HOAT—Engine coolant formulated with hybrid organic acid technology.
Horsepower—The measurement of an engine's ability to perform work.
Hydrolock—Hydrostatic lock; when a liquid is trapped between two parts, preventing them from coming any closer to each other.
Hydrostatic Lock—Hydrolock; when a liquid is trapped between two parts, preventing them from coming any closer to each other.
Hypereutectic—A high silicon content aluminum piston that expands less.

I

IAT—Inorganic acid technology coolant—the original green coolant.
I.D.—Inside diameter.
ILSAC—International Lubricant Standardization and Approval Committee. Provides minimum lubrication performance standards for gasoline-fueled (GF) passenger car and light truck engine oils to manufacturers.
Inducer—The leading edge of a turbocharger compressor wheel where the air enters.
Induction Hardening—A process by which an integral part is hardened.
Intake Manifold Vacuum—The vacuum that an engine makes as it runs. It can be measured anywhere in the intake manifold.
Integral Valve Seats and Guides—When the seat or guide is part of the cylinder head.
Interference Angle—When the valve and seat are ground at a different angle. It increases seating pressure, which helps the valve to seat initially.
Interference Fit—When a part is pounded or pressed into a slightly smaller space to provide a tight fit.

J

Journals—Crankshaft bearing surfaces for the main and rod bearings.

K

Knock Sensor—The sensor that senses when there is abnormal combustion. Also called a detonation sensor.
Knurling—A metal deformation process used to enlarge a metal surface.

L

Labor Intensive—A method of work that cannot be done by machine only, requiring an operator.
Lash Pad Adjusters—The wafer-type adjusters used on some overhead cam engines.
LCD—Liquid crystal display.
Leak Down—When a hydraulic lifter bleeds off until a valve is no longer held open.
Lift—The amount that a cam lobe lifts the valve off its valve seat.
Line Boring or Honing—Resizing the main bearing bores to realign them and make them the original size.
Lobe Center Angle (LCA)—A camshaft angle, measured in camshaft degrees, that describes the lobe-to-lobe distance by adding the centerlines of the intake and exhaust lobes together and then dividing by 2.
Locating Lug (Tang)—A tab extending from the parting line of the bearing that locates it correctly in the bearing bore during engine assembly.
Long Block—A complete engine assembly.

Lost Foam Casting—A type of metal casting that uses a foam core that is "lost" or burned up during the pour as it is replaced by molten metal.

Lower End—All of the parts in the engine block not including the heads.

Lugging the Engine—Lugging occurs when the load on the engine is greater than the rpm needed to develop enough horsepower to pull the load.

M

Metric System—The system of measurement used throughout the world.

Microinches—One microinch equals one millionth of an inch.

MSDS—Material safety data sheet.

Mushroomed Chisel—When the head of a chisel gets rounded over.

Mushroomed Valve Tip—When a valve tip wears, it becomes larger on the tip.

N

Naturally Aspirated—An engine that is not turbocharged or supercharged.

Neoprene—A synthetic rubber that is resistant to oil and heat.

Newtons—The metric method of measuring torque.

Normally Aspirated—An engine that is not turbocharged or supercharged.

O

OAT—Engine coolant formulated with organic acid technology.

O.D.—Outside diameter.

Oil Filter Bypass Valve—A valve in the oil filter that allows oil to bypass it if it is too thick or the filter is too dirty.

Oil Wash—When fuel washes oil from cylinder walls, resulting in cylinder wall wear.

Overhang—Topping the seat with a flatter angle exposes a small amount of the valve face to overhang into the combustion chamber.

Overhead Valve (OHV)—Also known as an I-head or valve-in-head engine.

P

PCM—Powertrain control module, or computer.

PCV—Positive crankcase ventilation.

PCV Valve—A crankcase ventilation control valve that modulates a small amount of air leakage into the intake manifold, pulling blowby gases from the crankcase.

pH Scale—A measurement of whether a material is alkaline/base/caustic or acid.

Pinning a Crack—A process of crack repair using tapered, threaded plugs; also called stitching a crack.

Piston Compression Height—If the piston pin is higher or lower on the piston, its compression height changes.

Piston Dwell Time—The time that the piston remains still at TDC while the crankshaft continues rotating for several degrees.

Planetary Gears—A gearset that consists of a sun gear, planetary pinions and their cage, and a ring gear.

Plastigage—A thin strip of plastic that is used to measure bearing clearances.

Plateau Honing—The cylinder is honed to a rough finish, followed by a fine finish.

Polymers—Oil additives that thicken when an oil is heated.

Popback—When an air-fuel mixture explodes in the intake system.

Poppet Valve—A mushroom-shaped valve used in many piston engine types.

Proud Surface—When the surface of a part extends above the surrounding surface.

Pumping Losses—The work used to move air into and out of the cylinders.

Pushrod Engine—An I-head engine with the camshaft located in the block; also called a cam-in-block engine.

Q

Quench—When cool engine surfaces are exposed to unburned fuel, the fuel ends up in the exhaust stream.

R

R&R—Remove and replace.

