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# Ball and roller bearings

Ball and roller bearings are being used increasingly because of their low cost, accuracy, and the ease of replacement, with short down-time. The high precision achieved by manufacturers enables these bearings to be used on precision high-speed spindles; when this type of equipment is serviced it is not only necessary to read the number of the bearing but also to look for the selection symbol usually engraved with electric pencil or diamond scriber. Precision bearings are specially selected for size, runout, internal clearance and matching if running in a pair; cage material may also be important in some applications.

## Bearing designations

Each standard metric bearing has a specific basic designation, which indicates the type of bearing and standardized sizes.

### Supplementary Designations

As well as carrying basic designations, bearings may have additional code letters to distinguish those bearings that differ from standard or have modified components. Where several code letters are required they are added to the bearing designation in the order given below.

Some of the most commonly used supplementary designations are as follows:

#### Prefixes

*Bearing components*

**L** Removable ring (inner or outer) of a separable bearing.

Examples:
- LNU 207 — inner ring of cylindrical roller bearing NU 207.
- L 30207 — outer ring of taper roller bearing 30207.

**R** Separable bearing less removable ring (inner or outer).

Examples:
- RNU 207 — outer ring and roller and cage assembly of cylindrical roller bearing NU 207.
- R 30207 — inner ring and roller and cage assembly of taper roller bearing 30207.

#### Suffixes

*Internal design*

**A, B, C, D, E** Modified internal design of bearing.
Example:
- 7205 B — single row angular contact ball bearing with a contact angle of 40°.

*External design*

**X** Boundary dimensions altered to conform to ISO standards.
**– RS, – LS** Synthetic rubber seal fitted at one side of bearing.
**– 2RS, – 2LS** Synthetic rubber seal fitted at both sides of bearing.
**– Z** Shield fitted at one side of bearing.
**– 2Z** Shield fitted at both sides of bearing.
**K** Tapered bore, taper 1:12 on diameter.
**K30** Tapered bore, taper 1:30 on diameter.
**N** Snap ring groove in outer ring.
**NR** Snap ring groove in outer ring, with snap ring.
**– ZN** Shield at one side and snap ring groove at the other.
**ZNR** As for ZN, but including snap ring.
**N2** Two diametrically opposed slots at one outside corner of the outer ring.
**G** Single row angular contact ball bearing with ring faces adjusted so that any two bearings can be mounted in pairs, either in tandem, back-to-back or face-to-face.

*Cage*

**J** Pressed steel cage, unhardened.
**Y** Pressed brass cage.
**M** Machined brass cage.
**F** Machined steel or cast iron cage.
**L** Machined light alloy cage.
**T** Cage of fabric-reinforced phenolic resin.
**TH** Fabric-reinforced phenolic resin cage with snap-type pockets.
**TN** Plastic cage (nylon).
**TN9** Reinforced plastic cage.

The code letter indicating the cage type and material may be followed by the letter A or B; A indicates that the cage is centred on the outer ring, and B indicates that it is centred on the inner ring.

**V** Cageless ball or roller bearing.

*Other bearing features*

The suffixes in the following groups are added to the bearing designation after an oblique stroke.

Bearing accuracy Accuracy is indicated by the following suffixes:

**P6** Accuracy to ISO class 6.
**P5** Accuracy to ISO class 5 (greater than P6).
**P4** Accuracy to ISO class 4 (greater than P5).
**PA97** Dimensional accuracy to AFBMA class 9, running accuracy to AFBMA class 7.
**PA9** Accuracy to AFBMA class 9.
**SP** Special precision, with dimensional accuracy similar to P5 and running accuracy similar to P4.
**UP** Ultra precision, with dimensional accuracy similar to P4 and running accuracy similar to P4.

Internal clearance This is indicated by these suffixes:

**C1** Clearance less than C2.
**C2** Clearance less than 'normal'.
**C3** Clearance greater than 'normal'.
**C4** Clearance greater than C3.
**C5** Clearance greater than C4.

The letter C is omitted when combining designations P6 or P5 with a clearance designation, e.g. P62 = P6 + C2.

Vibration, noise The following suffixes apply:

**Q6** Vibration level lower than normal.
**Q06** Vibration peaks lower than normal.
**Q66** Q6 + Q06.

Heat treatment Bearing inner and outer rings (or shaft and housing washers) stabilized for higher operating temperatures than normal are designated by the following suffixes:

**S0** Up to +150°C.
**S1** Up to +200°C.
**S2** Up to +250°C.
**S3** Up to +300°C.
**S4** Up to +350°C.

Lubrication features These features are designated by:

**W33** Peripheral groove and three lubrication holes in the outer ring.

Lubricants These suffixes comprise letters indicating the temperature range followed by a two-figure code denoting actual grease, e.g. HT20. The following letters are used:

**MT** Medium temperature grease (−30 to +110°C).
**LT** Low temperature grease (−50 to +80°C).
**HT** High temperature grease (−20 to +130°C).
**LHT** Low/high temperature grease (−40 to +140°C).

An MT suffix is used only if the grease is not the standard grease used for a particular bearing.

## Bearing checks during operation

Bearings mounted in machines where a stoppage would have serious consequences should be checked regularly. In less critical applications, where they operate under less demanding conditions, bearings can normally be left without attention except to see that they are well lubricated. This section deals with routine checks and is considered under four procedures – 'listen', 'feel', 'look', and 'lubricate', as illustrated in Figures 1 to 5.

*'Listen'*

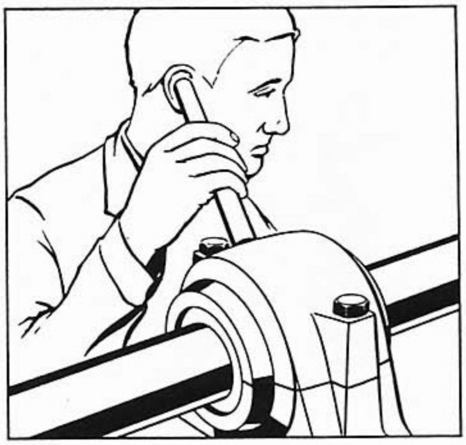


**Figure 1** 'Listen'

Place one end of a wooden listening rod, screwdriver or similar object against the bearing housing as close to the bearing as possible. Place your ear against the other end and listen. If all is well, a soft purring sound will be heard. A damaged bearing gives out a loud noise, often irregular and rumbling.

*'Feel'*

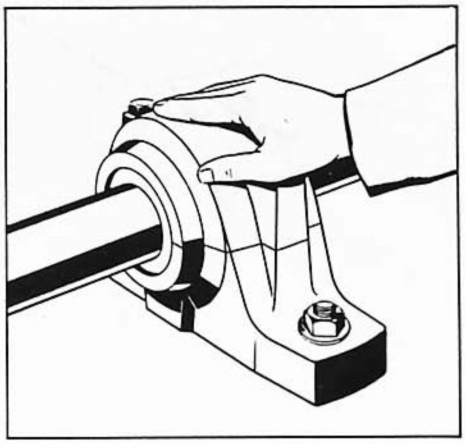


**Figure 2** 'Feel'

Check the temperature of the bearing arrangements by using a thermometer, heat-sensitive chalk, or often simply by placing a hand on the bearing housing. If the temperature seems unusually high or suddenly changes it is an indication that something is wrong. The reason may be insufficient or excess lubricant, impurities, overloading, bearing damage, insufficient clearance, pinching, high friction in the seals, or heat supplied by an external source. Remember, however, that immediately after relubrication there will be a natural rise in temperature, which may persist for 1 or 2 days.

*'Look'*

Ensure that lubricant does not escape through defective seals or insufficiently tightened plugs. Impurities generally discolour the lubricant, making it darker. Check the condition of the seals near the bearings to ensure that they will not, for example, permit hot or corrosive liquids or gases to penetrate the bearing arrangement. Any auto-

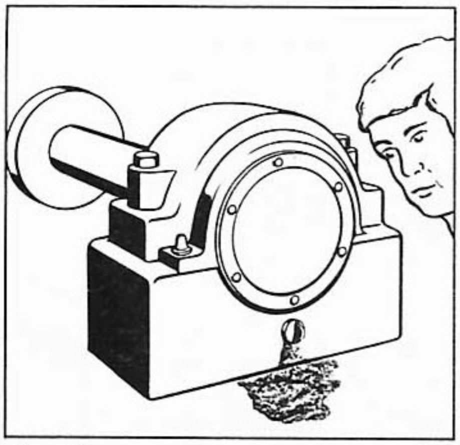


**Figure 3** 'Look'

matic lubricating devices should also be checked to see that they function correctly.

*'Lubricate'*

**Figure 4** Grease lubrication

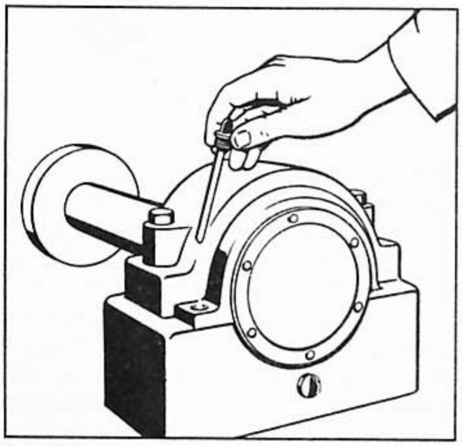


**Figure 5** Oil lubrication

Relubricate the bearing arrangements according to the instructions provided by the machine manufacturer or your lubricant supplier. (See recommendations given on pp. 517 to 519.) Wipe the lubricating nipples clean before fresh grease is injected (Fig. 4). If the bearing housing is not provided with nipples, requisite relubrication should be carried out during a planned stoppage of the machine. The housing cap or end cover has to be removed, the used grease taken out and fresh grease added (see 'Application of lubricant' on page 516). Even where nipples are fitted on the housing, the used grease should be removed and replaced with fresh, from time to time. Check the oil level and replenish if necessary (Fig. 5). Ensure that the air vent of the oil-level gauge is not blocked. When the oil is to be changed, drain off, and rinse the bearing arrangement with fresh clean oil of the same type before refilling to the required level. With oil bath lubrication it is generally sufficient to change the oil once a year provided that the operating temperature does not exceed 50°C and the oil does not become contaminated. The oil must be changed more frequently when operating temperatures are higher – four times a year up to 100°C, monthly up to 120°C and weekly at 130°C.

## Inspection during non-operation

Although rolling bearings are robust mechanical components, which give long service time, it is, however, wise to inspect them now and then. This can preferably be done during a planned stoppage of the machine or when the machine is to be dismantled for some reason, such as machine inspection or repair.

Begin operations by arranging the working area so that it is as clean and as dry as possible (see Fig. 6). Check that replacement bearings are readily available in case they are needed. If drawings are available they should be studied thoroughly before maintenance work is started.

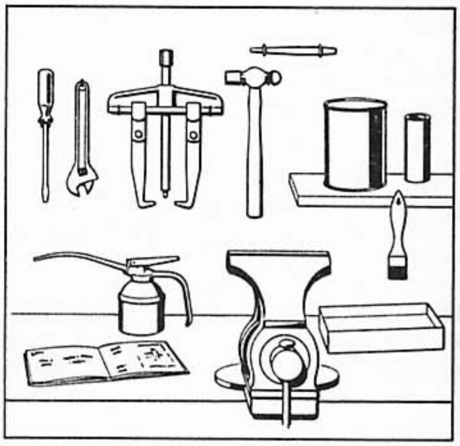


**Figure 6** A clean and dry area for working

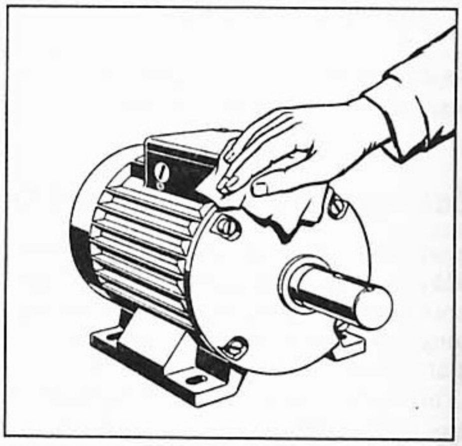


**Figure 7** Cleaning the external surfaces

Clean the external surfaces (Fig. 7). Note the order in which the machine components are removed and also their relative positions. Take care not to crack, for example, labyrinth seals as they are removed. Excessive force should never be used when removing a seal. Inspect the seals and other components of the arrangement.

Check the lubricant (Fig. 8). Impurities of various kinds can usually be felt if a little of the lubricant is rubbed between the fingers; or a thin layer may be spread on the back of the hand for inspection against the light.

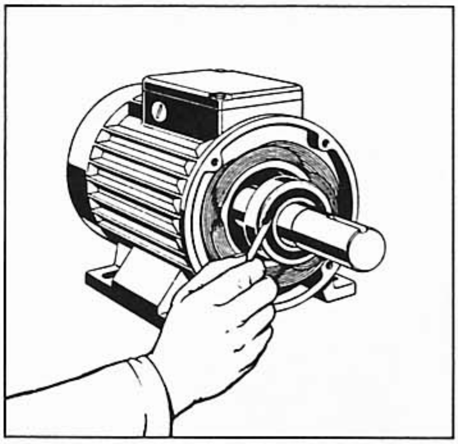


**Figure 8** Checking the lubricant

Ensure that dirt or moisture cannot enter the machine after the covers and seals have been removed. Cover the machine, exposed bearings and seatings with waxed paper, plastic sheeting or similar material if work is interrupted (see Fig. 9). Do not use cotton wase!

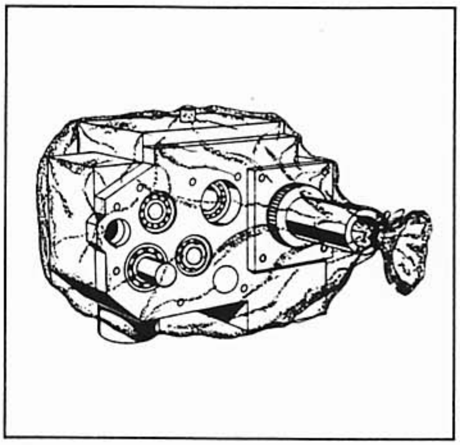


**Figure 9** Cover the work during any interruptions

Wash the exposed bearing where it is possible to carry out inspection without dismounting. Use a paint brush dipped in white spirit and dry with a clean lint-free cloth or compressed air (taking care that no bearing components start to rotate. (Fig. 10.) However, on no account should sealed or shielded bearings be washed.

A small mirror and a probe, such as dentists use, are useful when inspecting the raceways, cage and rolling elements of the bearing.

If the bearing is undamaged it should be relubricated according to the instructions provided by the machine manufacturer or to the recommendations given on pages 517 to 519. Carefully replace the seals and covers.

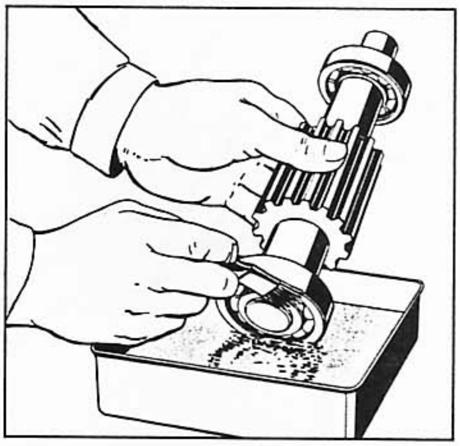


**Figure 10** Carefully inspect the work

## Dismounting bearings

An undamaged bearing should never be dismounted unless it is absolutely necessary! But, if a bearing has to be dismounted, it is advisable to mark it to show its relative mounted position, that is, which section of the bearing was 'up', which side was 'front' etc., so that the bearing can be remounted in the same position.

Start dismounting by selecting the correct tools for the job (see page 519).

Remember to treat all bearings carefully. Arrange for a suitable stop or support for the shaft, otherwise the bearings may be damaged by the dismounting forces normally occurring during the operation (Fig. 11).

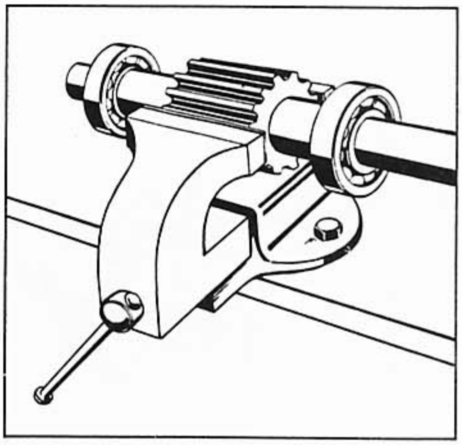


**Figure 11** Dismounting bearings—support the shaft

### Interference Fit on the Shaft

If the bearing has an interference fit on the shaft, a puller should be used as shown in Figure 12. This should normally engage on the inner ring face. Larger bearings may be dismounted more easily by using hydraulic tools (see Figs 72 and 73).

If it is not possible to get a purchase on the inner ring face, the puller may be applied to the outer ring face (see Fig. 13). However, it is very important that the outer ring be rotated during dismounting to prevent any bearing component being damaged by the dismounting force. Arrange a suitable stop for the handle of the spanner for the withdrawal screw, grip the puller legs and rotate.

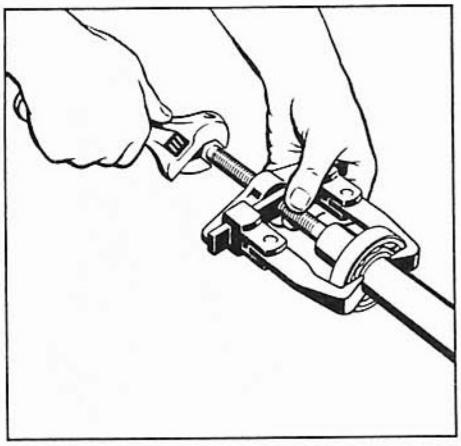


**Figure 12** Interference fit on the shaft

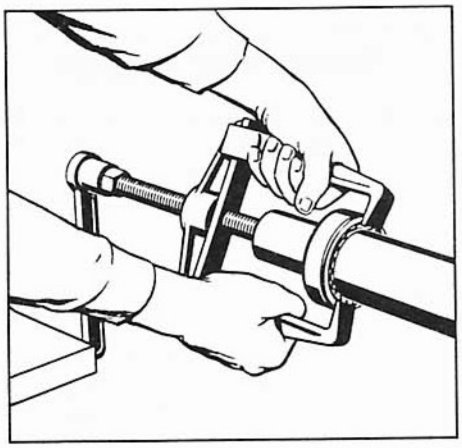


**Figure 13** The puller applied to the outer ring with caution

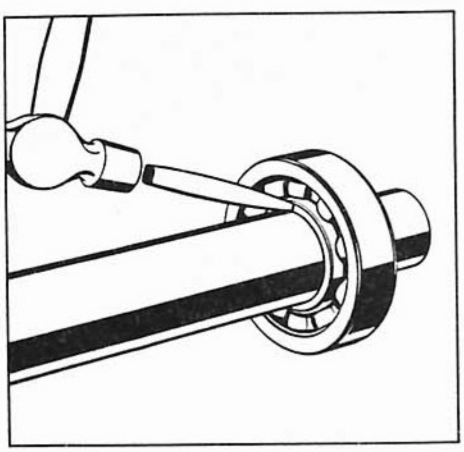


**Figure 14** A rounded point drift may be used if a suitable puller is not available

If a suitable puller is not available a soft metal drift with rounded point or another similar tool may be used. This should be applied to the inner ring face as shown in Figure 14. It is important that the bearing itself does not receive direct hammer blows. However, great care must be taken with this method because it is very easy to damage the shaft and bearing.

## Interference Fit in the Housing

If the bearing has an interference fit in the housing, for example in a wheel (see Fig. 15), it can be dismounted by using a mounting dolly or a length of tubing and

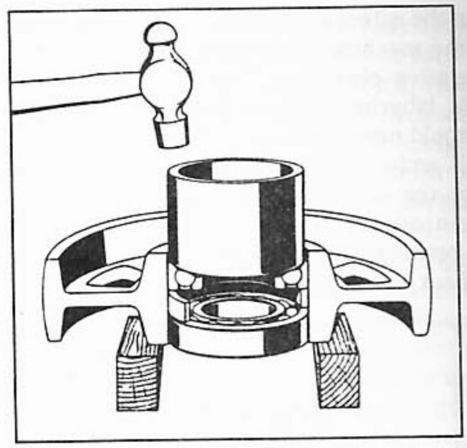


**Figure 15** Dismounting bearings—interference fit in the housing

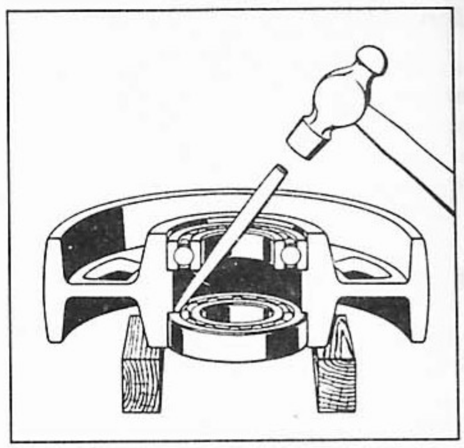


**Figure 16** A soft metal non splintering drift

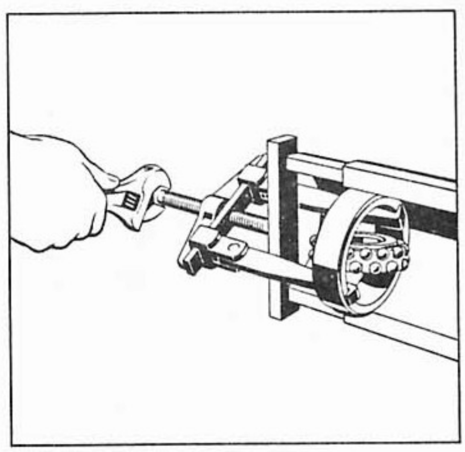


**Figure 17** Puller used through bearing

applying blows evenly distributed around the end face. The ends of the tube should be flat and free from burrs.

Use a soft metal drift with rounded point or another similar tool if there is an integral shoulder between the bearings (Fig. 16).

The inner ring assemblies of self-aligning ball bearings and spherical roller bearings can generally be swivelled so that a puller can be used (see Fig. 17).

## Bearings Mounted on Sleeves

Self-aligning ball bearings and spherical roller bearings are often mounted on adapter or withdrawal sleeves (Fig.

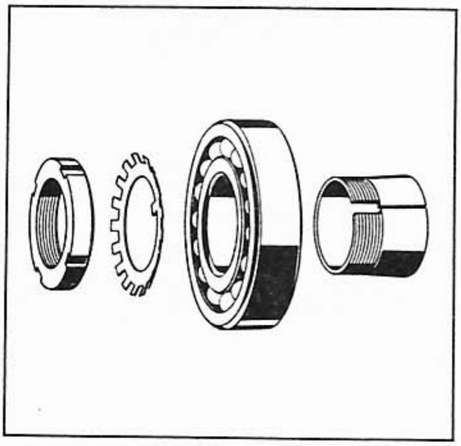


**Figure 18** Dismounting bearings—bearings mounted on sleeves

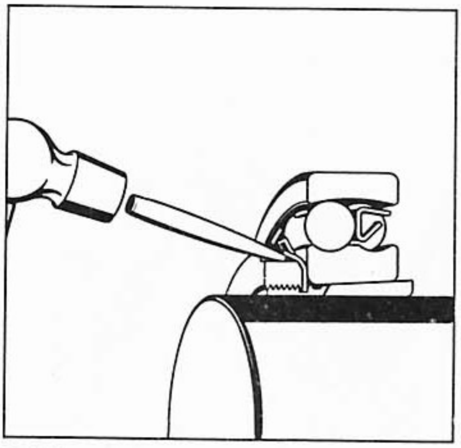


**Figure 19** Adapter sleeve disengaged locking tab

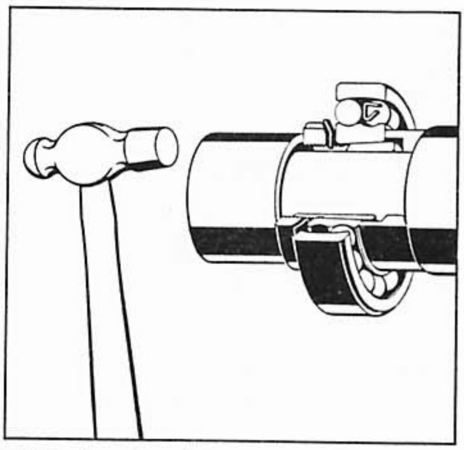


**Figure 20** Freeing the sleeve

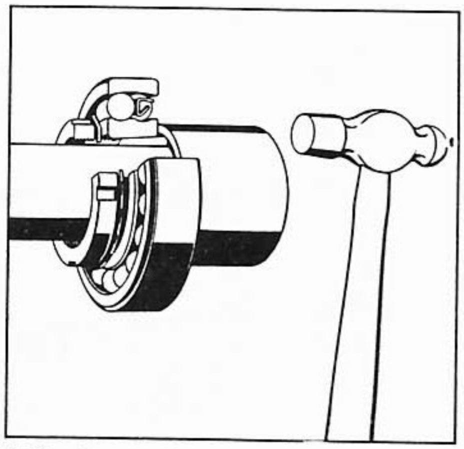


**Figure 21** Freeing the bearing from sleeve

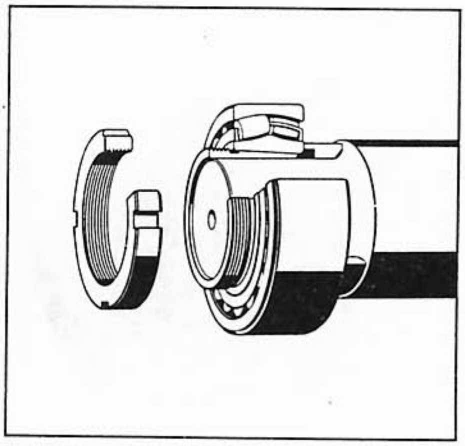


**Figure 22** Withdrawal sleeve

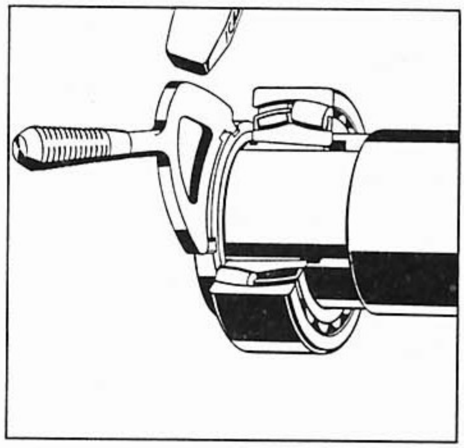


**Figure 23** Using a hook impact spanner

18). The advantages of using a sleeve are that the shaft seating does not need such accurate machining, and mounting and dismounting are made easier. Figure 18 shows, from left to right, a lock nut, a locking washer, a bearing and an adapter sleeve.

## Dismounting an Adapter Sleeve

First mark the position of the sleeve on the shaft. Then disengage the bent tab of the locking washer from the lock nut slot (Fig. 19).

Unscrew the lock nut a few turns. Place a mounting dolly or a length of tubing against the nut and apply sharp, evenly distributed blows until the bearing becomes loose (Fig. 20).

If the bearing is mounted on a smooth shaft or if there is no spacer sleeve between the bearing and the shaft shoulder, the tool should be applied to the inner ring of the bearing instead. (Fig. 21.)

## Dismounting a Withdrawal Sleeve

For small and medium-sized bearings, the sleeve may be removed using a lock nut similar to that used for adapter sleeves. Remember to lubricate the thread and

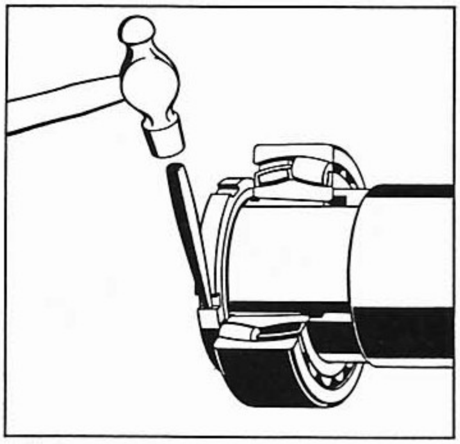


**Figure 24** Using a drift

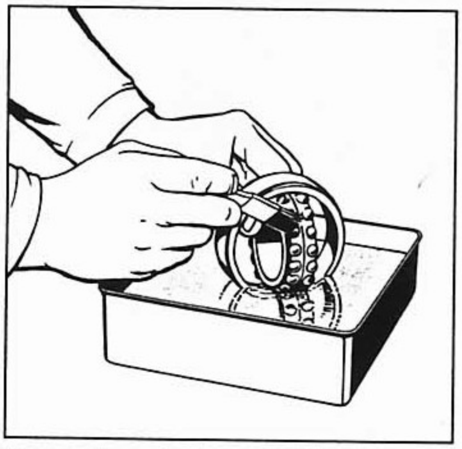


**Figure 25** Inspection of dismounted bearings

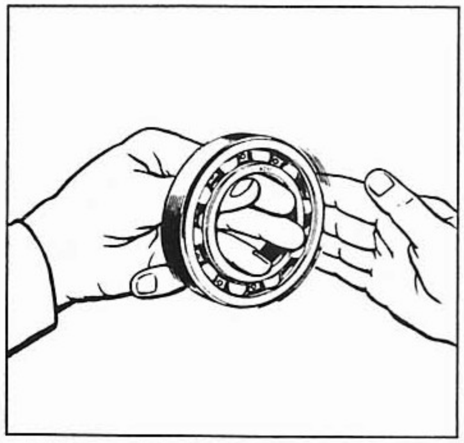


**Figure 26** Listen and feel

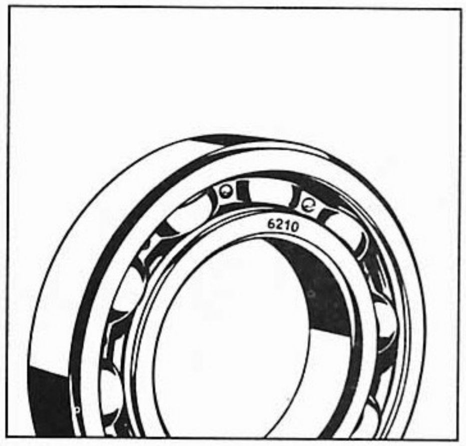



**Figure 27** Record

the lock nut face adjacent to the bearing with, for example, molybdenum disulphide paste. (Fig. 22.)

Tighten the nut using a hook or impact spanner until the bearing becomes loose (Fig. 23). If the sleeve protrudes from the end of the shaft a suitable support must be provided. Larger bearings can easily be dismounted from their sleeve by using a hydraulic nut (see Fig. 72).

If the sleeve is small, a soft metal drift may be used instead of a hook spanner (Fig. 24).

## Inspecting Dismounted Bearings

When the bearing has been dismounted, it should be inspected. First wash it in white spirit (see Fig. 25) and then dry carefully using a clean lint-free cloth or compressed air (taking care that no bearing components start rotating). The bearing raceways and rolling elements should be inspected for any signs of damage.

However, sealed or shielded bearings should never be washed, and, for obvious reasons, cannot be inspected.

Spin the outer ring and ascertain whether the bearing noise is normal (see Fig. 26).

A bearing that is undamaged, that is, has no marks or other defects on the ring raceways, rolling elements or cage, and runs evenly without abnormally large radial internal clearance, can be remounted without risk. (Instructions regarding relubrication of the bearing are given on page 516.) If the bearing designation is not shown in any machine instructions, it should be recorded for future reference. The designation will usually be found on the side face of either the inner or outer ring of the bearing. (Fig. 27.)

## Bearing damage

This section discusses the different types of bearing damage and their probable causes. If a bearing has failed, the reason should be investigated so that the cause can be eliminated.

Dismantle the damaged bearing. If the cage is riveted together, remove some rivet heads and lever the cage apart using a screwdriver or similar tool. (See Fig. 28.) Generally, bearing damage takes the form of flaking (spalling), that is, fragments of material break loose from the raceways. Initial flaking is often very slight, but because of the increased stresses at its edges and the fragments being carried in the lubricant, the flaked area begins to spread. Typical causes of bearing damage are:

- faulty mounting;
- faulty lubrication;
- foreign matter in the bearing;
- water in the bearing arrangement;
- inaccuracies of form of the shaft or housing seating;
- vibration;
- passage of an electric current;
- metal fatigue.

If the bearing has been mounted incorrectly, for

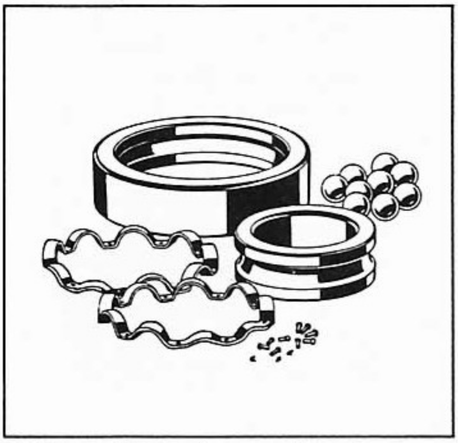


**Figure 28** Dismantle the damaged bearing

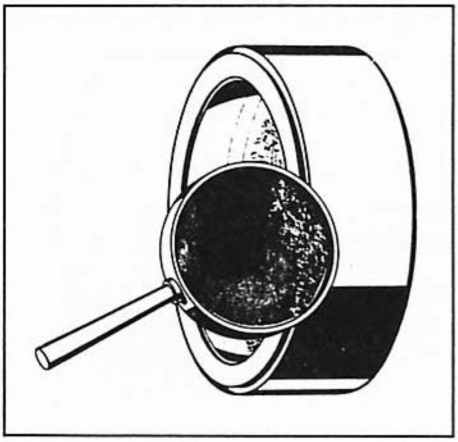


**Figure 29** Flaking of the outer ring raceway

example by being driven up too hard on an adapter sleeve or on a tapered seating, it can be preloaded. Figure 29 shows flaking of the outer ring raceway caused by such radial preloading.

Axial preloading can, for example, occur when a bearing has been nipped sideways. The damage shown in Figure 30 was caused by insufficient space for the bearing in the housing; the bearing could not follow the axial displacement of the shaft that occurred during thermal expansion.

If a bearing that is to be mounted with an interference fit on the shaft is driven up by blows to the outer ring, damage of the type shown in Figure 31 can occur. Such damage may also result if blows are directed against a shaft end, a pulley, etc., without suitable support. Indentations on raceways and rolling elements can easily be caused in this way and bearing life will be shortened as a result.

A bearing that has been inadequately lubricated will have highly polished raceways but can often have surface micro-cracks (see Fig. 32). However, the cage would normally be the first component to fail, and a ball or roller may be trapped, resulting in complete bearing seizure. The bearing may also run hot if there is insufficient lubricant available.

If foreign matter, in the form of solid particles, enters the bearing, damage of the type shown in Figure 33 may easily occur. The particles cause indentations in the raceways and rolling elements, and eventually flaking will

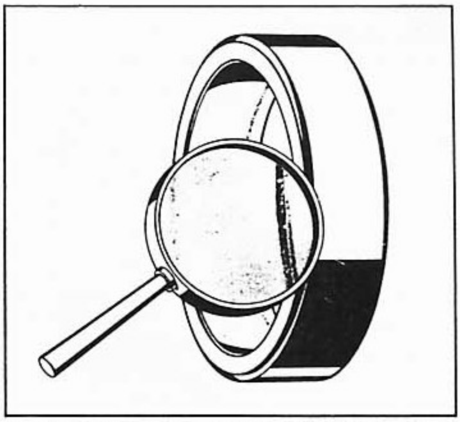


**Figure 30** Damage caused by insufficient space for bearing in the housing

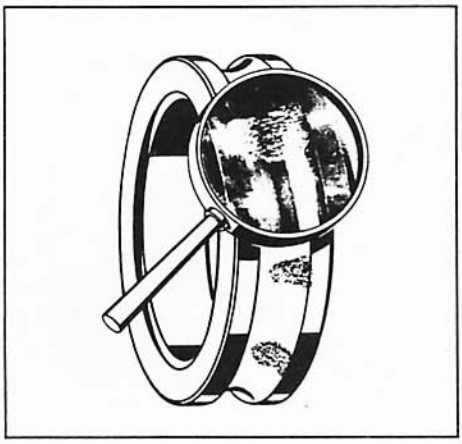


**Figure 31** Damage caused by blows

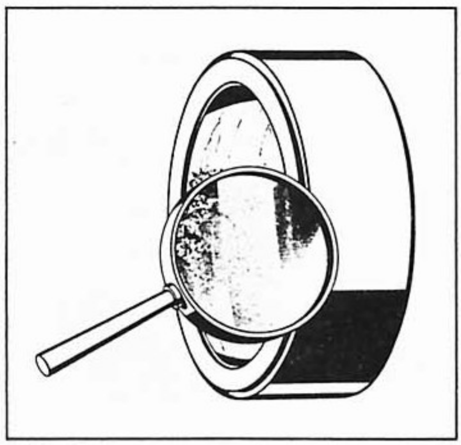


**Figure 32** Surface micro-cracks lack of lubrication

follow. Foreign matter may have entered the bearing during mounting, but the most general cause is inadequate sealing.

Bearing components are usually made of metal. They are therefore sensitive to attack by water, particularly salt water. A sudden drop in temperature may result in condensation and thus cause corrosion (see Fig. 34).

Ovality of the housing or shaft seating can result in bearing damage. Such damage often appears at two diametrically opposite points on the bearing ring. Other errors of form can also lead to bearing damage. A fragment of metal between the outer ring and the housing

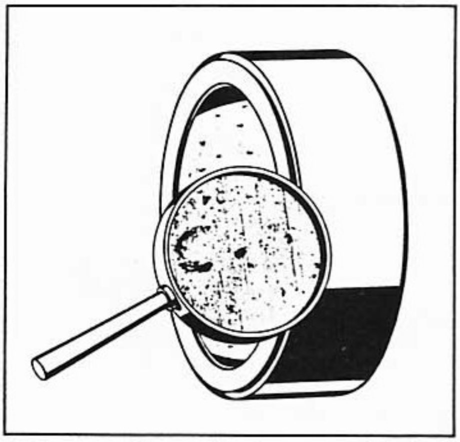


Figure 33 Damage due to foreign matter in the bearing

Figure 34 Corrosion damage

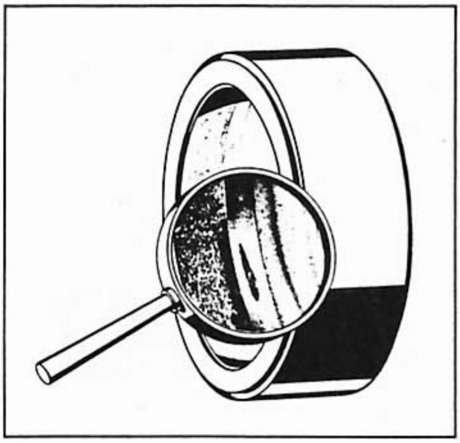


Figure 35 Damage due to poor quality bearing seating

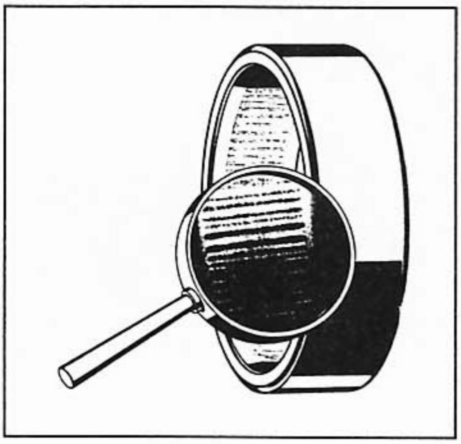


Figure 36 Damage caused by vibration

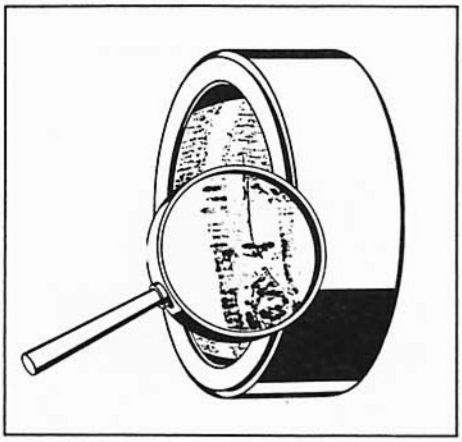


Figure 37 Electrically caused burn craters

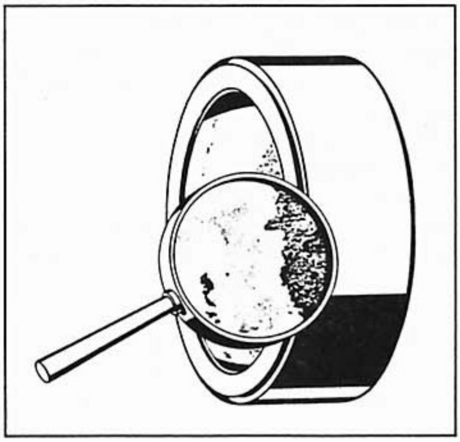


Figure 38 Fatigue

can cause a change in form sufficient to cause damage to the outer ring raceway. (See Fig. 35.)

In machines subject to vibrations, damage may occur in bearings when they are stationary, because the rolling elements will wear the raceways by a rubbing action having the same frequency as the vibrations. (See Fig. 36.) To prevent such damage the shaft should be supported and locked to unload the bearings, or should be slowly rotated. Often, however, shortening the stationary periods of the machine can be enough to stop damage from occurring.

Even at a very small potential difference (0.4 V) between shaft and bearing housing an electric current may 'jump' the thin film of lubricant between rolling elements and raceways. The result will be a number of burn craters or 'washboard effect' (see Fig. 37). Such damage may be caused, for example, by faulty earthing when welding a component to the machine.

The reason that fatigue occurs is sometimes simply that the bearing has reached its endurance life. This is, however, usually far in excess of the calculated basic rating life. (Fig. 38.)

## Mounting bearings

It is necessary to use the correct method of mounting and the rules of cleanliness must be observed if a rolling bearing is to function with satisfaction and achieve the requisite life. Mounting should be carried out in a dust-free, dry environment. Machines that produce metal particles, swarf or sawdust should not be in the vicinity.

Start mounting by selecting the correct tools for the job (see Figs 72-74).

Carefully inspect the components close to the bearing location. Remove burrs, and clean shafts and shoulders. Check the accuracy of form and dimensions of the shaft and housing bearing seatings. (See Fig. 39.) These may have been damaged during dismounting. Check the seals and replace any that have become worn or damaged.

If a bearing is to be replaced, take the bearing out of its package just before it is to be mounted. Leave the rust-inhibiting compound on the bearing except on the outside diameter and bore surfaces. Wipe over these surfaces with white spirit and dry with a clean lint-free cloth.

### Interference Fit on the Shaft

Lightly smear the bearing seating with thin oil prior to mounting (Fig. 40). This is done to avoid damage to the shaft during mounting.

Never apply direct blows to the bearing—always use a length of tubing or a similar tool—otherwise the rings may crack, the cage may become damaged, or metal fragments may break off and cause damage when the bearing is put into operation. (Fig. 41.)

Small bearings may be mounted with the aid of a mounting dolly or a length of tubing. The tube should be clean and have flat parallel ends, which are free from burrs. Place the tool against the inner ring and apply blows, evenly distributed around its end face, with an ordinary hammer as shown in Figure 42 (hammers with lead or other soft metal heads are unsuitable as fragments can easily break off and enter the bearing). Ensure that the bearing does not skew on the shaft.

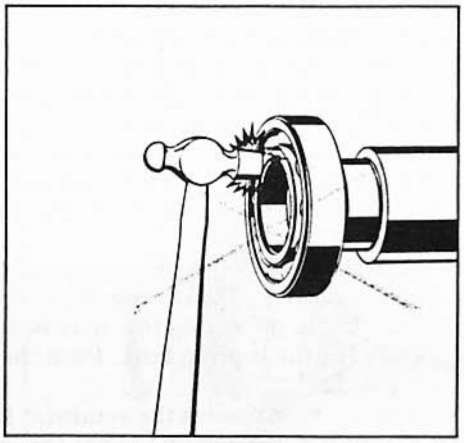


**Figure 41** No direct hammer

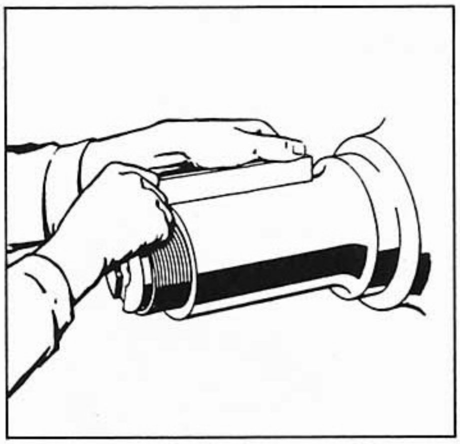


**Figure 39** Inspect seating before assembly

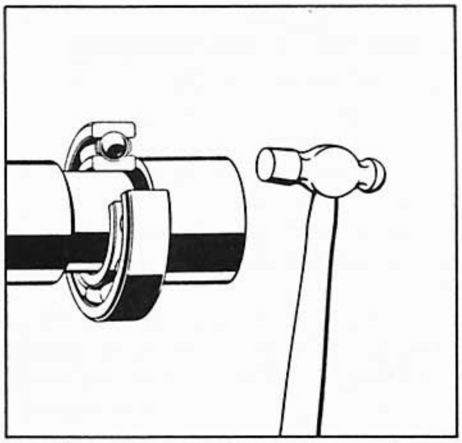


**Figure 42** Use dolly

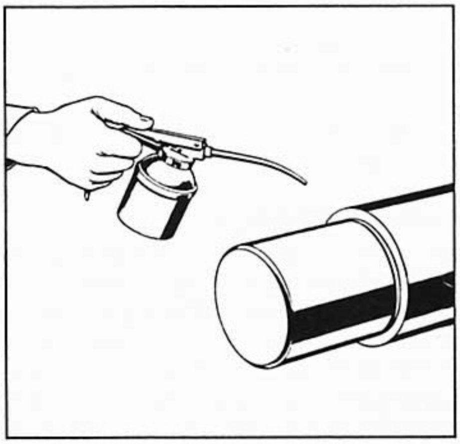


**Figure 40** Mounting bearings—interference fit on the shaft

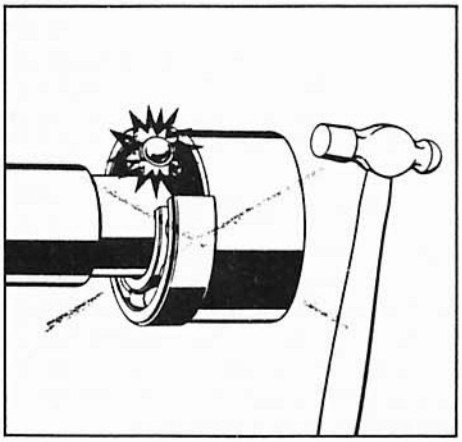


**Figure 43** Not on outer ring

Never apply force to the outer ring when mounting a bearing on a shaft. The raceways and rolling elements can easily be damaged and the bearing life considerably reduced as a consequence. (Fig. 43.)