Regenerative Characteristic—When there is a return of energy, such as when one valve spring is compressed as another extends.

Reversion—When exhaust reverses direction and it is drawn back into the cylinder at low speed.

Rigid Hone—A hone for making a cylinder larger after boring it.

Ring Ridge—A ridge that forms at the top of the cylinder as the cylinder wall wears.

Rockwell "C" Scale—A hardness rating for metals commonly used in industry.

Room Temperature Vulcanizing (RTV)—Aerobic sealer, commonly known as silicone.

Roto-Groove—Passive valve rotation in which multi-grooved valve stems allow vibration to cause the valve to rotate when the valve is opened.
Rotor—The assembled turbine wheel and shaft and compressor wheel of a turbocharger.
RTV—Room temperature vulcanizing.
Run-In Stand—A stand for running a newly rebuilt engine.

S

SAE—Society of Automotive Engineers.
Scale—A hard insulating substance that occurs on the inside of cast iron water jackets when the cooling system is not maintained.
SCFM—Standard cubic feet per minute.
Seized Engine—When an engine is damaged to the point where its crankshaft will not turn.
Serpentine—A type of accessory drive belt. "Serpentine" refers to the snakelike route that the belt follows.
Short Blocks—Complete blocks assembled without heads.
Shrouding—An area in a valve port or combustion chamber that obstructs the smooth flow of air.
Skin Effect—When cool engine surfaces are exposed to unburned fuel and the unburned fuel ends up in the exhaust stream.
Sludge—A mixture of water and oil that resembles dirty mayonnaise that results when oil is not changed often enough.
Small Block—A physically smaller version of a manufacturer's engine block design.
Solvent Test—A wet test following valve and seat machining.
Spin Test—When a newly rebuilt engine is spun by a machine. Oil pressure and compression can be checked.
Splayed Crankpin—Two connecting rod journals on one crankthrow that are offset from each other, rather than together, in the same plane.
Splitter Blade Wheel—A turbocharger wheel that has alternating blades of short and full lengths.
Spontaneous Combustion—When a flammable substance ignites on its own.
Spooling—When an engine produces enough exhaust flow to spin a supercharger or turbocharger enough to create boost.
Static Timing—Setting ignition timing while the engine is not running.
Stitching a Crack—Using threaded plugs to repair a crack.
Stock—The way an engine comes from the factory.
Stress Raiser—When the surface of a part is damaged, stress is raised in that area. If a break occurs it will probably be there.
Stretchy Belt—A belt that does not require a belt tensioner because it acts like a rubber band and applies tension when the belt is stretched past its relaxed length.

T

Tack Coat—The first coat when painting. It is allowed to get tacky before the second coat is sprayed.
Tap Drill—The correct size drill to use before tapping threads in a part.
TDC—Top dead center. When the piston is as high as it can travel in the cylinder.
Thermoplastic Seizure—The result of coolant entering the engine oil; it prevents the crankshaft from rotating.
Thermostat Bypass—A passage that allows coolant to circulate in the block when the thermostat is closed.
Thrust Bearing Surfaces—Flat bearing surfaces at 90° to the bearing load surface that control fore and aft movement of the crankshaft.
Torque—A twisting effort.
Torque Plate—Also called deck plate or honing plate, it is used when honing to keep the cylinder bores from distorting.
Torsional Vibration—The twisting force imparted on a crankshaft from the firing impulses of the cylinders.
Transverse Engine—An engine that is mounted sideways.
Trimming a Turbo—When engineers who design a turbocharger match the size of the turbine and the compressor to the engine's displacement, rpm, and volumetric efficiency.
Turbo Lag—The time required to bring the turbo up to a speed where it can function effectively.
Turbo Surge—A back-and-forth movement of the air above the throttle plate that occurs when there is high boost pressure and the throttle plate is closed quickly.

V

Valley—The area between the heads that is covered by the intake manifold.
Valve Lash—Clearance at the end of the valve stem.
Valve Overlap—When the intake and exhaust valves are both open at the same time.
Valve Spring Inserts—Shims used to increase valve spring tension.
Valve Stem Height—The amount that the valve stem tip extends above the upper surface of the cylinder

head. As the valve and seat are ground, the valve stem height changes.

Vapor Lock—When fuel boils in the line and cannot be pumped, the vehicle stops running.

Vernier Scale—A short scale that reads against a longer scale to tell divisions.

Vibration Damper Another name for a harmonic balancer found on the front of the crankshaft.

Viscosity—The tendency of a liquid to resist flow. A thicker oil has a higher viscosity.

Viscosity Index—A rating that tells how well an oil resists changes in its viscosity with temperature change.

Volumetric Efficiency—The amount of air that an engine could theoretically breathe.

Volute—The curved funnel in a turbocharger cover that increases in size from small to large.

W

Water Jackets—The chambers cast into the block or head that hold the engine's coolant.

Wet Manifold—An intake manifold used with a carburetor or throttle body fuel injection designed to provide optimum flow for the air-fuel mixture.

Y

Yield Point—The point where a fastener will not return to its original length.

Z

Zero Lash—When there is no clearance in the valvetrain.

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