If the shaft has external or internal threads, they may be utilized when mounting the bearing (see Fig. 44).

If a mechanical or hydraulic press is available, this can be used for mounting small and medium-sized bearings. Use a mounting dolly or a clean piece of tubing between the press and the inner ring (see Fig. 45).

Large bearings are easier to mount if they are first heated to a temperature of 80° to 90°C above ambient temperature. However, the bearing should never be allowed to reach a temperature above 120°C. One method is to use an oil bath as shown in Figure 46. The oil should be clean and have a flash point above 250°C. Clean a suitable receptacle and pour in sufficient oil to completely cover the bearing. The bearing should not be in direct contact with the base of the receptacle but should be placed on a suitable platform to avoid local heating. Heat the bath on an electric hot plate, gas flame, or similar equipment. (Fig. 47.)

*A bearing should never be heated using a naked flame!*

Put on clean protective gloves or use clean rags to hold the hot bearing. Drain off any oil that may be left in the outer ring and wipe the bearing bore. Push the bearing quickly into position.

Press the bearing hard against the abutment face (Fig. 48) until it has cooled sufficiently so that the inner ring fits well to the shoulder.

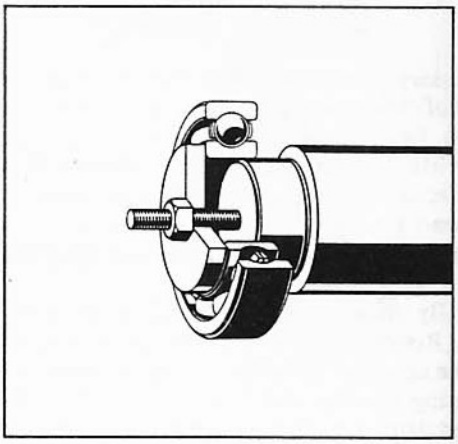


**Figure 44** Draw on with screw

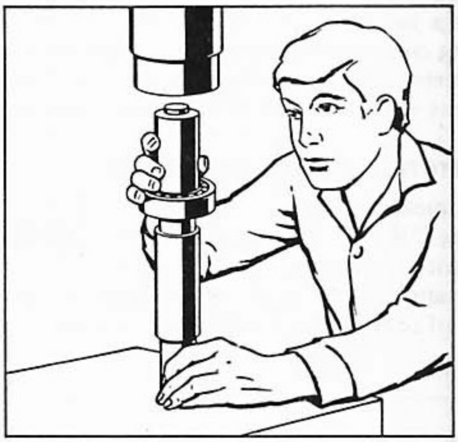


**Figure 45** Using a press

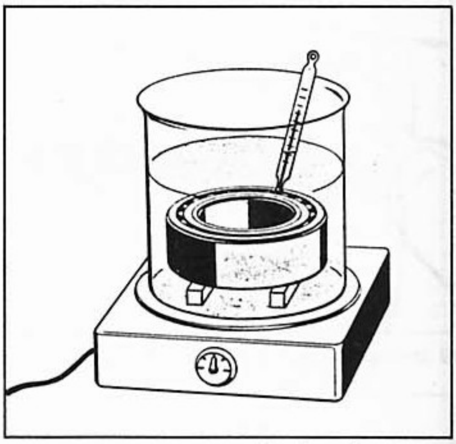


**Figure 46** Using heat to expand a bearing

## Interference Fit in the Housing

Lightly smear the bearing seating with oil. Use a mounting dolly or a clean piece of tubing, but place it against the outer ring face (Fig. 49). Ensure that the bearing does not skew in the housing. A mechanical or hydraulic press may also be used to advantage. Otherwise the rules for mounting bearings with an interference fit on shafts are valid when the bearing is to have an interference fit in the housing.

It may sometimes be necessary to heat the housing in order to mount the bearing. Normally, a small rise in temperature will be sufficient because the interference is rarely tight. An electric lamp, a special heating tool, hot oil or a naked flame may be used to heat the housing (Fig. 50). If a naked flame is used, great care must be exercised, otherwise the housing may crack or distort. The dimension of the bearing seating must be checked after heating and the seating wiped clean before the bearing is mounted. The bearing should be pressed hard against the abutment face until the housing has cooled sufficiently for the bearing to have an interference fit.

## Cylindrical Roller Bearings

The separable parts of a cylindrical roller bearing are generally mounted independently. Mount the separable ring first and oil its raceway lightly. After oiling or greasing the rollers, fit the other ring with the roller and cage assembly. Rotate the shaft or housing during this operation. (Fig. 51.) Ensure that the roller assembly is not at an angle; a guide sleeve may be useful.

If the roller assembly is entered askew (see Fig. 52) without having been oiled and rotated during entry, a ring or rollers may easily be damaged.

## Taper Roller Bearings

Taper roller bearings may be quite complicated to mount. (Fig. 53.) Often they have to be adjusted to a certain amount of internal clearance or to a given preload using springs or shims (calibrated distance pieces). If instructions from the machine manufacturer are not available, the bearing supplier should be contacted for advice.

Simple wheel bearing arrangements may, however, be dealt with quite easily. Start by mounting the outer ring

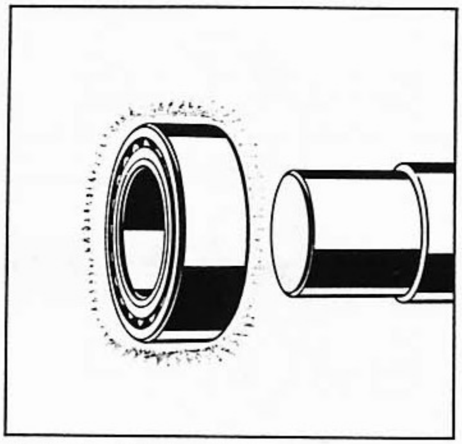


**Figure 47** Placing the bearing

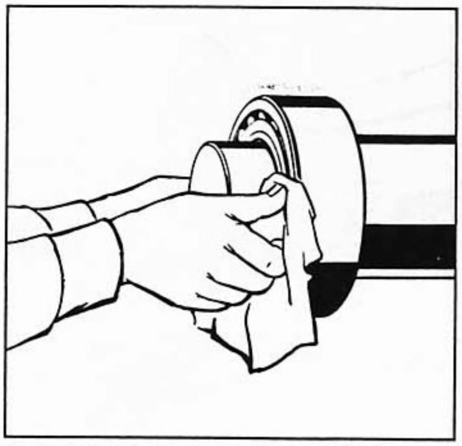


**Figure 48** Hold in its final position until nipped

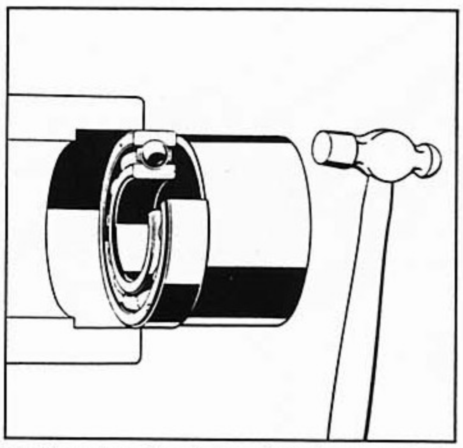


**Figure 49** Mounting bearings—interference fit in the housing

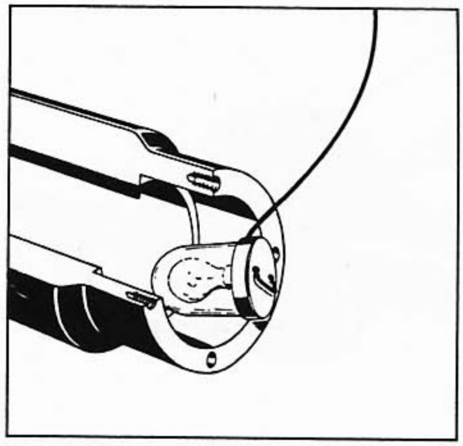


**Figure 50** Heating a housing

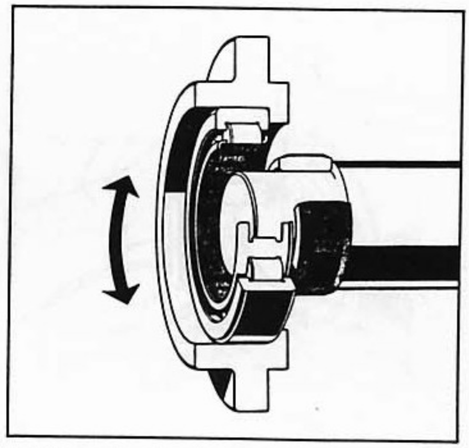


**Figure 51** Mounting bearings—cylindrical roller bearings

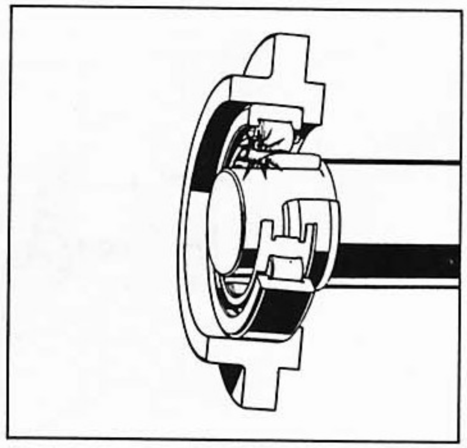


**Figure 52** Enter squarely and rotate

into the hub using a mounting dolly or clean length of tubing. Check that the rings abut the retaining rings (shoulders). (Fig. 54.)

The inside bearing inner ring with its roller and cage assembly should then be mounted on the axle. (Fig. 55.) Fill the space between the rollers in both bearings and between the outer rings with a suitable grease. Place the wheel in position and finally mount the outside bearing inner ring with its roller and cage assembly.

Screw on the nut and tighten it as the wheel is rotated. (Fig. 56.) When the wheel can no longer be rotated easily, loosen the nut just enough to allow the wheel to rotate freely again. Lock the nut and put on the hub cap immediately.

Check the play in the bearing arrangement if possible, for example by rocking a wheel, a bearing housing or a shaft. (Fig. 57.) If the bearings are mounted too tightly, bearing failure could occur quite quickly.

If high accuracy is required, a gauge can be used to measure the axial internal clearance of the bearing. (Fig. 58.) It is important that during adjustment and before measuring, the shaft or housing is rotated for a few revolutions so that the roller ends take up their correct position against the guide flange.

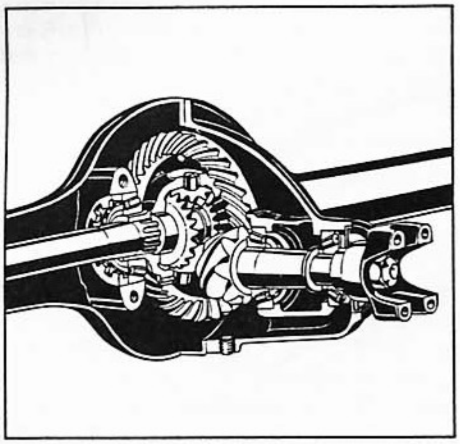


**Figure 53** Mounting bearings—taper roller bearings

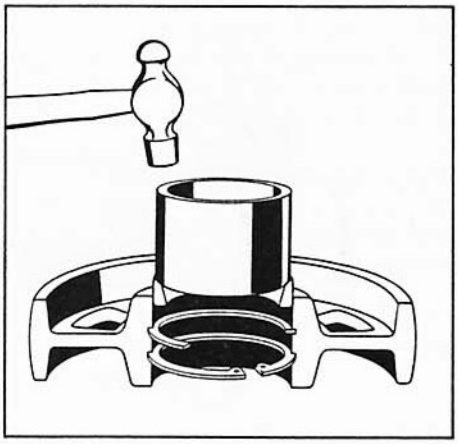


**Figure 54** Inserting the outer ring

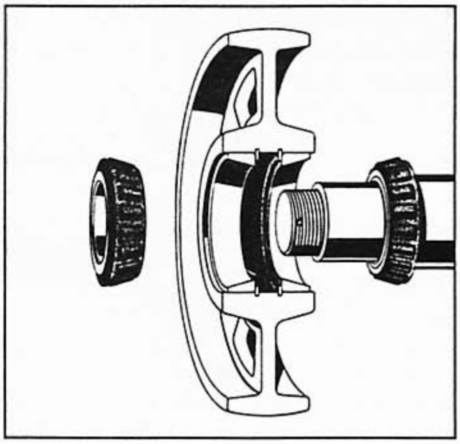


**Figure 55** Inner ring (cone) assemble to axle

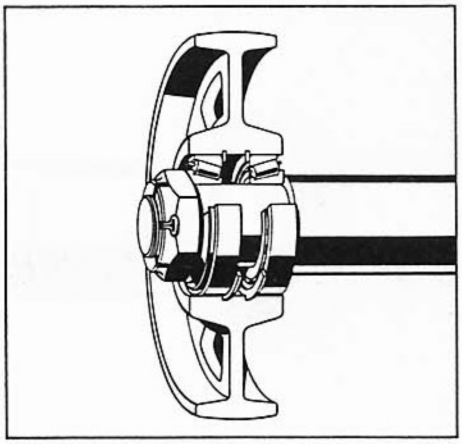


**Figure 56** Rotate as nut is tightened

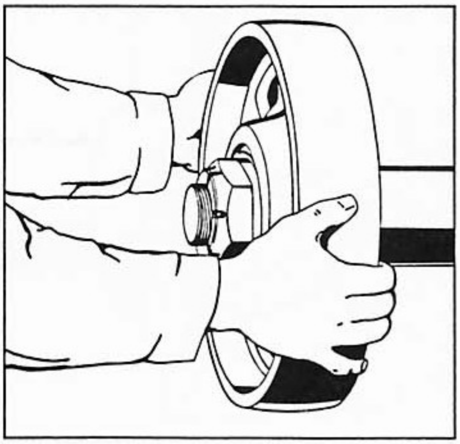


**Figure 57** Feel the end play

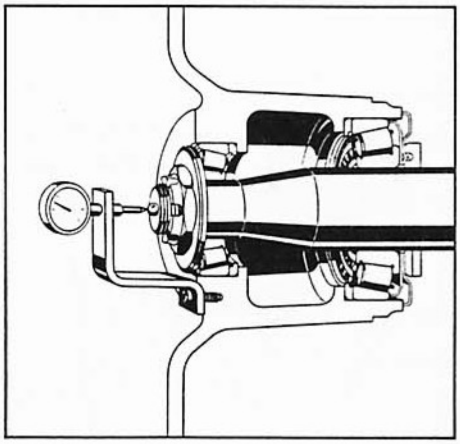


**Figure 58** Accurate set end play using clock indicator

## Bearings on Sleeves

The inner ring of bearings with a tapered bore is always mounted with an interference fit, usually on an adapter sleeve or a withdrawal sleeve. The degree of interference depends on the distance the bearing is driven up the tapered surface. The original radial internal clearance of the bearing is gradually reduced as the bearing is driven up. Thus, reduction in clearance is a measure of the degree of interference. (Fig. 59.)

### Adapter Sleeve

Place the sleeve on the shaft at the position marked before it was dismounted; this can be done easily if the slot is opened slightly using a screwdriver, for example (see Fig. 60). If, for some reason, the position of the sleeve on the shaft has not been marked, then the correct position of the bearing must be ascertained and the sleeve placed in relation to it. In certain cases, trial mounting of the bearings may be necessary to ensure that the sleeve is correctly positioned.

Before mounting, remove the rust-inhibiting compound from the bearing bore only. Place the bearing on the sleeve and screw on the lock nut. Drive the bearing up the sleeve by tightening the lock nut (Fig. 61).

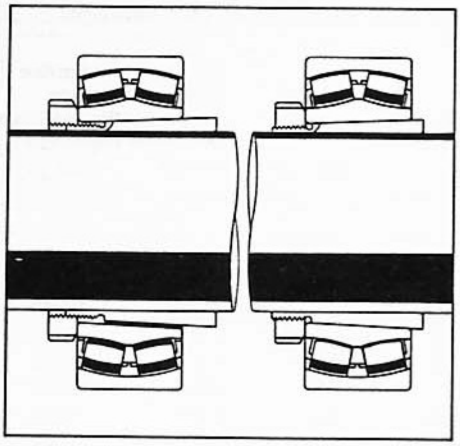


**Figure 59** Mounting bearings—bearings on sleeves

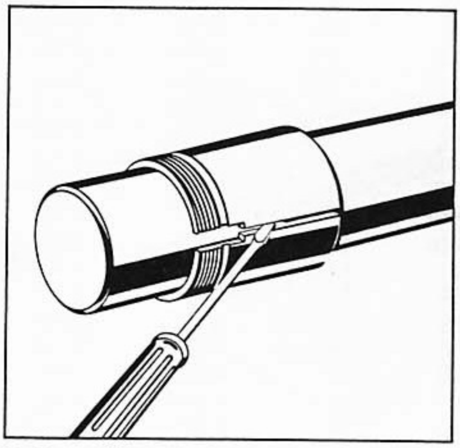


**Figure 60** Open sleeve for ease of positioning

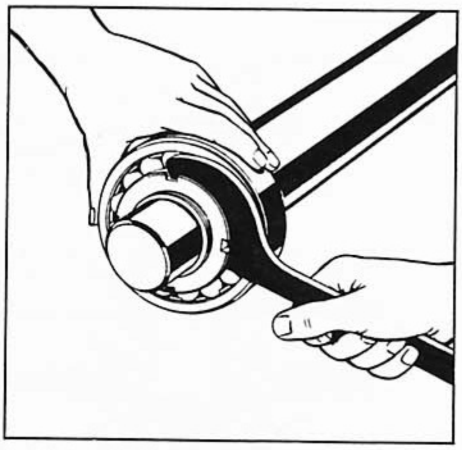


**Figure 61** Tighten lock nut

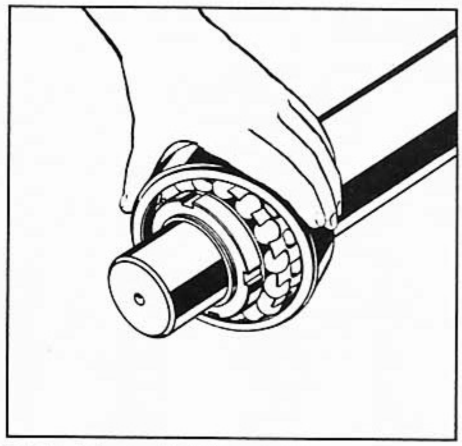


**Figure 62** Feel the radial clearance

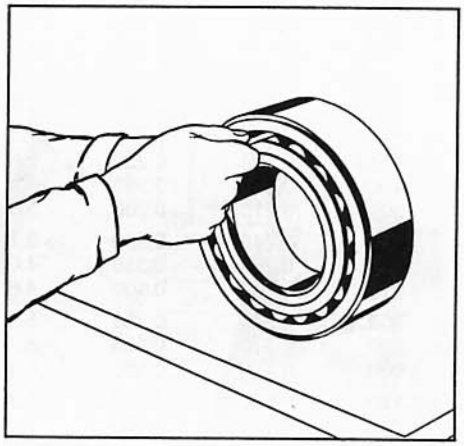


**Figure 63** Measuring radial clearance of roller bearing

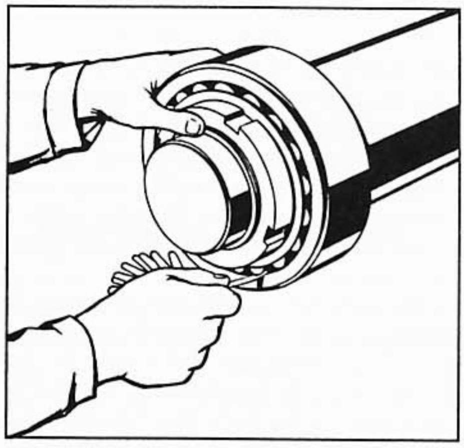


**Figure 64** Check radial clearance after tightening sleeve

When mounting self-aligning ball bearings on adapter sleeves, the reduction in radial internal clearance can be checked by rotating the bearing and swivelling the outer ring during the drive-up (see Fig. 62). When the lock nut has been correctly tightened it should still be possible to rotate the outer ring easily, but there should be a certain amount of resistance when trying to swivel it.

Before spherical roller bearings are mounted on adapter sleeves, the radial internal clearance should be measured using a feeler gauge. Stand the bearing on the work bench and rotate the inner ring a few times to allow the rollers to assume their correct positions, before inserting the blade of the feeler gauge between the uppermost roller and the outer ring raceway (see Fig. 63). Use a thin blade to start with and increase the thickness gradually until the blade can just be inserted. The measured clearance should be the same for both rows of rollers.

Check the reduction in clearance frequently during the driving-up process. Measure between the lowest roller and the outer ring raceway (see Fig. 64). Table 1 contains guideline values for the reduction in radial internal clearance and axial drive-up for spherical roller bearings.

Heavy loads, high speeds, or large differences in temperature between inner and outer rings (inner ring hotter

**Table 1** Reduction in radial internal clearance and axial drive-up for spherical roller bearings

| Bearing bore diameter d | | Reduction in radial internal clearance | | Axial drive-up* | | | | Minimum permissible residual clearance after mounting bearings with initial clearance | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Taper 1:12 on diameter | | Taper 1:30 on diameter | | | | |
| over | incl. | min. | max. | min. | max. | min. | max. | Normal | C3 | C4 |
| (mm) | | (mm) | | (mm) | | | | (mm) | | |
| 30 | 40 | 0.020 | 0.025 | 0.35 | 0.4 | — | — | 0.015 | 0.025 | 0.040 |
| 40 | 50 | 0.025 | 0.030 | 0.45 | 0.45 | — | — | 0.020 | 0.030 | 0.050 |
| 50 | 65 | 0.030 | 0.040 | 0.45 | 0.6 | — | — | 0.025 | 0.035 | 0.055 |
| 65 | 80 | 0.040 | 0.050 | 0.6 | 0.75 | — | — | 0.025 | 0.040 | 0.070 |
| 80 | 100 | 0.045 | 0.060 | 0.7 | 0.9 | 1.75 | 2.25 | 0.035 | 0.050 | 0.080 |
| 100 | 120 | 0.050 | 0.070 | 0.75 | 1.1 | 1.9 | 2.75 | 0.050 | 0.065 | 0.100 |
| 120 | 140 | 0.065 | 0.090 | 1.1 | 1.4 | 2.75 | 3.5 | 0.055 | 0.080 | 0.110 |
| 140 | 160 | 0.075 | 0.100 | 1.2 | 1.6 | 3.0 | 4.0 | 0.055 | 0.090 | 0.130 |
| 160 | 180 | 0.080 | 0.110 | 1.3 | 1.7 | 3.25 | 4.25 | 0.060 | 0.100 | 0.150 |
| 180 | 200 | 0.090 | 0.130 | 1.4 | 2.0 | 3.5 | 5.0 | 0.070 | 0.100 | 0.160 |
| 200 | 225 | 0.100 | 0.140 | 1.6 | 2.2 | 4.0 | 5.5 | 0.080 | 0.120 | 0.180 |
| 225 | 250 | 0.110 | 0.150 | 1.7 | 2.4 | 4.25 | 6.0 | 0.090 | 0.130 | 0.200 |
| 250 | 280 | 0.120 | 0.170 | 1.9 | 2.7 | 4.75 | 6.75 | 0.100 | 0.140 | 0.220 |
| 280 | 315 | 0.130 | 0.190 | 2.0 | 3.0 | 5.0 | 7.5 | 0.110 | 0.150 | 0.240 |
| 315 | 355 | 0.150 | 0.210 | 2.4 | 3.3 | 6.0 | 8.25 | 0.120 | 0.170 | 0.260 |
| 355 | 400 | 0.170 | 0.230 | 2.6 | 3.6 | 6.5 | 9.0 | 0.130 | 0.190 | 0.290 |
| 400 | 450 | 0.200 | 0.260 | 3.1 | 4.0 | 7.75 | 10 | 0.130 | 0.200 | 0.310 |
| 450 | 500 | 0.210 | 0.280 | 3.3 | 4.4 | 8.25 | 11 | 0.160 | 0.230 | 0.350 |
| 500 | 560 | 0.240 | 0.320 | 3.7 | 5.0 | 9.25 | 12.5 | 0.170 | 0.250 | 0.360 |
| 560 | 630 | 0.260 | 0.350 | 4.0 | 5.4 | 10 | 13.5 | 0.200 | 0.290 | 0.410 |
| 630 | 710 | 0.300 | 0.400 | 4.6 | 6.2 | 11.5 | 15.5 | 0.210 | 0.310 | 0.450 |
| 710 | 800 | 0.340 | 0.450 | 5.3 | 7.0 | 13.3 | 17.5 | 0.230 | 0.350 | 0.510 |
| 800 | 900 | 0.370 | 0.500 | 5.7 | 7.8 | 14.3 | 19.5 | 0.270 | 0.390 | 0.570 |
| 900 | 1 000 | 0.410 | 0.550 | 6.3 | 8.5 | 15.8 | 21 | 0.300 | 0.430 | 0.640 |
| 1 000 | 1 120 | 0.450 | 0.600 | 6.8 | 9.0 | 17 | 23 | 0.320 | 0.480 | 0.700 |
| 1 120 | 1 250 | 0.490 | 0.650 | 7.4 | 9.8 | 18.5 | 25 | 0.340 | 0.540 | 0.770 |

* Valid for solid steel shafts only.

than outer) mean that a relatively large residual radial internal clearance is needed. In such cases a bearing having larger initial radial internal clearance than 'normal', that is, C3 or C4, is generally used and mounted using the maximum reduction clearance figures shown in the table. If the outer ring is hotter than the inner, a bearing having less initial radial internal clearance than 'normal' is generally used.

Remove the lock nut after the drive-up has been completed and place the locking washer in position. (Fig. 65.) Screw on the lock nut again and tighten it. Bend down a suitable tab of the locking washer so that it engages in one of the slots in the lock nut. Measure the residual clearance again to see that it is unchanged.

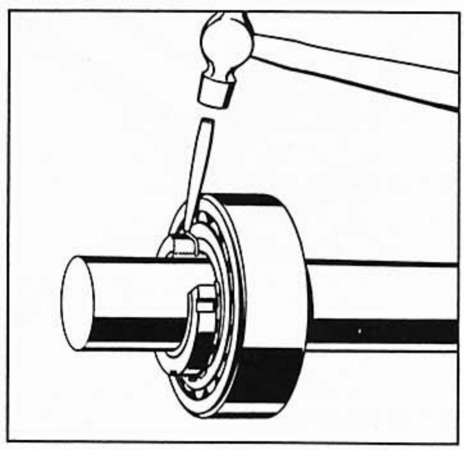


**Figure 65** Securing locknut at predetermined setting

### Withdrawal Sleeve

Drive the withdrawal sleeve into the bearing bore using a mountain dolly or a length of clean tubing (Fig. 66). Check the drive-up by measuring the reduction in radial internal clearance of the bearing.

## Applying Lubricant

### Grease Lubrication

Fill the space between the balls or rollers with a grease that is suitable for the operating conditions. (Figs. 67.) The free space around the bearing should normally be between one-third and one-half filled with grease. If the bearing is to operate at very high speeds, the quantity of grease in the free space should be just less than one-third. Or, where the bearing is to operate at very slow speeds, the free space may be completely filled with grease.

### Oil Lubrication

Use oil of the type prescribed and fill to the specified level. (Fig. 68.) If there is also an operating oil level, check that this is correct too.

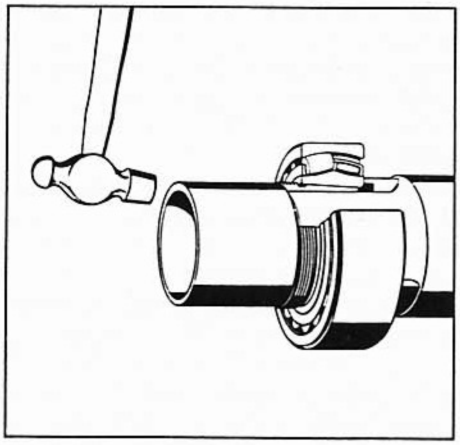


**Figure 66** Setting a withdrawal sleeve

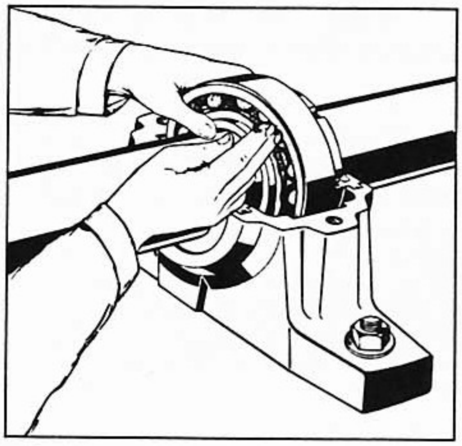


**Figure 67** Grease lubrication

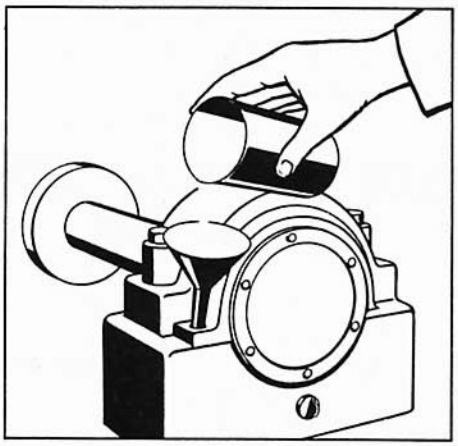


**Figure 68** Oil lubrication

## Test Running

It is during the very first period of operation after starting up that any mounting errors can be corrected. Keep a check on bearing behaviour immediately after starting up, as indicated on pages 503 to 504. (Fig. 69.) If there is the slightest doubt as to bearing performance, the machine should be stopped and the bearing arrangement checked.

Mounting data, such as the date, the full designation of the bearing, results of dimensional checks, bearing radial internal clearance before and after mounting, the lubricant used, etc., should be noted in report form. (See

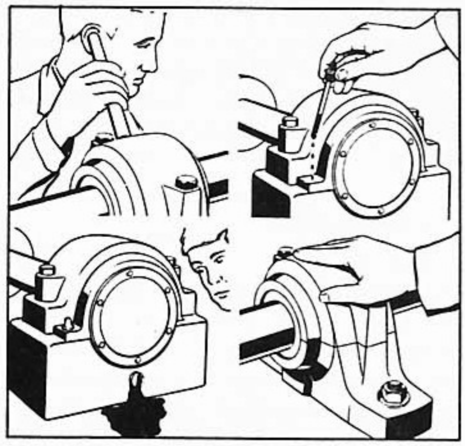


**Figure 69** Test running

**Figure 70** Reports

Fig. 70.) A maintenance schedule should be attached to the report, giving details of relubrication, inspection routines, operating temperature, etc. If this is done, a good record of the bearing will be obtained and any future replacement can be planned well in advance.

## Lubrication Instructions

A correctly lubricated rolling bearing will not become worn, since the lubricant will prevent metallic contact beween the various bearing components. Where the machine manufacturer indicates the type of lubricant to be used and the period of relubrication these instructions should be followed. If, however, instructions are not available, the following recommendations may prove useful.

All rolling bearings can, as a rule, be lubricated either with grease or oil. Spherical roller thrust bearings must normally be lubricated with oil, grease being permitted only where operating speeds are very low. Sealed or shielded bearings are lubricated-for-life, that is, they are filled with grease before leaving the factory and do not need relubrication.

The choice of lubricant is primarily determined by the operating temperature and speed of the bearing. Under normal operating conditions grease can usually be used. It is more easily retained in the bearing arrangement than oil and also serves to protect the bearing against moisture and impurities. Oil lubrication is generally recommended where speeds or temperatures are high, when heat is to be conducted away from the bearing, or where adjacent machine components are oil lubricated. Always store lubricants in clean, sealed containers in a dry store. The bearing supplier will, on request, usually suggest suitable greases or oils.

## Grease Lubrication

### Types of Grease

Lubricating greases are oils that contain thickeners, generally in the form of metallic soaps. When selecting a suitable grease it is necessary to consider the consistency, operating temperature range and rust-inhibiting properties. Consistency is classified according to the National Lubricating Grease Institute (NLG) scale. In general, greases with a metallic-soap base, of consistency, 1, 2, or 3, may be used for rolling bearings.

The upper temperature limit for calcium-based greases is approximately 60°C. Calcium-based greases containing additions of lead soaps are particularly suitable for 'wet' bearing arrangements, for example the wire section of a paper-making machine. Certain calcium/lead-based greases provide protection against salt water.

Sodium-based greases are available for the temperature range −30 to +80°C and provide protection against corrosion in that they absorb any moisture and form an emulsion with it. However, if the amount of moisture absorbed becomes excessive, the lubricating properties will deteriorate and there is a risk that the grease will run out of the arrangement.

Lithium-based greases may generally be used at temperatures of −30 to +110°C and they are resistant to water. If moisture can enter the bearing arrangement, they should therefore contain a rust inhibitor. Lithium-based greases with lead soap additives provide relatively good lubrication even where free water can penetrate.

A number of different types of high-temperature grease are available for temperatures in excess of 120°C.

### Relubrication Interval

If no instructions are available, Figure 71 may be used as a guide. It is based on lubrication using an age-resistant grease of normal quality and gives the relubrication interval expressed in operating hours. The diagram is valid for stationary machines, normal bearing loads and operating temperatures up to 70°C, measured at the bearing outer ring. For every 15°C increase in temperature above 70°C, the relubrication interval obtained from the diagram must be halved, but the upper temperature limit for the grease must not be exceeded. Bearing arrangements, where the grease is likely to become contaminated quickly or is to seal against water, should be relubricated at more frequent intervals than those obtained from the diagram.

### Amount of Grease

Where no recommendations are given, the quantity of grease to be used can be calculated from the equation:

$$G = 0.005 \times D \times B$$

where

$G$ = grease quantity in grams
$D$ = bearing outside diameter in millimetres
$B$ = bearing width in millimetres

## Oil Lubrication

Solvent-refined mineral oils should be used for lubricating rolling bearings. At temperatures above 125°C, the

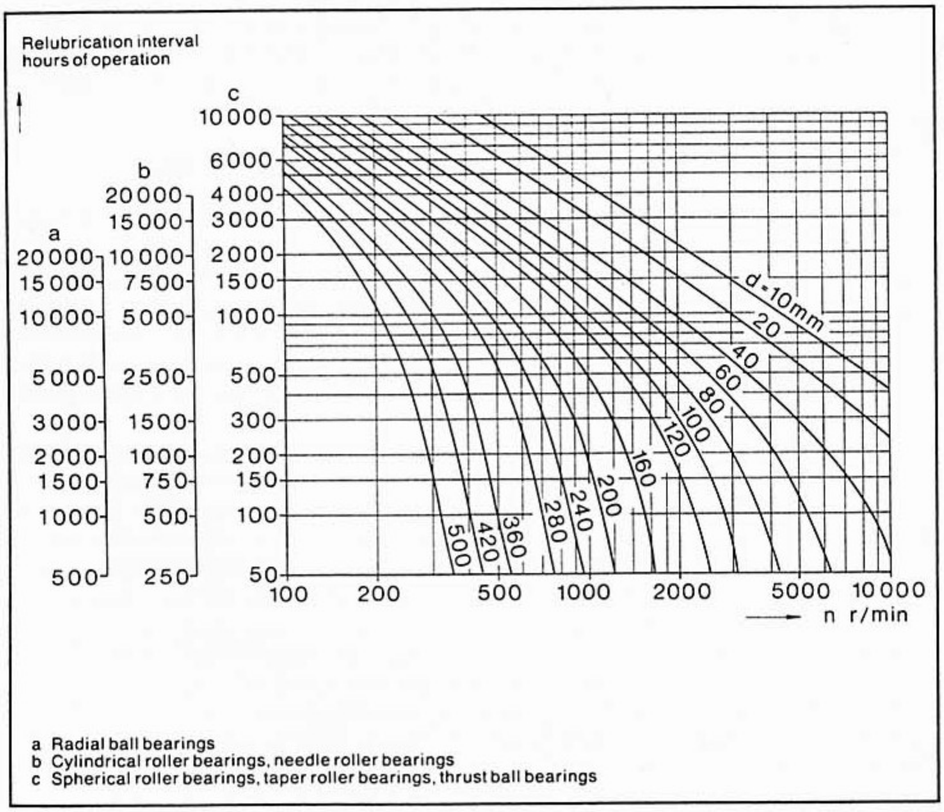



**Figure 71** Relubrication interval

use of synthetic oils, for example of the polyglycol type, is recommended. Additives to improve certain properties are generally needed only when operating conditions are exceptional. Oils having a medium to high viscosity index should normally be used. However, at high speeds, oils of low viscosity may be used to keep bearing temperature down and, at very low speeds, highly viscous oils must be used to ensure that a sufficiently thick film of lubricant is formed.

## Mounting and dismounting tools

### Hydraulic Tools

When mounting or dismounting larger bearings, the oil injection method is useful. Figure 72 shows how the oil injection method is used in conjunction with a hydraulic nut to mount a spherical roller bearing on a tapered journal.

The oil injection method involves introducing oil under high pressure between the bearing seating and bearing bore, forming a film that separates the surfaces. Oil is fed to the contact surfaces via ducts (a) in the shaft and is distributed via grooves (b). Shafts without ducts and grooves can easily be modified, for example during an overhaul.

The hydraulic nut is screwed onto a thread on the shaft or sleeve. Oil is injected into the nut (c) so that its annular piston (d) presses against the inner ring of the bearing, against a shaft nut or against a washer screwed onto the shaft end. The oil is pressurized by means of an oil injector or pump.

Figure 73 shows dismounting of the same bearing, using the oil injection method. The shaft lock nut has been loosened a few turns. When oil is injected between the bearing and its seating, the bearing slides away easily and is stopped by the lock nut.

### Mechanical Tools

A selection of mechanical tools that can be used for mounting and dismounting bearings is shown in Figure 74.

## Fits and tolerances for shaft and housing

When machining a shaft or housing for a bearing never unpack the bearing to measure its dimensions, always refer to a catalogue for the nominal size or use your ruler – the paper wrapping will not affect your nominal dimensions. Consult Table 2 for the appropriate shaft tolerance designation and then read the actual shaft tolerance from Table 3.

The same applies to the housing dimension using Table 4 for the appropriate housing tolerance symbol then the actual tolerance for the diameter from Table 5.

The above recommendations apply to solid steel shafts and cast iron or steel housings. Many years of experience

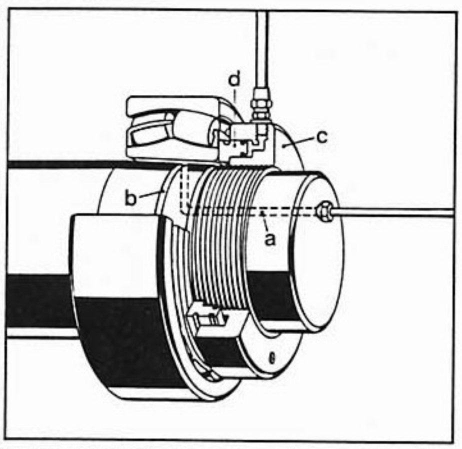



**Figure 72** Hydraulic tools—mounting a spherical roller bearing on a tapered journal

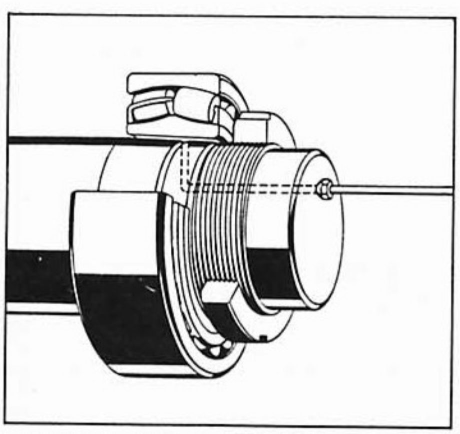


**Figure 73** Hydraulic tools—dismounting the bearing

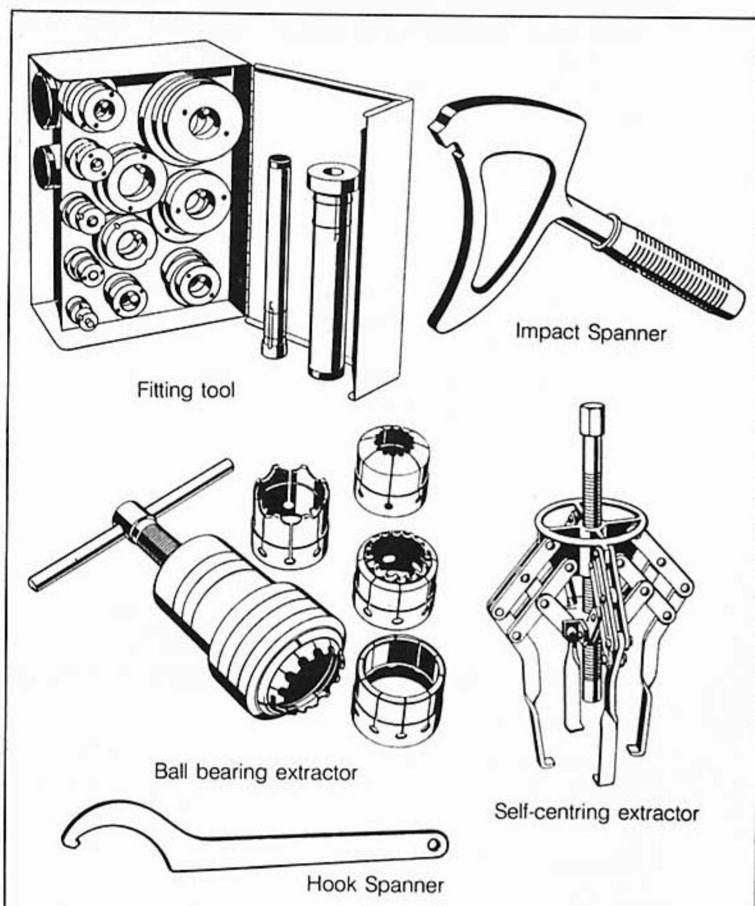



**Figure 74** Mechanical tools

with a wide variety of applications have enabled the compilation of these tables and proven correctness.

Following the above procedure, keeping the bearing clean and the fit correct are all important in achieving long bearing life.

## Abutment and fillet dimensions

The dimensions of components adjacent to the bearing (shaft and housing shoulders, spacer sleeves etc.) must be such that sufficient support is provided for the bearing rings but there must be no contact between the rotating parts of the bearing and a stationary component. Appropriate abutment and fillet dimensions are quoted by the manufacturer for each individual bearing listed in his bearing tables. (See Table 6.)

The greater the fillet radius in the shaft, the more favourable is the stress distribution. For heavily loaded shafts, therefore, a large radius is generally required. In such cases a spacing collar should be provided between the inner ring and shaft shoulder to provide a sufficiently large support surface for the bearing ring. The side of the collar facing the shaft shoulder should be relieved so that it does not contact the shaft fillet.

It may also be necessary to machine slots in shaft and housing shoulders to enable withdrawal tools to be used to dismount the bearing.

Table 2 Fits for solid steel shafts

| Conditions | Examples | Shaft diameter (mm) | | | Tolerance |
|---|---|---|---|---|---|
| | | Ball bearings | Cylindrical and taper roller bearings | Spherical roller bearings | |
| *Radial bearings with cylindrical bore* | | | | | |
| Stationary inner ring load: | | | | | |
| Easy axial displacement of inner ring on shaft desirable | Wheels on non-rotating axles | | | | g6* |
| Easy axial displacement of inner ring on shaft unnecessary | Tension pulleys, rope sheaves | | | | h6 |
| Rotating inner ring load or direction of loading indeterminate: | | | | | |
| Light and variable loads (*P* ≦ 0.06 C) | Conveyors, lightly loaded gearbox bearings | (18) to 100 | ≦ 40 | — | j6 |
| | | (100) to 140 | (40) to 100 | — | k6 |
| Normal loads and heavy loads (*P* > 0.06C) | Bearings applications generally electric motors, turbines, pumps, internal combustion engines, gearing, woodworking machines | ≦ 18 | — | — | j5 |
| | | (18) to 100 | ≦ 40 | ≦ 40 | k5 (k6)† |
| | | (100) to 140 | (40) to 100 | (40) to 65 | m5 (m6)† |
| | | (140) to 200 | (100) to 140 | (65) to 100 | m6 |
| | | (200) to 280 | (140) to 200 | (100) to 140 | n6 |
| | | — | (200) to 400 | (140) to 280 | p6 |
| | | — | — | (280) to 500 | r6 |
| | | — | — | > 500 | r7 |
| Very heavy loads and shock loads with difficult working conditions (*P* > 0.12C) | Axleboxes for heavy railway vehicles, traction motors, rolling mills | — | (50) to 140 | (50) to 100 | n6** |
| | | — | (140) to 200 | (100) to 140 | p6** |
| | | — | > 200 | > 140 | r6** |
| High demands on running accuracy with light loads (*P* ≦ 0.06C) | Machine tools | ≦ 18 | — | — | h5†† |
| | | (18) to 100 | ≦ 40 | — | j5†† |
| | | (100) to 200 | (40) to 140 | — | k5†† |
| | | — | (140) to 200 | — | m5†† |
| Axial loads only | | | | | |
| | Bearing applications of all kinds | ≦ 250 | ≦ 250 | ≦ 250 | j6 |
| | | > 250 | > 250 | > 250 | js6 |

| Conditions | Tolerance | Remarks |
|---|---|---|
| *Radial bearings with tapered bore and adapter or withdrawal sleeve* | | |
| Loads of all kinds: | | |
| Railway axleboxes | h9/IT5 | Suffixes IT5 and IT7 in this instance mean that the deviation of the shaft from its true geometric form, e.g. out-of-round and taper, must be no greater than the tolerance of grades 5 and 7 respectively |
| General engineering | h9/IT5 or h10/IT7 | |

| Conditions | Shaft diameter (mm) | Tolerance |
|---|---|---|
| ***Thrust bearings*** | | |
| **Axial loads only:** | | |
| Thrust ball bearings | | h6 |
| Cylindrical roller thrust bearings | | h6 (h8) |
| Cylindrical roller and cage thrust assemblies | | h8 |
| **Radial and axial loads on spherical roller thrust bearings:** | | |
| Stationary load on shaft washer | ≦ 250 | j6 |
| | > 250 | js6 |
| Rotating load on shaft washer or direction of laoding indeterminate | ≦ 200 | k6 |
| | (200) to 400 | m6 |
| | > 400 | n6 |

* Tolerance f5 can be selected for large bearings to ensure easy displacement.
† The tolerances in brackets are generally used for taper roller bearings and single row angular contact ball bearings. They can also be used for other types of bearing where speeds are moderate and the effect of bearing internal clearance is not significant.
** Bearings with radial internal clearance greater than normal are necessary.
†† For high precision bearings other recommendations apply.

Table 3 ISO shaft limits

| Shaft diameter nominal over | incl. | Bearing bore tolerance $d_{mp}$ min. | max. | Shaft diameter tolerances (Deviations) f6 high | f6 low | g6 high | g6 low | h11 high | h11 low | h10 high | h10 low | IT7 | h9 high | h9 low | IT5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (μm) | | (μm) | | (μm) | | | | | | | | | | | |
| 3 | 6 | −8 | 0 | −10 | −18 | −4 | −12 | 0 | −75 | 0 | −48 | 12 | 0 | −30 | 5 |
| 6 | 10 | −8 | 0 | −13 | −22 | −5 | −14 | 0 | −90 | 0 | −58 | 15 | 0 | −36 | 6 |
| 10 | 18 | −8 | 0 | −16 | −27 | −6 | −17 | 0 | −110 | 0 | −70 | 18 | 0 | −43 | 8 |
| 18 | 30 | −10 | 0 | −20 | −33 | −7 | −20 | 0 | −130 | 0 | −84 | 21 | 0 | −52 | 9 |
| 30 | 50 | −12 | 0 | −25 | −41 | −9 | −25 | 0 | −160 | 0 | −100 | 25 | 0 | −62 | 11 |
| 50 | 80 | −15 | 0 | −30 | −49 | −10 | −29 | 0 | −190 | 0 | −120 | 30 | 0 | −74 | 13 |
| 80 | 120 | −20 | 0 | −36 | −58 | −12 | −34 | 0 | −220 | 0 | −140 | 35 | 0 | −87 | 15 |
| 120 | 180 | −25 | 0 | −43 | −68 | −14 | −39 | 0 | −250 | 0 | −160 | 40 | 0 | −100 | 18 |
| 180 | 250 | −30 | 0 | −50 | −79 | −15 | −44 | 0 | −290 | 0 | −185 | 46 | 0 | −115 | 20 |
| 250 | 315 | −35 | 0 | −56 | −88 | −17 | −49 | 0 | −320 | 0 | −210 | 52 | 0 | −130 | 23 |
| 315 | 400 | −40 | 0 | −62 | −98 | −18 | −54 | 0 | −360 | 0 | −230 | 57 | 0 | −140 | 25 |
| 400 | 500 | −45 | 0 | −68 | −108 | −20 | −60 | 0 | −400 | 0 | −250 | 63 | 0 | −155 | 27 |
| 500 | 630 | −50 | 0 | — | — | −22 | −66 | 0 | −440 | 0 | −280 | 70 | 0 | −175 | — |
| 630 | 800 | −75 | 0 | — | — | −24 | −74 | 0 | −500 | 0 | −320 | 80 | 0 | −200 | — |
| 800 | 1 000 | −100 | 0 | — | — | −26 | −82 | 0 | −560 | 0 | −360 | 90 | 0 | −230 | — |
| 1 000 | 1 250 | −125 | 0 | — | — | −28 | −94 | 0 | −660 | 0 | −420 | 105 | 0 | −260 | — |

| Shaft diameter nominal over | incl. | Bearing bore tolerance $d_{mp}$ min. | max. | Shaft diameter tolerances (Deviations) h8 high | h8 low | h7 high | h7 low | h6 high | h6 low | h5 high | h5 low | j5 high | j5 low | j6 high | j6 low | js6 high | js6 low |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (μm) | | (μm) | | (μm) | | | | | | | | | | | | | |
| 3 | 6 | −8 | 0 | 0 | −18 | 0 | −12 | 0 | −8 | 0 | −5 | +3 | −2 | +6 | −2 | +4 | −4 |
| 6 | 10 | −8 | 0 | 0 | −22 | 0 | −15 | 0 | −9 | 0 | −6 | +4 | −2 | +7 | −2 | +4,5 | −4,5 |
| 10 | 18 | −8 | 0 | 0 | −27 | 0 | −18 | 0 | −11 | 0 | −8 | +5 | −3 | +8 | −3 | +5,5 | −5,5 |
| 18 | 30 | −10 | 0 | 0 | −33 | 0 | −21 | 0 | −13 | 0 | −9 | +5 | −4 | +9 | −4 | +6,5 | −6,5 |
| 30 | 50 | −12 | 0 | 0 | −39 | 0 | −25 | 0 | −16 | 0 | −11 | +6 | −5 | +11 | −5 | +8 | −8 |
| 50 | 80 | −15 | 0 | 0 | −46 | 0 | −30 | 0 | −19 | 0 | −13 | +6 | −7 | +12 | −7 | +9,5 | −9,5 |
| 80 | 120 | −20 | 0 | 0 | −54 | 0 | −35 | 0 | −22 | 0 | −15 | +6 | −9 | +13 | −9 | +11 | −11 |
| 120 | 180 | −25 | 0 | 0 | −63 | 0 | −40 | 0 | −25 | 0 | −18 | +7 | −11 | +14 | −11 | +12,5 | −12,5 |
| 180 | 250 | −30 | 0 | 0 | −72 | 0 | −46 | 0 | −29 | 0 | −20 | +7 | −13 | +16 | −13 | +14,5 | −14,5 |

*Continued on next page*

| Shaft diameter nominal over | incl. | Bearing bore tolerance $d_{mp}$ min. | max. | h8 high | low | h7 high | low | h6 high | low | h5 high | low | j5 high | low | j6 high | low | js6 high | low |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (μm) | | (μm) | | Shaft diameter tolerances, Deviations (μm) | | | | | | | | | | | | | |
| 250 | 315 | -35 | 0 | 0 | -81 | 0 | -52 | 0 | -32 | 0 | -23 | +7 | -16 | +16 | -16 | +16 | -16 |
| 315 | 400 | -40 | 0 | 0 | -89 | 9 | -57 | 0 | -36 | 0 | -25 | +7 | -18 | +18 | -18 | +18 | -18 |
| 400 | 500 | -45 | 0 | 0 | -97 | 0 | -63 | 0 | -40 | 0 | -27 | +7 | -20 | +20 | -20 | +20 | -20 |
| 500 | 630 | -50 | 0 | 0 | -110 | 0 | -70 | 0 | -44 | — | — | — | — | — | — | +22 | -22 |
| 630 | 800 | -75 | 0 | 0 | -125 | 0 | -80 | 0 | -50 | — | — | — | — | — | — | +25 | -25 |
| 800 | 1 000 | -100 | 0 | 0 | -140 | 0 | -90 | 0 | -56 | — | — | — | — | — | — | +28 | -28 |
| 1 000 | 1 250 | -125 | 0 | 0 | -165 | 0 | -105 | 0 | -66 | — | — | — | — | — | — | +33 | -33 |

| Shaft diameter nominal over | incl. | Bearing bore tolerance $d_{mp}$ min. | max. | k5 high | low | k6 high | low | m5 high | low | m6 high | low | n6 high | low | p6 high | low |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (mm) | | (μm) | | Shaft diameter tolerances, Deviations (μm) | | | | | | | | | | | |
| 3 | 6 | -8 | 0 | +6 | +1 | +9 | +1 | +9 | +4 | +12 | +4 | +16 | +8 | +20 | +12 |
| 6 | 10 | -8 | 0 | +7 | +1 | +10 | +1 | +12 | +6 | +15 | +6 | +19 | +10 | +24 | +15 |
| 10 | 18 | -8 | 0 | +9 | +1 | +12 | +1 | +15 | +7 | +18 | +7 | +23 | +12 | +29 | +18 |
| 18 | 30 | -10 | 0 | +11 | +2 | +15 | +2 | +17 | +8 | +21 | +8 | +28 | +15 | +35 | +22 |
| 30 | 50 | -12 | 0 | +13 | +2 | +18 | +2 | +20 | +9 | +25 | +9 | +33 | +17 | +42 | +26 |
| 50 | 80 | -15 | 0 | +15 | +2 | +21 | +2 | +24 | +11 | +30 | +11 | +39 | +20 | +51 | +32 |
| 80 | 120 | -20 | 0 | +18 | +3 | +25 | +3 | +28 | +13 | +35 | +13 | +45 | +23 | +59 | +37 |
| 120 | 180 | -25 | 0 | +21 | +3 | +28 | +3 | +33 | +15 | +40 | +15 | +52 | +27 | +68 | +43 |
| 180 | 250 | -30 | 0 | +24 | +4 | +33 | +4 | +37 | +17 | +46 | +17 | +60 | +31 | +79 | +50 |
| 250 | 315 | -35 | 0 | +27 | +4 | +36 | +4 | +43 | +20 | +52 | +20 | +66 | +34 | +88 | +56 |
| 315 | 400 | -40 | 0 | +29 | +4 | +40 | +4 | +46 | +21 | +57 | +21 | +73 | +37 | +98 | +62 |
| 400 | 500 | -45 | 0 | +32 | +5 | +45 | +5 | +50 | +23 | +63 | +23 | +80 | +40 | +108 | +68 |
| 500 | 630 | -50 | 0 | — | — | +44 | 0 | — | — | +70 | +26 | +88 | +44 | +122 | +78 |
| 630 | 800 | -75 | 0 | — | — | +50 | 0 | — | — | +80 | +30 | +100 | +50 | +138 | +88 |
| 800 | 1 000 | -100 | 0 | — | — | +56 | 0 | — | — | +90 | +34 | +112 | +56 | +156 | +100 |
| 1 000 | 1 250 | -125 | 0 | — | — | +66 | 0 | — | — | +106 | +40 | +132 | +66 | +186 | +120 |

| Shaft diameter nominal over | incl. | Bearing bore tolerance $d_{mp}$ min. | max. | r6 high | low | r7 high | low |
|---|---|---|---|---|---|---|---|
| (mm) | | (μm) | | Shaft diameter tolerances, Deviations (μm) | | | |
| 120 | 140 | -25 | 0 | +88 | +63 | +103 | +63 |
| 140 | 160 | -25 | 0 | +90 | +65 | +105 | +65 |
| 160 | 180 | -25 | 0 | +93 | +68 | +108 | +68 |
| 180 | 200 | -30 | 0 | +106 | +77 | +123 | +77 |
| 200 | 225 | -30 | 0 | +109 | +80 | +126 | +80 |
| 225 | 250 | -30 | 0 | +113 | +84 | +130 | +84 |
| 250 | 280 | -35 | 0 | +126 | +94 | +146 | +94 |
| 280 | 315 | -35 | 0 | +130 | +98 | +150 | +98 |
| 315 | 355 | -40 | 0 | +144 | +108 | +165 | +108 |
| 355 | 400 | -40 | 0 | +150 | +114 | +171 | +114 |
| 400 | 450 | -45 | 0 | +166 | +126 | +189 | +126 |
| 450 | 500 | -45 | 0 | +172 | +132 | +195 | +132 |
| 500 | 560 | -50 | 0 | +194 | +150 | +220 | +150 |
| 560 | 630 | -50 | 0 | +199 | +155 | +225 | +155 |
| 630 | 710 | -75 | 0 | +225 | +175 | +255 | +175 |
| 710 | 800 | -75 | 0 | +235 | +185 | +265 | +185 |
| 800 | 900 | -100 | 0 | +266 | +210 | +300 | +210 |
| 900 | 1 000 | -100 | 0 | +276 | +220 | +310 | +220 |
| 1 000 | 1 120 | -125 | 0 | +316 | +250 | +355 | +250 |
| 1 120 | 1 250 | -125 | 0 | +326 | +260 | +365 | +260 |

Table 4 Fits for cast iron and steel bearings

| Conditions | Examples | Tolerance | Displacement of outer ring |
|---|---|---|---|
| *Radial bearings—solid housings* | | | |
| Rotating outer ring load: | | | |
| Heavy loads on bearings in thin-walled housings, heavy stock loads ($P > 0.12C$) | Roller bearing wheel hubs, big-end bearings | P7 | Cannot be displaced |
| Normal loads and heavy loads ($P > 0.06C$) | Ball bearing wheel hubs, big-end bearings, crane travelling wheels | N7 | Cannot be displaced |
| Light and variable loads ($P \leqq 0.06C$) | Conveyor rollers, rope sheaves, belt tension pulleys | M7 | Cannot be displaced |
| Direction of load indeterminate: | | | |
| Heavy shock loads | Electric traction motors | M7 | Cannot be displaced |
| Normal loads and heavy loads ($P > 0.06C$), axial displacement of outer ring unnecessary | Electric motors, pumps, crankshaft bearings | K7 | Cannot be displaced as a rule |
| Accurate or silent running: | | | |
| | Roller bearings for machine tool work spindles | K6* | Cannot be displaced as a rule |
| | Ball bearings for grinding spindles, small electric motors | J6† | Can be displaced |
| | Small electric motors | H6 | Can easily be displaced |

* For heavier loads a tighter fit than K6 should be selected, e.g. M6 or N6. For high-precision bearings other recommendations apply.
† For high-precision bearings other recommendations apply.

| Conditions | Examples | Tolerance | Displacement of outer ring |
|---|---|---|---|
| *Radial bearings—split or solid housings* | | | |
| Direction of load Indeterminate: | | | |
| Light loads and normal loads ($P \leqq 0.12C$), axial displacement of outer ring desirable | Medium-sized electrical machines, pumps, crankshaft bearings | J7 | Can be normally displaced |
| Stationary outer ring load: | | | |
| Loads of all kinds | Railway axleboxes | H7* | Can easily be displaced |
| Light loads and normal loads ($P \leqq 0.12C$) with simple working conditions | General engineering | H8 | Can easily be displaced |
| Heat conduction through shaft | Drying cylinders, large electrical machines with spherical roller bearings | G7† | Can easily be displaced |

* For large bearings ($D > 250$ mm) and temperature differences between outer ring and housing > 10°C, G7 may be used instead of H7.
† For large bearings ($D > 250$ mm) and temperature differences between outer ring and housing > 10°C, F7 may be used instead of G7.

| Conditions | Tolerance | Remarks |
|---|---|---|
| *Thrust bearings* | | |
| Axial loads only: | | |
| Thrust ball bearings | H8 | For less accurate bearing arrangements there can be radial clearance of up to 0.001 D |
| Cylindrical roller thrust bearings | H7 (H9) | |
| Cylindrical roller and cape thrust assemblies | H10 | |
| Spherical roller thrust bearings, where another bearing is used for radial location | — | Housing washer fitted with radial clearance of up to 0.001 D. |
| Radial and axial loads on spherical roller thrust bearings: | | |
| Stationary load on housing washer | H7 | |
| Rotating load on housing washer | M7 | |

Table 5 ISO housing limits

| Housing bore diameter nominal (mm) | | Bearing outside diameter tolerance $D_{mp}$ (µm) | | Housing bore tolerances, Deviations (µm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | F7 | | G7 | | H10 | | H9 | | H8 | |
| over | incl. | max. | min. | low | high | low | high | low | high | low | high | low | high |
| 10 | 18 | 0 | −8 | +16 | +34 | +6 | +24 | 0 | +70 | 0 | +43 | 0 | +27 |
| 18 | 30 | 0 | −9 | +20 | +41 | +7 | +28 | 0 | +84 | 0 | +52 | 0 | +33 |
| 30 | 50 | 0 | −11 | +25 | +50 | +9 | +34 | 0 | +100 | 0 | +62 | 0 | +39 |
| 50 | 80 | 0 | −13 | +30 | +60 | +10 | +40 | 0 | +120 | 0 | +74 | 0 | +46 |
| 80 | 120 | 0 | −15 | +36 | +71 | +12 | +47 | 0 | +140 | 0 | +87 | 0 | +54 |
| 120 | 150 | 0 | −18 | +43 | +83 | +14 | +54 | 0 | +160 | 0 | +100 | 0 | +63 |
| 150 | 180 | 0 | −25 | +43 | +83 | +14 | +54 | 0 | +160 | 0 | +100 | 0 | +63 |
| 180 | 250 | 0 | −30 | +50 | +96 | +15 | +61 | 0 | +185 | 0 | +115 | 0 | +72 |
| 250 | 315 | 0 | −35 | +56 | +108 | +17 | +69 | 0 | +210 | 0 | +130 | 0 | +81 |
| 315 | 400 | 0 | −40 | +62 | +119 | +18 | +75 | 0 | +230 | 0 | +140 | 0 | +89 |
| 400 | 500 | 0 | −45 | +68 | +131 | +20 | +83 | 0 | +250 | 0 | +155 | 0 | +97 |
| 500 | 630 | 0 | −50 | — | — | +22 | +92 | 0 | +280 | 0 | +175 | 0 | +110 |
| 630 | 800 | 0 | −100 | — | — | +26 | +116 | 0 | +360 | 0 | +230 | 0 | +140 |
| 800 | 1 000 | 0 | −75 | — | — | +24 | +104 | 0 | +320 | 0 | +200 | 0 | +125 |
| 1 000 | 1 250 | 0 | −125 | — | — | +28 | +133 | 0 | +420 | 0 | +260 | 0 | +165 |
| 1 250 | 1 600 | 0 | −160 | — | — | +30 | +155 | 0 | +500 | 0 | +310 | 0 | +195 |

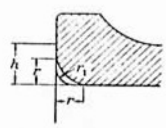
| Housing bore diameter nominal (mm) | | Bearing outside diameter tolerance $D_{mp}$ (µm) | | Housing bore tolerances, Deviations (µm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | H7 | | H6 | | J7 | | JS7 | | J6 | |
| over | incl. | max. | min. | low | high | low | high | low | high | low | high | low | high |
| 10 | 18 | 0 | −8 | 0 | +18 | 0 | +11 | −8 | +10 | −9 | +9 | −5 | +6 |
| 18 | 30 | 0 | −9 | 0 | +21 | 0 | +13 | −9 | +12 | −10,5 | +10,5 | −5 | +8 |
| 30 | 50 | 0 | −11 | 0 | +25 | 0 | +16 | −11 | +14 | −12,5 | +12,5 | −6 | +10 |
| 50 | 80 | 0 | −13 | 0 | +30 | 0 | +19 | −12 | +18 | −15 | +15 | −6 | +13 |
| 80 | 120 | 0 | −15 | 0 | +35 | 0 | +22 | −13 | +22 | −17,5 | +17,5 | −6 | +16 |
| 120 | 150 | 0 | −18 | 0 | +40 | 0 | +25 | −14 | +26 | −20 | +20 | −7 | +18 |
| 150 | 180 | 0 | −25 | 0 | +40 | 0 | +25 | −14 | +26 | −20 | +20 | −7 | +18 |
| 180 | 250 | 0 | −30 | 0 | +46 | 0 | +29 | −16 | +30 | −23 | +23 | −7 | +22 |
| 250 | 315 | 0 | −35 | 0 | +52 | 0 | +32 | −16 | +36 | −26 | +26 | −7 | +25 |
| 315 | 400 | 0 | −40 | 0 | +57 | 0 | +36 | −18 | +39 | −28,5 | +28,5 | −7 | +29 |
| 400 | 500 | 0 | −45 | 0 | +63 | 0 | +40 | −20 | +43 | −31,5 | +31,5 | −7 | +33 |
| 500 | 630 | 0 | −50 | 0 | +70 | 0 | +44 | — | — | −35 | +35 | — | — |
| 630 | 800 | 0 | −75 | 0 | +80 | 0 | +50 | — | — | −40 | +40 | — | — |
| 800 | 1 000 | 0 | −100 | 0 | +90 | 0 | +56 | — | — | −45 | +45 | — | — |
| 1 000 | 1 250 | 0 | −125 | 0 | +105 | 0 | +66 | — | — | −52 | +52 | — | — |
| 1 250 | 1 600 | 0 | −160 | 0 | +125 | 0 | +78 | — | — | −62 | +62 | — | — |

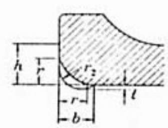
| Housing bore diameter nominal (mm) | | Bearing outside diameter tolerance $D_{mp}$ (µm) | | Housing bore tolerances, Deviations (µm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | K6 | | K7 | | M6 | | M7 | |
| over | incl. | max. | min. | low | high | low | high | low | high | low | high |
| 10 | 18 | 0 | −8 | −9 | +2 | −12 | +6 | −15 | −4 | −18 | 0 |
| 18 | 30 | 9 | −9 | −11 | +2 | −15 | +6 | −17 | −4 | −21 | 9 |
| 30 | 50 | 0 | −11 | −13 | +3 | −18 | +7 | −20 | −4 | −25 | 0 |
| 50 | 80 | 0 | −13 | −15 | +4 | −21 | +9 | −24 | −5 | −30 | 0 |
| 80 | 120 | 0 | −15 | −18 | +4 | −25 | +10 | −28 | −6 | −35 | 0 |
| 120 | 150 | 0 | −18 | −21 | +4 | −28 | +12 | −33 | −8 | −40 | 0 |
| 150 | 180 | 0 | −25 | −21 | +4 | −28 | +12 | −33 | −8 | −40 | 0 |
| 180 | 250 | 0 | −30 | −24 | +5 | −33 | +13 | −37 | −8 | −46 | 0 |
| 250 | 315 | 0 | −35 | −27 | +5 | −36 | +16 | −41 | −9 | −52 | 0 |

| Housing bore diameter nominal over | incl. | Bearing outside diameter tolerance $D_{mp}$ max. | min. | K6 low | K6 high | K7 low | K7 high | M6 low | M6 high | M7 low | M7 high |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (mm) | | (μm) | | Housing bore tolerances Deviations (μm) | | | | | | | |
| 315 | 400 | 0 | −40 | −29 | +7 | −40 | +17 | −46 | −10 | −57 | 0 |
| 400 | 500 | 0 | −45 | −32 | +8 | −45 | +18 | −50 | −10 | −63 | 0 |
| 500 | 630 | 0 | −50 | −44 | 0 | −70 | 0 | −70 | −26 | — | — |
| 630 | 800 | 0 | −75 | −50 | 0 | −80 | 0 | −80 | −30 | — | — |
| 800 | 1 000 | 0 | −100 | −56 | 0 | −90 | 0 | −90 | −34 | — | — |
| 1 000 | 1 250 | 0 | −125 | −66 | 0 | −105 | 0 | −106 | −40 | — | — |
| 1 250 | 1 600 | 0 | −160 | −78 | 0 | −125 | 0 | −126 | −48 | — | — |

| Housing bore diameter nominal over | incl. | Bearing outside diameter tolerance $D_{mp}$ max. | min. | N6 low | N6 high | N7 low | N7 high | P7 low | P7 high |
|---|---|---|---|---|---|---|---|---|---|
| (μm) | | | | Housing bore tolerances Deviations (μm) | | | | | (μm) |
| 10 | 18 | 0 | −8 | −20 | −9 | −23 | −5 | −29 | −11 |
| 18 | 30 | 0 | −9 | −24 | −11 | −28 | −7 | −35 | −14 |
| 30 | 50 | 0 | −11 | −28 | −12 | −33 | −8 | −42 | −17 |
| 50 | 80 | 0 | −13 | −33 | −14 | −39 | −9 | −51 | −21 |
| 80 | 120 | 0 | −15 | −38 | −16 | −45 | −10 | −59 | −24 |
| 120 | 150 | 0 | −18 | −45 | −20 | −52 | −12 | −68 | −28 |
| 150 | 180 | 0 | −25 | −45 | −20 | −52 | −12 | −68 | −28 |
| 180 | 250 | 0 | −30 | −51 | −22 | −60 | −14 | −79 | −33 |
| 250 | 315 | 0 | −35 | −57 | −25 | −66 | −14 | −88 | −36 |
| 315 | 400 | 0 | −40 | −62 | −26 | −73 | −16 | −98 | −41 |
| 400 | 500 | 0 | −45 | −67 | −27 | −80 | −17 | −108 | −45 |
| 500 | 630 | 0 | −50 | −88 | −44 | — | — | −148 | −78 |
| 630 | 800 | 0 | −75 | −100 | −50 | — | — | −168 | −88 |
| 800 | 1 000 | 0 | −100 | −112 | −56 | — | — | −190 | −100 |
| 1 000 | 1 250 | 0 | −125 | −132 | −66 | — | — | −225 | −120 |
| 1 250 | 1 600 | 0 | −160 | −156 | −78 | — | — | −265 | −140 |

Table 6 Fillets and shoulder heights for shafts and housings





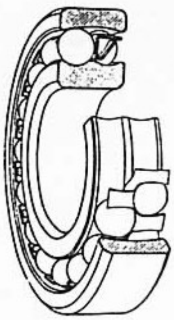
*Metric bearings (mm)*

| Nominal bearing chamfer $r$ | Shoulder height for radial bearings* $h$ | $h_{min.}$ | Fillet radius $r_1$ max. | Fillet with relief $t$ | $r_2$ | $b$ |
|---|---|---|---|---|---|---|
| 0.5 | 1 | 1 | 0.3 | — | — | — |
| 1 | 2.5 | 2 | 0.6 | — | — | — |
| 1.5 | 3 | 2.5 | 1 | 0.2 | 1.3 | 2 |
| 2 | 3.5 | 3 | 1 | 0.3 | 1.5 | 2.4 |
| 2.5 | 4.5 | 3.5 | 1.5 | 0.4 | 2 | 3.2 |
| 3 | 5 | 4 | 2 | 0.5 | 2.5 | 4 |
| 3.5 | 6 | 4.5 | 2 | 0.5 | 2.5 | 4 |
| 4 | 7 | 5.5 | 2.5 | 0.5 | 3 | 4.7 |
| 5 | 9 | 7.5 | 3 | 0.5 | 4 | 5.9 |
| 6 | 11 | 9 | 4 | 0.6 | 5 | 7.4 |
| 8 | 14 | 11 | 5 | 0.6 | 6 | 8.6 |
| 10 | 18 | 14 | 6 | 0.6 | 7 | 10 |

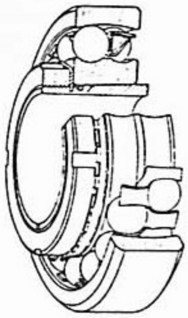
*Inch bearings (in.)*

| Nominal bearing chamfer $r$ | Shoulder height for radial bearings* $h$ | $h_{min.}$ | Fillet radius $r_1$ max. | Fillet with relief $t$ | $r_2$ | $b$ |
|---|---|---|---|---|---|---|
| 0.02 | $\frac{3}{64}$ | $\frac{3}{64}$ | 0.016 | — | — | — |
| $\frac{1}{32}$ | $\frac{5}{64}$ | $\frac{5}{64}$ | 0.025 | — | — | — |
| 0.04 | $\frac{3}{32}$ | $\frac{5}{64}$ | 0.03 | — | — | — |
| $\frac{1}{16}$ | $\frac{1}{8}$ | $\frac{7}{64}$ | 0.04 | 0.008 | 0.05 | 0.075 |
| $\frac{3}{32}$ | $\frac{3}{16}$ | $\frac{3}{32}$ | 0.06 | 0.015 | 0.08 | 0.125 |
| $\frac{1}{8}$ | $\frac{7}{32}$ | $\frac{3}{16}$ | 0.08 | 0.02 | 0.10 | 0.16 |
| $\frac{5}{32}$ | $\frac{9}{32}$ | $\frac{7}{32}$ | 0.10 | 0.02 | 0.12 | 0.185 |
| $\frac{3}{16}$ | $\frac{11}{32}$ | $\frac{9}{32}$ | 0.12 | 0.02 | 0.15 | 0.225 |

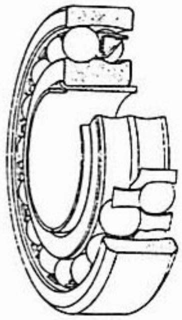
* The shoulder height h is generally used. The shoulder height $h_{min.}$ is only used if no axial loads or only very slight axial loads act on the bearings. The shoulder height $h_{min.}$ is suitable for deep groove ball bearings with sideplates or seals. It is, however, not suitable for taper roller bearings or single row angular contact ball bearings.



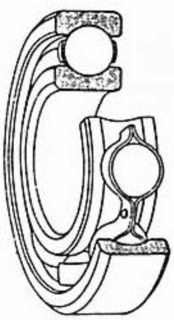
Self-aligning ball bearing with cylindrical bore



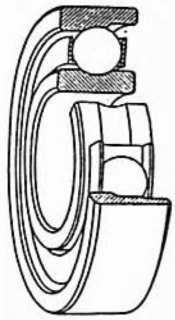
Self-aligning ball bearing with taper bore (and adaptor sleeve)



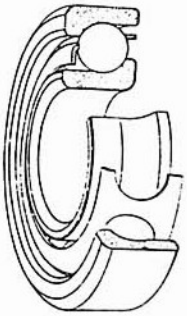
Self-aligning ball bearing with taper bore (and unthreaded adaptor sleeve)



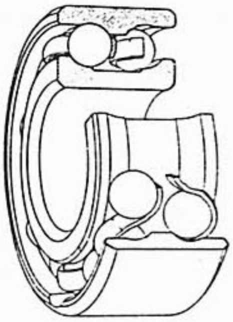
Single row deep groove ball bearing



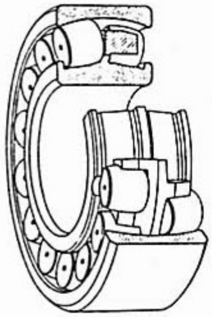
Magneto bearing (separable ball bearing)



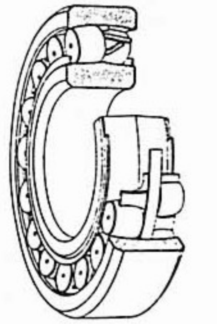
Single row angular contact ball bearing



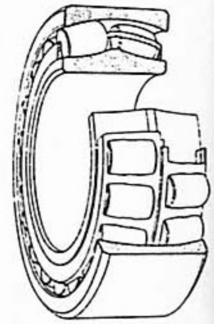
Double row angular contact ball bearing



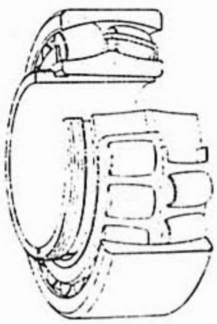
Spherical roller bearing



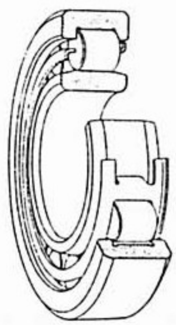
Spherical roller bearing (narrow type)



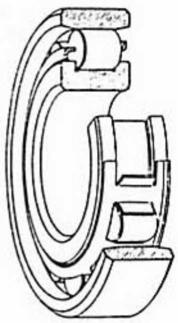
Spherical roller bearing (C design)



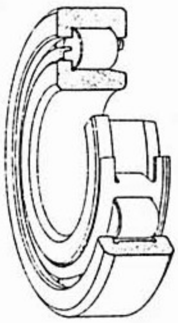
Spherical roller bearing with taper bore (and withdrawal sleeve)



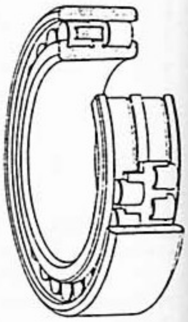
Cylindrical roller bearing NU type



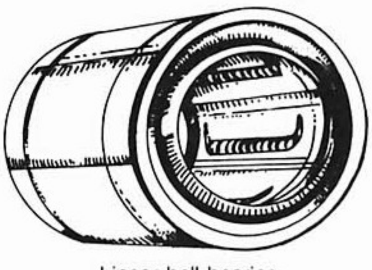
Cylindrical roller bearing N type



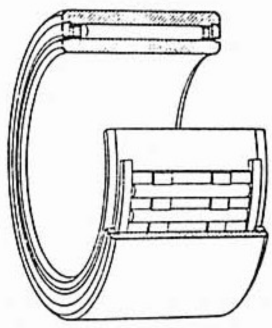
Cylindrical roller bearing NJ type



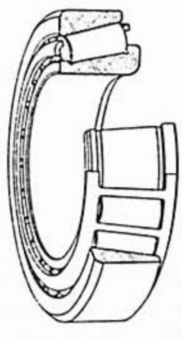
Double row cylindrical roller bearing



Linear ball bearing



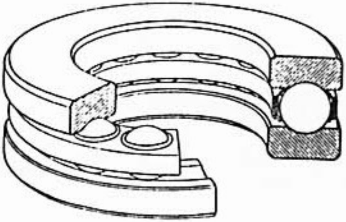
Needle roller bearing



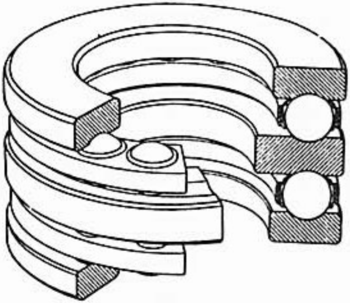
Taper roller bearing

**Figure 75** Various ball and roller bearings by common name

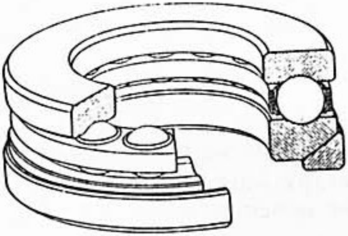
# Ball and roller bearings



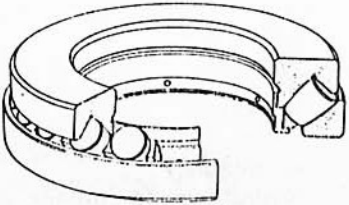
Single thrust ball bearing



Double thrust ball bearing



Single thrust ball bearing
with sphered housing washer and
seating ring



Spherical roller thrust bearing

# 51

# Power transmission

Power transmission is the term used for the connection of a rotary motion of energy to another rotary member at the same or different speed.

When one shaft is required to drive another at a different speed the following formula is used:

$D \times R = d \times r$

where $D$, or $d$ = diameter of flat pulley, or pitch diameter of the V-pulley, or number of teeth in gear or sprocket.
(*Note* O.D. of V-pulley is often acceptable.)

$R$, or $r$ = revolutions per minute of the appropriate shaft.

*Example:* An electric motor is to drive a piston pump; the motor runs at 1440 r.p.m., the pump shaft must run at 400 r.p.m. and for efficiency a 100 mm V-pulley is fitted to the motor.

$$D \times R = d \times r$$
$$100 \times 1440 = d \times 400$$
$$\frac{100 \times 1440}{400} = d$$
$$\frac{1440}{4} = 360 \text{ mm} = \text{diameter of pump pulley}$$

## Line shafts

A line shaft is usually mounted in ball bearing plummer blocks appropriately positioned and carrying pulleys or sprockets to transmit motion from one power source to another or to more than one unit of machine requiring power. (See Fig. 1.)

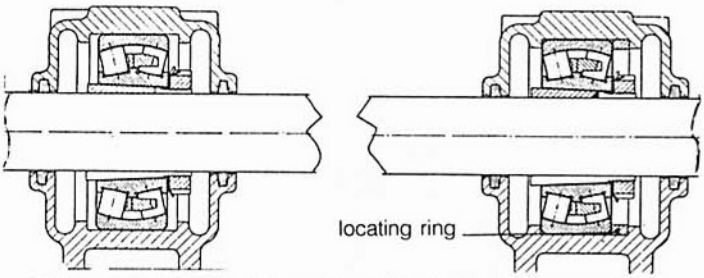



**Figure 1** Line shaft bearings showing location ring

Two important factors must be considered in using line shafts:

- Have only one bearing with the locating ring installed to prevent axial movement (the centre one if more than two are used), to allow for expansion or movement caused by external sources, which may ruin the bearings. All others should be central in the plummer block on assembly.
- A table in an engineers handbook should be consulted to establish bearing spacing for a given shaft and speed, as incorrect spacing can lead to a whipping shaft and subsequent disaster if bending occurs.

## Flat belts

Flat belts are not widely used in industry today but will always have a purpose, and a few important points must be remembered.

- Leather belts, because of the varying size of the hide from which they are made, have scarfed random cemented joints. The running direction should always be with the end of the joint leaving the pulley face not approaching it.
- Various types of fastener are used in joining belts; always ensure that they are no wider than the belt and not dangerous to the user.
- Canvas moulded into rubber is also used in the same applications as leather.
- Endless belts of cotton, cotton and natural and synthetic rubber are widely used for drives where quiet smooth running is essential.

### Flat Belt Pulleys

The shafts on which the pulleys are mounted should be so arranged that the centre of the face of the driven pulley must be aligned with the centre of the face of the driving pulley from which the belt leaves.

The pulley must be crowned (larger diameter at its centre) because the belt always runs towards the larger diameter and therefore runs central to the pulley.

An easy way of machining a crown without copy turning is to turn about one-third of its width from each edge at 1.5° to 2° included angle.

## V-belts

V-belts are moulded in a range of standard lengths and are constructed of cotton cord moulded into rubber. They are probably the most common form of belt transmission used today.

Belts should always be used in matched sets when more than one belt is used in a drive. Some manufacturers mark the belt, for example B75 Code 4; all code 4 belts will be suitably matched and will all transmit their share of power. (The length, i.e. B75, is a nominal length only.)

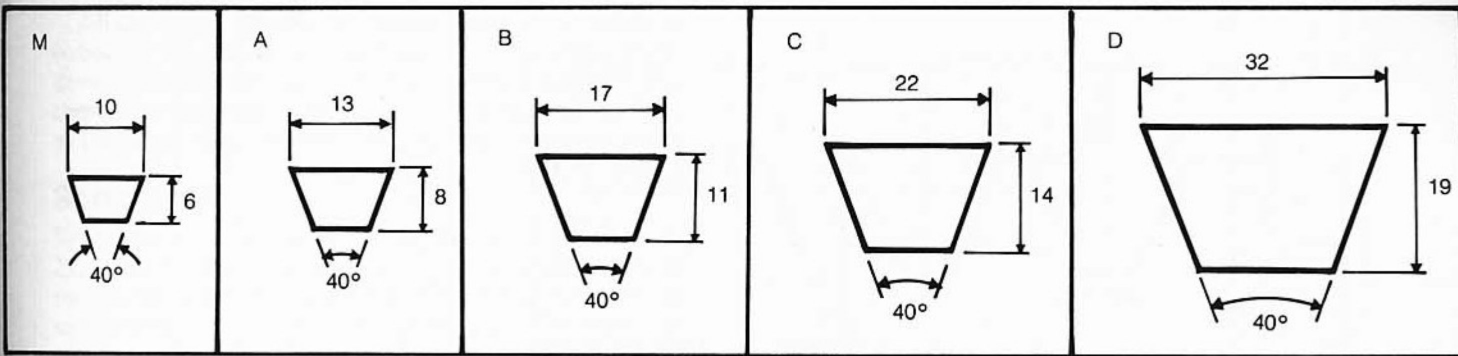



**Figure 2** Cross-section dimensions—V-belts

If the belts are not coded the supplier must be asked to supply a matched set, which he can select by measuring his stock on an acceptable measuring device in his warehouse.

Belts are manufactured in five sections, as shown in Figure 2, in lengths from 200 to 15 200 mm.

The smallest recommended pulley of 20 mm using the smallest belt M running at 1440 r.p.m. will transmit 0.02 kW and the smallest pulley of 355 mm using the largest section, belt D, will transmit 21.22 kW at the same speed.

## V-grooved Pulleys

The V-grooves in pulleys must be machined with care, the angle of V correct and square to the bore, and the width must be constant for each groove, otherwise all the belts will not transmit power, and belt life will be reduced. V-groove angles vary in relation to diameter. (See Table 1 and Fig. 3.)

## Assembly of the Drive

Ensure that the pulleys are properly aligned. Put the set of belts onto the pulleys and work them around until all the slack of each belt is on one side of the drive before tensioning them, otherwise some belts will not do their share of the work—they will not work themselves around as might be thought.

When using V-belt drives never use smaller pulleys than those recommended by the belt manufacturer.

# Taper bushes

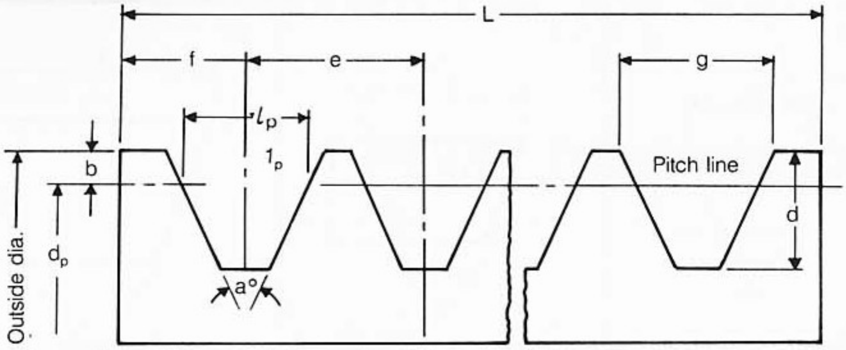
This type of split bush is tapered on its outside diameter and bored and keywayed to suit a shaft from which power is taken or delivered with a pulley, sprocket, or coupling that has been bored to accurately fit the taper.

From Figure 4, it can be seen that the pulley has been drilled and tapped prior to being bored, leaving only half of the threaded hole; when the screws are inserted they

**Table 1** Dimensions of standard grooved V-pulleys (read in conjunction with Fig. 3)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Groove cross-section symbol | Pitch diameter of the pulley (dp) | Groove angle (a) | Minimum top width of groove (g) | Minimum groove depth below outside diameter (d) | Centre-to-centre of grooves (e)* | Edge of pulley to first groove† centre (f) | Minimum distance from outside diameter to pitch diameter (b) | Groove pitch width (lp) |
| | (mm) | (deg.) | (mm) | (mm) | (mm) | (mm) | (mm) | (mm) |
| A | 75 (recommended minimum) and under 125 | 34 ± 0.5 | 13.0 | 12 | 15 ± 0.3 | 10 + 2 − 1 | 3.3 | 11 |
| | 125 and over | 38 ± 0.5 | 13.3 | | | | | |
| B | 125 (recommended minimum) and under 200 | 34 ± 0.5 | 16.6 | 15 | 19 ± 0.4 | 12.5 + 2 − 1 | 4.2 | 14 |
| | 200 and over | 38 ± 0.5 | 16.9 | | | | | |
| C | 200 (recommended minimum) and under 300 | 36 ± 0.5 | 22.7 | 20 | 25.5 ± 0.5 | 17 + 2 − 1 | 5.7 | 19 |
| | 300 and over | 38 ± 0.5 | 22.9 | | | | | |
| D | 355 (recommended minimum) and under 500 | 36 ± 0.5 | 32.3 | 28 | 37 ± 0.6 | 24 + 3 − 1 | 8.1 | 27 |
| | 500 and over | 38 ± 0.5 | 32.6 | | | | | |

* The tolerances on dimension e apply to the distance between the centres of any two grooves whether consecutive or not.
† It is recommended that the tolerance on dimension f should be taken into account in the alignment of pulleys.




The maximum distance L between the outside edge of the pulley, i.e. the face width, $= (x-1)e + 2f$, where x is the number of grooves

**Figure 3** Dimensions of standard V-grooved pulleys

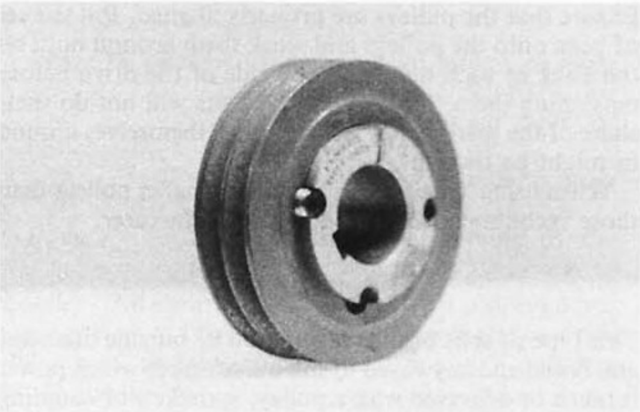


**Figure 4a** Taper bush assembled

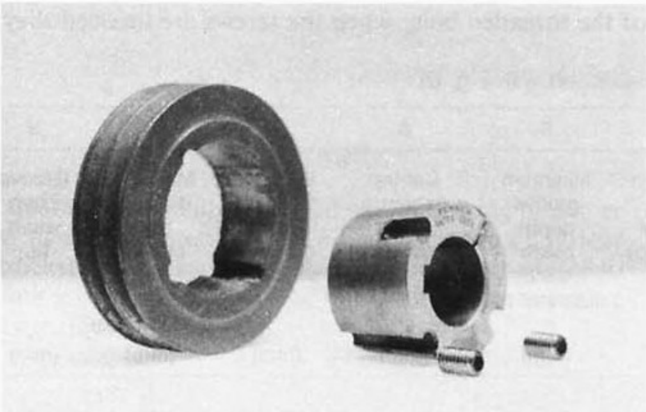


**Figure 4b** Taper bush disassembled

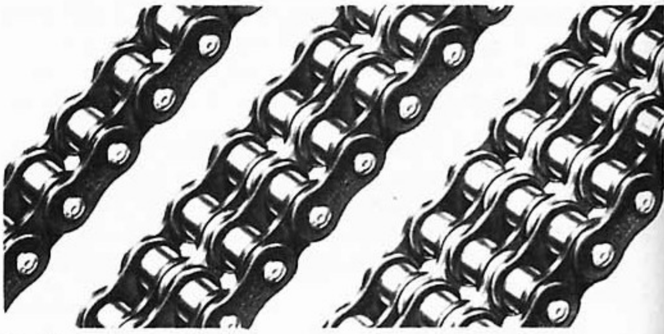
engage these threads only and are guided and kept in engagement by the half plain holes in the bush (they are not through holes). Tightening the screws draws the pulley over the bush, closing it securely onto the shaft.

To remove the assembly from the shaft firstly remove the screws and insert one or two in the holes where the thread is in the bush; tightening will push the pulley off the taper.

Assembly and disassembly sometimes needs to be aided by the use of hammer and dolly. Always oil before assembly and fill the unused holes with grease to prevent corrosion and the ingress of dirt, which would prevent subsequent removal.

## Roller chains

The precision steel roller chain is a highly efficient and versatile means of transmitting mechanical power, and, in the field of industrial application, has almost completely superseded all other types of chain previously used. (Fig. 5.)



Simple Duplex Triplex

**Figure 5** Roller chains

A precision steel roller chain consists of a series of journal bearings held in precise relationship to each other by the constraining link plates. Each bearing comprises a bearing pin and bush on which the chain roller revolves. The bearing pin and bush are case hardened to allow articulation under pressures, and to contend with the load-carrying pressures and gearing action imparted via the chain rollers. Component parts of the outer and inner links of a simple roller chain are shown in Figure 6.


**Figure 6** Components of a roller chain

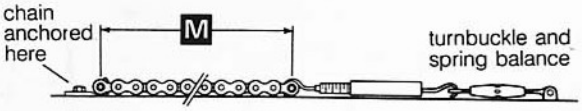



**Figure 11** Measuring chain wear

2 By means of the turnbuckle, apply a tension load equal to:

$P^2 \times 0.079$ kg for a simple chain
$P^2 \times 0.158$ kg for a duplex chain
$P^2 \times 0.237$ kg for a triplex chain

where $P$ is the pitch in mm.

In the case of extended-pitch chains (i.e. chains having the same breaking load and twice the pitch) apply a measuring load as for the equivalent short-pitch chains.

As an alternative to the use of a turnbuckle and spring balance, the chain may be hung vertically and an equivalent weight attached to the lower end.

3 Measure length $M$ (see Fig. 11) in millimetres, from which the percentage extension can be obtained using the following formula:

$$\text{Percentage extension} = \frac{M - (X \times P)}{X \times P} \times 100$$

where $X$ = number of pitches measured.

As a general rule, the useful life of the chain is terminated, and the chain should be replaced, when the percentage extension reaches 2% (1% in the case of extended-pitch chains). For drives with no provision for adjustment, the rejection limit is lower, dependent on speed and layout. A usual figure is between 0.7 and 1% extension.

Chains are also made in different configurations for conveyors where different side plates or hollow pins allow the fitting of slats, rails, hooks, or whatever is required to do the conveying. Chain can also be used to suspend a counterweight on machine tools, in a straight line used as a rack, or around a diameter as a ring gear.

## Silent chains

This chain can be likened to a rack that can wrap around a gear wheel. Each link has teeth on one side and when stacked together to the required width the chain resembles a belt with teeth on one side. In the centre of the chain there is a plain link, which runs in a central groove in the gear. (Fig. 12.)

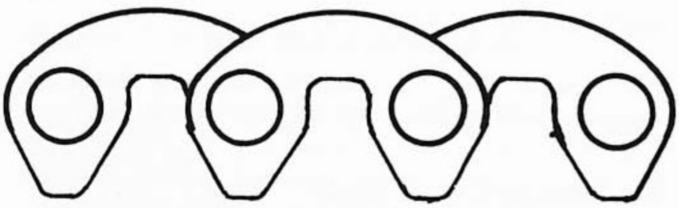


**Figure 12** 'Silent' chain links

The tooth form of the gear and chain have evolved over the years from the work of several manufacturers. As the chain bends around the gear the chain teeth close onto it, giving the silent action. The tooth form is such that as the chain stretches in use the links work on a larger pitch circle diameter over the gear but maintain their correct relation to it.

### Toothed Belt

This has evolved from the silent chain and in many installations has replaced it. Made from synthetic rubber with steel cords, it can operate in dry or wet localities. The belts are made in a standard range of widths and lengths, which must be used with matching pulleys. (Fig. 13.)

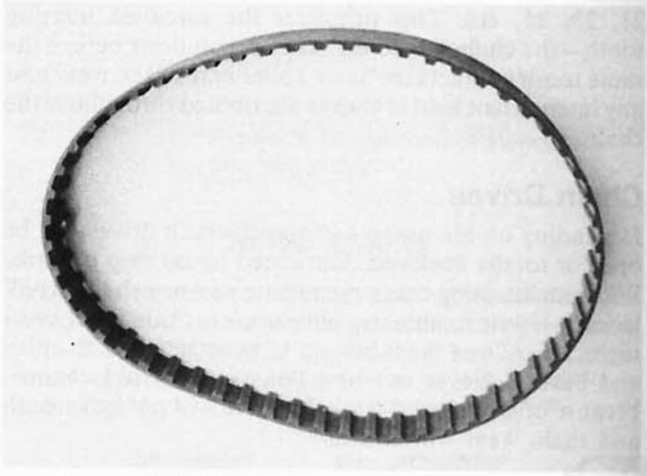


**Figure 13** Toothed belt

## Couplings

Many kinds of couplings are used in industry. Some of the common types are described below.

### Compression Coupling

The shaft coupling used to join two line shafts is a split sleeve with opposed O.D. tapers on either end, which grip the shaft when the flanged collars with matching taper bores are pulled together over the sleeve. A key and keyway can be used but is seldom necessary. (Fig. 14.)

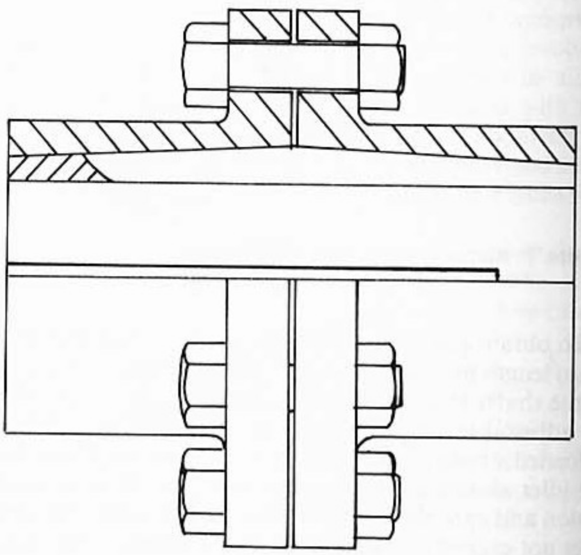


**Figure 14** Compression coupling

## Flexible Coupling—Disc Type

The flexible coupling consists of two cast iron bodies machined all over, with three high-tensile pins seated in tapers and drawn in with a nut in each. (Fig. 15.) The pins pass through a rubberized fabric disc with steel reinforcement, which transmits the torque, absorbing shock and vibration. Although called a flexible coupling it must be mounted in true concentricity, for long life and durability. In assembly the bodies without the pins are mounted and aligned on the shaft and the assembly bolted in position, then the pins are inserted through the fabric and into their taper seating and secured by nut and spring washer.

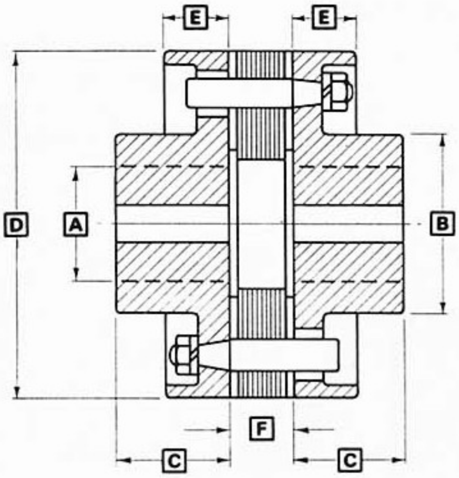



**Figure 15** Flexible coupling—disc type

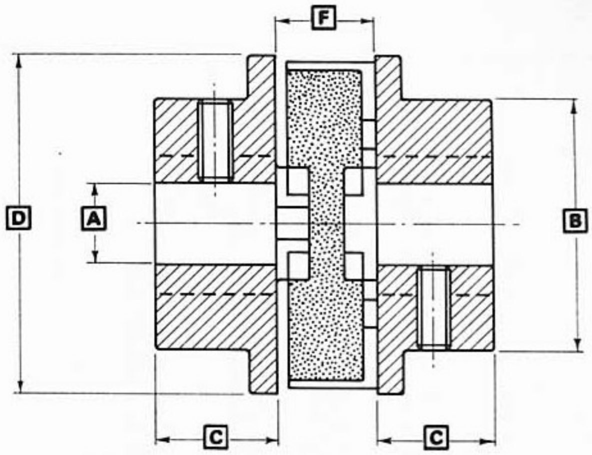



**Figure 16** Flexible coupling—spider type

## Flexible Coupling—Spider Type

This coupling (Fig. 16) is used for low-power drives up to 4 kW. The torque is transmitted through a synthetic rubber cross, which assembles into mating lugs in the cast iron bodies. A small misalignment can be accommodated but should be avoided if possible (Fig. 16).

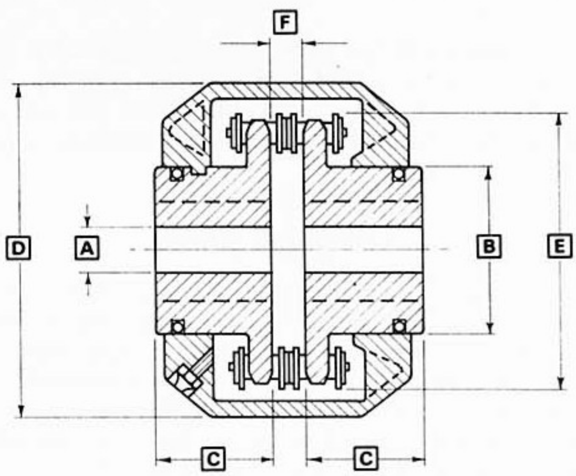



**Figure 17** Chain coupling

## Chain Coupling

A chain coupling comprises two simple chain sprockets mounted opposed to each other; after alignment, a duplex chain is wrapped around and joined, to transmit the torque. (See Fig. 17.)

A cover can be fitted to exclude dirt and retain lubricant and the cover also is a safety feature, having a smooth concentric exterior.

Many other couplings will be found in use in industry too numerous to include in this publication.

*Note:* When boring a coupling to suit the shaft application (see Fig. 18), always remove the minimum of metal from the diameters *C*, to finish with both halves the same diameter; clean up faces A or, in some couplings, B.

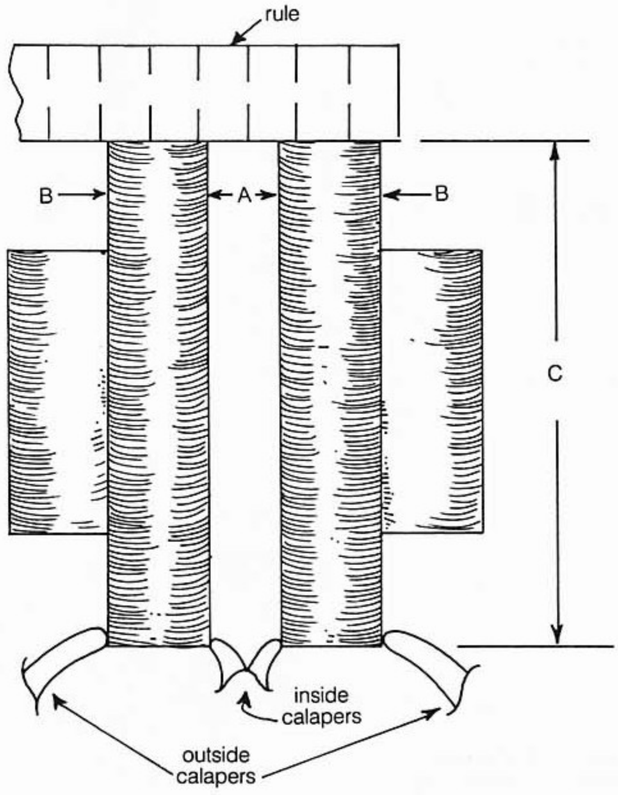



**Figure 18** Measuring coupling alignment

This then allows the use of a straight edge at 90° intervals around the peripheries of the flanges and the use of calipers to check the gap or width, also at 90° intervals. With perfect alignment the measurements should be equal at all four points.

## Universal joints

There are many different designs of joints but all are based on the same principle. If only one joint were used in a drive a variation in angular velocity would be produced during one revolution, that is, the speed of the driven shaft would increase and decrease during one revolution. It is necessary to use two joints, one cancelling out the change in velocity of the other.

The angle of the driver and the driven shaft with the centre member should be the same, and the axis of each of the pivots of the centre or connecting member must be in the same plane.

Preferably, the angle should be kept to about 25° or less, universal joints do not operate efficiently if the angle is more than 45°. (Fig. 19.)

## Clutches

A clutch is a link between the power source and the driven part of a machine. Some clutches engage instantly and positively; they require the machine to be stopped for engagement and disengagement e.g. dog clutch. Other clutches allow a certain amount of slip to occur as they are engaged and therefore the machine does not need to be stopped.

Many types of clutch are used in industry, most of similar overall design, but made to suit the application. Electrical, mechanical, pneumatic or hydraulic methods of engagement and disengagement are used.

### Dog-tooth Clutch

Dog-tooth clutches allow a positive drive from shaft to shaft. They can be operated in either direction, are cheap, and require very little maintenance (Fig. 20). The machine must be stopped prior to engagement or disengagement.

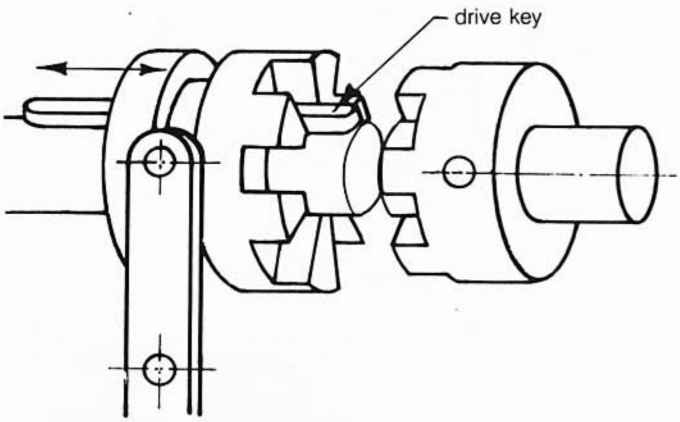



**Figure 20** Dog-tooth clutch

### Cone-type Clutch

Internal and external cones fit together to form a drive. (Fig. 21.) The external cone has a woven asbestos lining bonded to it. Some types use metal to metal contact. The operating lever moves a thrust bearing along the driven shaft to engage the cone with the driver. Cone clutches are used in machine power trains for occasional operation only. They 'take up' abruptly and are therefore not very satisfactory for frequent use. Maintenance involves adjustment of linkages for correct meshing and very occasional replacement of linings.

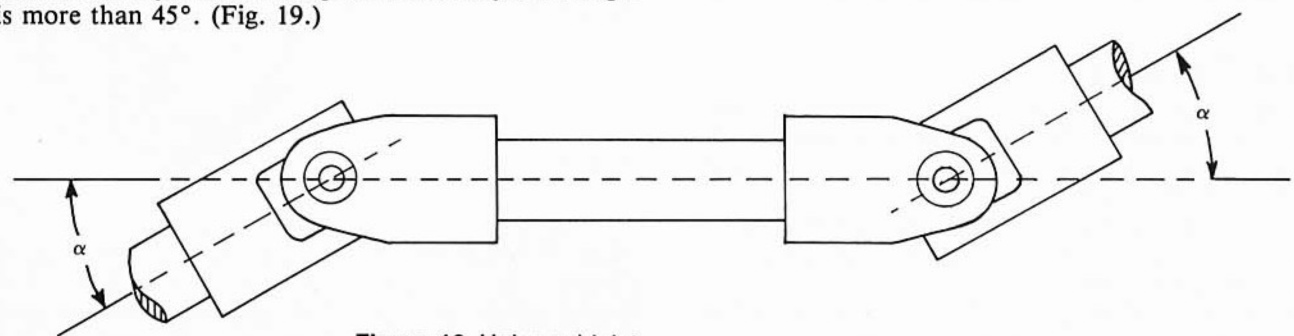



**Figure 19** Universal joint

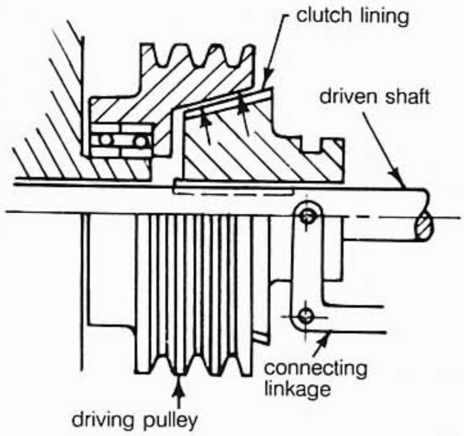



**Figure 21** Cone-type clutch

## Expanding Shoe-type Clutch

The outer member of this type of clutch is bored to accept the drive shoes, which are attached to a linkage system. A lever operates the linkage through a sliding collar. A similar principle is employed in centrifugal clutches wherein centrifugal forces throw the shoes out to the walls of the outer member. The faster the inner member (the driver) rotates the greater the centrifugal force and the driving force.

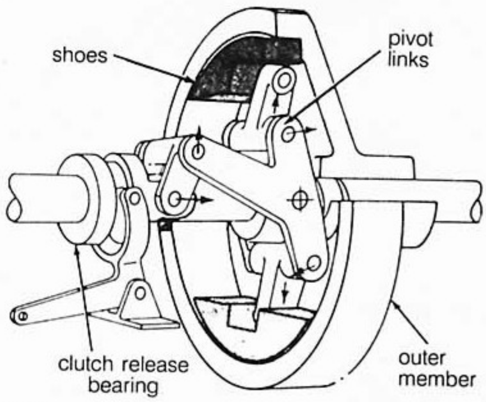



**Figure 22** Expanding shoe clutch

## Plate-type Clutch

Plate-type clutches are probably the most popular for machines, machine tools, and motor cars.

Figure 23 illustrates a single-plate clutch of the type used on the outside of a lathe headstock or similar application. Multi-disc clutches, 5, 7, or 9 plates enclosed in a drive and running in oil usually at higher speed and of smaller diameter than the simple-disc type, are used in greater numbers today; the plates are usually metal.

## Toggle Action Linkage

Many clutches make use of a toggle action to obtain mechanical advantage and to provide a locking arrangement. Toggle action is shown in Figure 24.

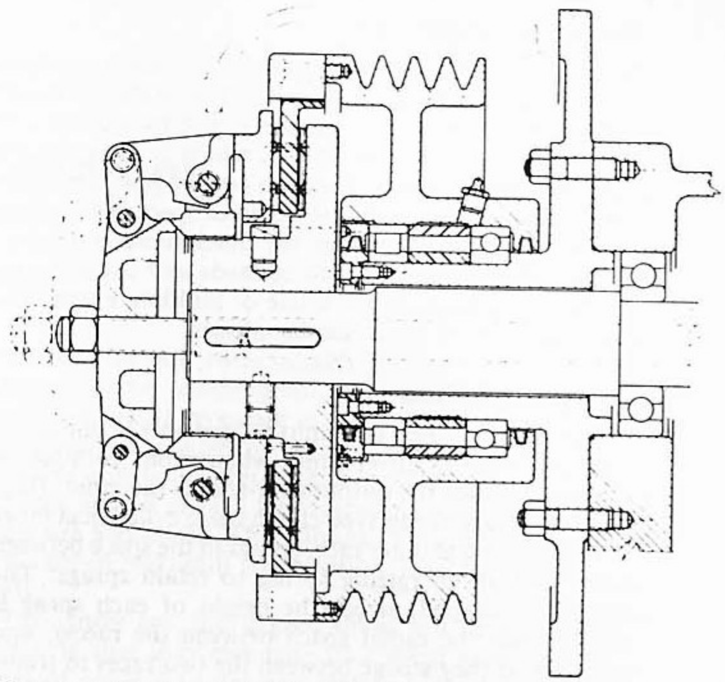


**Figure 23** Clutch assembly—plate type

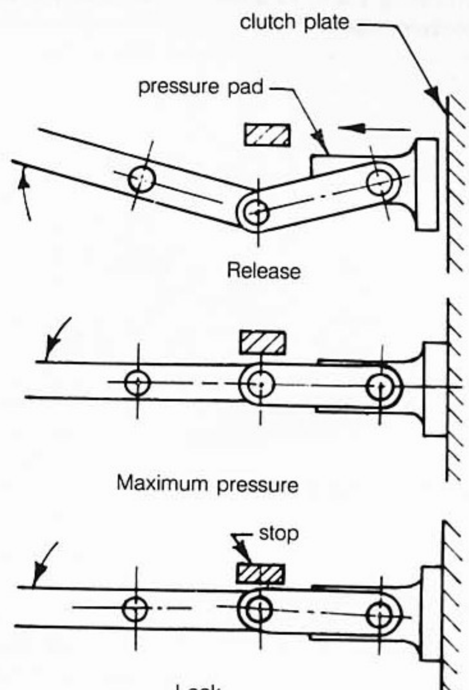



**Figure 24** Toggle action principle

## Centrifugal Clutches

Centrifugal clutches are made in various designs and as their name implies are operated by centrifugal force. They are used in special applications, for example where, for ease of starting, an engine first runs with no load; when it has accelerated to its running speed, the clutch is engaged. A chain saw uses this type of clutch.

## Magnetic Clutches

Magnetic clutches are being used in increasing numbers because of the introduction of the bridge diode, which easily and conveniently converts alternating current (A.C.) to direct current (D.C.), which is essential for operation of this clutch. They can now be found in many engineering machine tools, where quick speed changes can be made using a push button; the clutch replaces the sliding gear, allowing changes to be made without stopping the drive. This clutch is a single or multiplate type; the plates are usually of dissimilar metals.

## Sprag Clutches

The sprag-type clutch transmits torque only in one direction and releases (over-runs) when input rotation is reversed or when the output over-speeds the input. (Fig. 25.) The typical sprag-type clutch has a cylindrical inner race, a cylindrical outer race, sprags in the space between races, and an energizing spring to retain sprags. The sprags are shaped, sized (the height of each sprag is greater than the radial space between the races), and mounted so they wedge between the two races to transmit torque when rotation occurs in one direction. When rotation occurs in the opposite direction the sprags are freed, enabling them to slide on the races, causing the clutch to over-run.

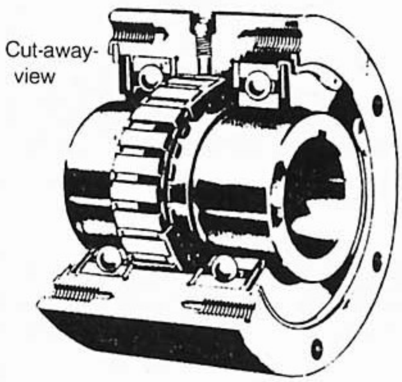



**Figure 25** Sprag-type clutch

## Brakes

As it is often necessary to rapidly stop the rotation of a mechanism, brakes are as important as clutches.

### Band-type Brakes

Band-type brakes are operated by a steel band (to which leather or asbestos woven material is fixed), which wraps around and engages with the braking wheel. (Fig. 26.) These brakes are often used on guillotines, presses, etc. Maintenance involves adjustment or replacement of worn bands.

### Clutches as Brakes

All disc-type clutches can be used as brakes and will often be found as a pair, one as a clutch, and, as it becomes disengaged, the other is engaged as a brake. Cone-type clutches also apply very well as brakes.

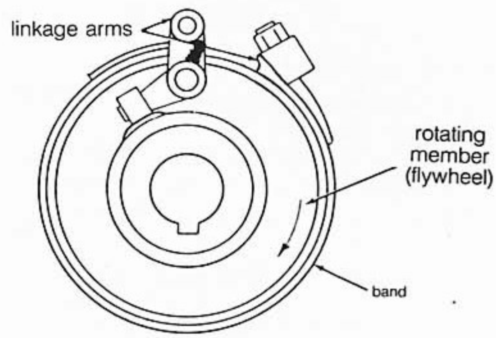



**Figure 26** Band-type brake

# Gear boxes and gear motors

Geared electric motors and geared drives are available in a vast range of speed ratios. (Figs 27 and 28.) They are either foot or flange mounted and are totally enclosed; they can be used in almost any position. If the unit has been properly selected for type and size the only maintenance required over many years is lubrication, and a regular check of oil level and quality.

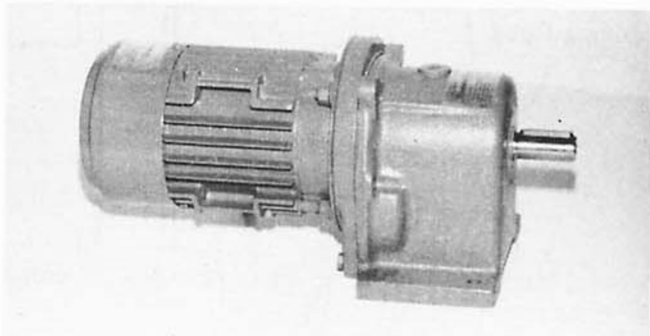


**Figure 27** Helical-geared motor

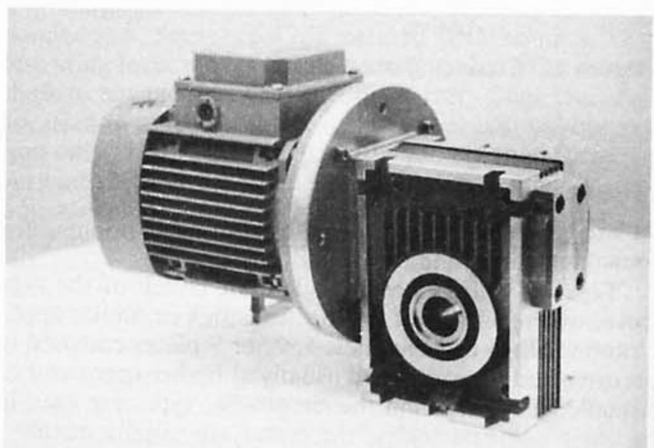


**Figure 28** Worm-geared motor

# 52

# Lifting and slinging

## Slinging practice

### Introduction

There are almost as many ways of slinging as there are loads to be slung, but over the years certain fairly standard items of gear have evolved.

On considering the variety of loads to be handled in different industries, it will be realized that all of the methods of applying this gear can never be stated.

The purpose of this section, therefore, is firstly to give examples of typical lifting gear, and secondly, to state the general principles governing its use.

Thirdly, it must be emphasized that experience and common sense play a great part in the application of all but the simplest types of lifting gear.

Certain available Standards cover both the usage and types of lifting gear and also the signals used for directing the movements of loads. These are intended to improve the safe working of all concerned, by promoting the use of good practices.

Slings etc. should not be treated casually. They should always be inspected before each use, for signs of damage, over-strain or faulty manufacture.

Obviously any piece of lifting gear must be strong enough to safely handle the load. It is not always realized that the method of applying a sling can greatly reduce its apparent safe working load.

### Basic Materials

Three basic materials are in constant use:

- Natural or manufactured fibre rope.
- Steel wire rope.
- Mild steel or alloy steel chain.

Apart from their more usual forms, these can come in the following: belting, fibre webbing, fibre netting, braided fibre, braided wire, wire net, chain belt, chain mesh.

The choice of sling material is governed at times by the type of load; for instance, a fibre rope sling is obviously the choice of, say, lifting a bale of cotton waste, or a light piece of machined shafting, although the latter can also be handled without damage by a fibre webbing sling.

On the other hand, heavy rough castings obviously need the use of chain slings, and here the alloy (higher-tensile) types have a much better abrasion resistance than mild steel.

Steel wire ropes probably serve the majority of needs in between the extremes cited above, where reasonable lightness, wear resistance and flexibility form a compromise to suit the job in hand.

Chain is the only form suitable for situations close to furnaces, or for handling hot forgings. Chain slings of the higher tensile types are in frequent use on building sites where all manner of objects are to be lifted, with probably only two or three choices of slings on the job.

Slings should always be ordered at least in pairs of equal size and length. This eliminates much wasted time or the use of makeshift combinations in order to balance loads.

Two, three and four-legged slings will be great time savers, in that they eliminate time spent searching for slings of equal diameter and matched length.

### Basic Configurations

Some common types of slings in general use are illustrated in Figures 1 to 8. Some are interchangeable with others.

Where the eyes of several slings are all on the same hook it is good practice, where wire slings are used, to shackle the eyes together, because even with a safety hook it is possible for the eyes to jump off, especially if one sling has a twist in it.

Figure 9 shows how this can occur. If there is some twist in the sling nearest the point of the hook, when the load is put down it is possible for this sling to release itself from the hook.

Ideally all eyes should be coupled by a shackle large enough to go on the crane hook. If this is not available, then at least all of the eyes should be coupled together with a suitable shackle. Even if a load has been set down safely once, it pays to re-check all attachments before lifting again. Slings shackled to loads are basically safer than hooks used for the same purpose.

*Note:* A mousing usually consists of several turns of light cord or wire across the opening of a hook, wrapped tightly around the bill and the back of the throat as depicted in Figure 10.

## Some dangers with temporary slings

### Wire Rope Clips (Bull-dog grips)

These have a limited use, as they *must never be used for hoisting loads*, either on a crane rope, or as part of a sling or other lifting device.

### Knots

Some dangers inherent in the use of knots are as follows:

- The best of knots will develop little more than 50% of the rope strength.
- With synthetic fibre ropes (nylon, polypropylene, etc.) a knot may not hold at all.

**Figure 1** Single-leg slings

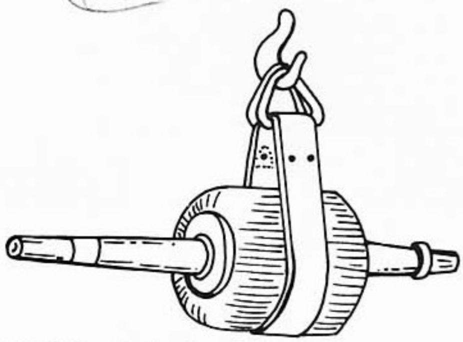


**Figure 7** Webbing belt sling

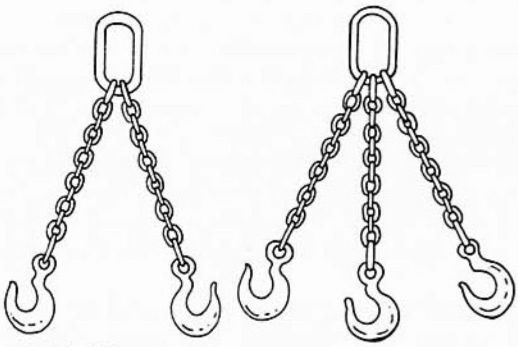


**Figure 2** Multi-leg slings

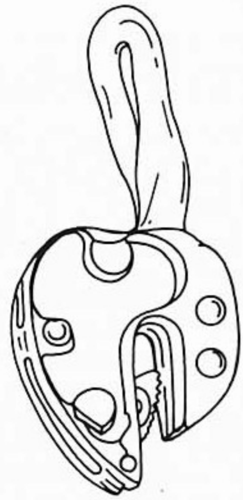


**Figure 8** Plate clamp

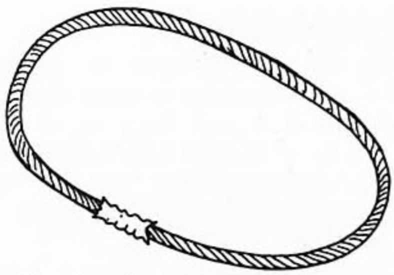


**Figure 3** Spliced endless sling

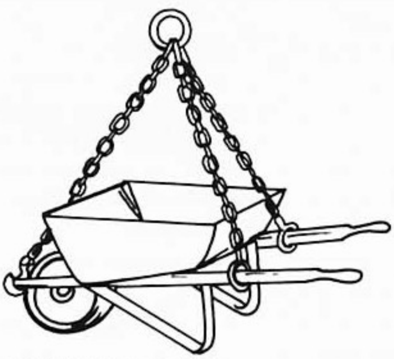


**Figure 4** Special-purpose sling

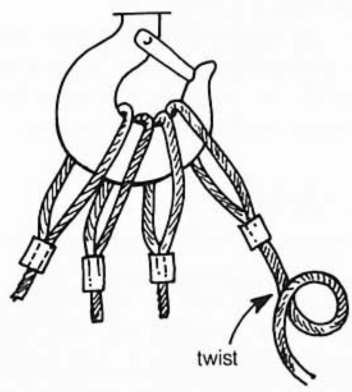



**Figure 9** Showing the effect of a twisted sling

**Figure 5** Reeved endless grommet

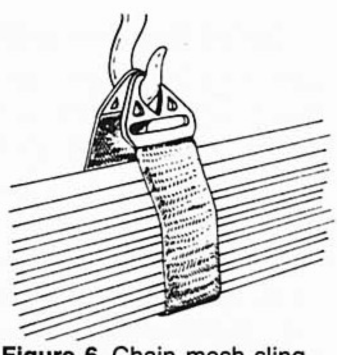


**Figure 6** Chain mesh sling (reevable)

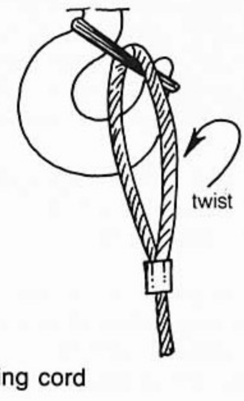



**Figure 10** Mousing cord

- The knot most likely to be used is the reef knot. Originally it was intended for tying the reef-points of a boat's sails, where both parts are under constant tension. Unless the ends are seized back to the working parts it can upset into two half-hitches and then slip, thus dropping the load. It does not hold wet greasy ropes, or ropes of different sizes.
  In the hands of the inexperienced, a granny knot may be tied accidentally, with disastrous results, as it is certain to slip. Any knot that is likely to be used for joining two rope ends (reef knot, sheet bend, double sheet bend, fisherman's knot, etc.) will jam under extreme tension and may be impossible to untie without rope damage. An exception is the carrick bend, which may be tied in several ways, of varying efficiency, and is mainly used for ships' hawsers.

It will be seen therefore that knotting is not recommended for slings used for lifting loads. Where tail ropes, load lashing, etc. are used, a few simple knots and hitches should be practised for this purpose.

If knotting a sling has to be resorted to, take notice of the reduction in safe working load by taking into account all of the factors mentioned. There is no substitute for the correctly made short splice or endless grommet.

*Note:* Never knot a synthetic (man-made) fibre rope, as many have very little frictional grip.

## Knots, bends and hitches

A few knots may be useful when slinging loads.

Reef knot Note the difference between the reef knot and the granny knot, observing carefully where the ends come out. Never use the granny, and when using the reef knot for important duties, always seize the short ends back to the standing or working parts of the rope.

Sheet bend The sheet bend is used for joining two ropes of unequal sizes, the larger rope forming the eye. The double sheet bend is used where two ropes may be wet or greasy but still need to be joined, whether equal in size or not.

Carrick bend The carrick bend is the best for not jamming under load, being easy to untie, although again for security the short ends should also be seized to the working parts.

Half-hitch The two half-hitches are suitable for tail ropes or where a rope barrier may need to be tied to a post. The round turn and two half-hitches is used where, after undoing the hitches, a strain may need to be gradually released, the friction of the round turn on the post allowing this to be done.

Clove hitch The clove hitch performs a similar function to the half-hitch, or for attaching the first end of a load lashing. It may also be used where the central part of a rope needs to be attached to a post or similar.

Blackwall hitch The blackwall hitch should never be used for lifting loads, and it is dependent solely on the weight of the load to nip the rope to the hook. Nevertheless it is a useful hitch for 'over-hauling' or drifting apart the respective blocks of a rope purchase, pulling out a winch rope, etc., where no danger exists should the tension slacken and the rope come off the hook.

However, the principle of the blackwall hitch nip may be used when only one sling is available and a load heavier at one end needs to be balanced with respect to a crane hook, the sling being taken around the crane hook as shown in Figure 11. The heavier end of the load must be attached to the part uppermost on the hook, in order to provide the nip. Due care and allowance for the nip should be exercised.

**Figure 11** Blackwall hitch

Timber hitch This is a useful hitch for many jobs; it develops approximately 80% of rope strength and is easy to untie, the extra half-hitch being used for vertical loads. (See Fig. 12.)

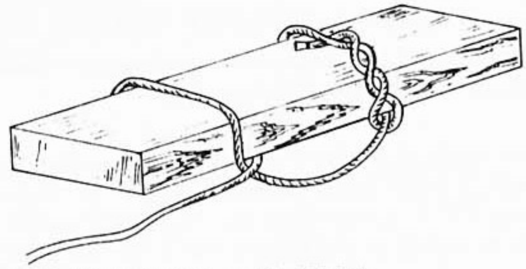


**Figure 12** Timber hitch and half hitch

## Factors affecting the safe working load of slings

It may be thought than any given sling would have only one maximum safe working load (SWL). This would be determined by its breaking load divided by a factor of safety, usually 5. For example, a wire rope having a minimum breaking load of 10 000 kg would have an SWL of 2000 kg (10 000 divided by 5).

This is so in general and is the case where the load is applied in a straight line as in Figure 13. However, once the method of applying the sling is changed, the tension in some parts of the sling may also be considerably altered. The two main ways in which this can occur are shown in Figures 14 and 15, which show a single and a two-legged sling, respectively. The principle however is the same in both cases, as the maximum tension induced in part of the sling is governed by the angle $\alpha$ between the parts attached to the load. It is in these parts that the maximum tension will be imposed, the vertical parts only

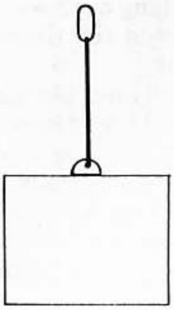


**Figure 13** Vertical load on sling

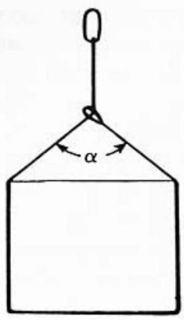



**Figure 14** Angle α changes tension in sling

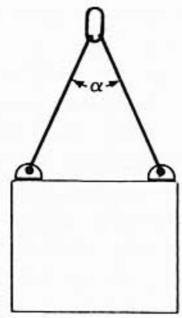



**Figure 15** Angle α has the same effect here

in Figures 13 and 14 carrying the actual load. This applies equally to fibre rope, chain or webbing slings.

Carrying a parcel tied with string strong enough to support the actual weight of the parcel is a common experience. By slipping a finger under the string, we then find that the string breaks quite easily. This is because the tension applied to the string is much greater than the breaking strength of the string. This is entirely due to the very flat angle α between the parts, as in Figure 16.

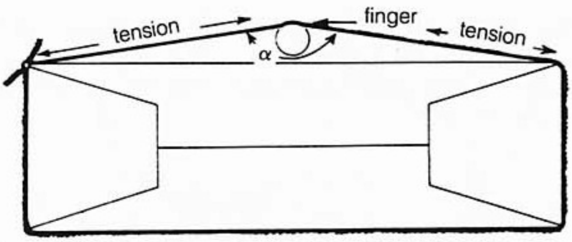



**Figure 16** Weakness of the flat angle

How this angle affects the tension, as compared with the actual load being lifted is shown in Figure 17. Although 170° is shown by way of example, 120° must not be exceeded. It will be seen that in this case the SWL

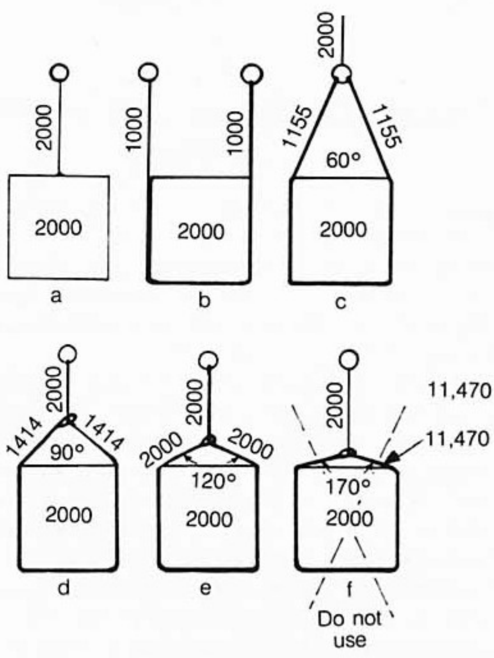



**Figure 17** Safe working angle depicted

of the sling would need to be $5\frac{1}{2}$ times greater for f than for the same load as slung in a.

So far we have dealt with the effects of tension alone, and looking again at Figure 17e we find that at 120° included angle, the tension in any part is equal to the load (2000 kg).

However, in the case of reeved (or choked) slings an arbitrary factor of 2 is applied, and for Figure 17e a sling with an SWL of at least 4000 kg would be used.

In Figure 17f, with 11 470 kg tension in each leg, we need a sling of 22 940 kg SWL or over 10 tonnes for less than a one-tonne load. This is not $5\frac{1}{2}$ tims greater than the example shown in Figure 16e, but is 11 times greater. It should now be clear why excessive angles are not used in this type of slinging.

A sling's margin of safety would be further reduced by bad nips (where the parts cross, or at corners of a load), and a factor of 2 is applied to the sling for such cases.

A study of capacity charts will show how these principles are applied for reevings on circular and rectangular loads, as well as for different included angles for multi-legged slings.

*Note:* Three- and four-legged slings are rated as if there were only two legs, as all legs may not be loaded evenly unless the load is very flexible. They are rated for the greatest angle between any two legs.

If a sling having two legs is also reeved or back-hooked, and all parts are at 120° (as in Fig. 18) a factor of 4 is applied. Thus for a 2000 kg load we need a sling with an SWL of 8000 kg.

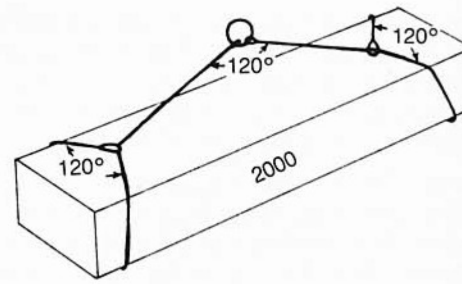



**Figure 18** 'Factor of 4' applied

120° is the maximum angle to be used and is not to be exceeded. In no circumstances should reeving (or back-hooking) be used in combination with 120° of spread. In such a case the spread should be limited to 60°, as the spread between attachment points is equal to the length of one leg.

Where spread is used, means should be employed to prevent the legs sliding together and thus upsetting the load when more than one reeved sling is used to take a lift, either by a spreader, or by taking a round turn.

## Capacities of Two-leg Slings or Pairs of Slings

In practice it is not easy to measure the included angle, but this may be done by measuring the length of a sling leg, and the rise and then using the formula below (see Fig. 18):

$$W = \frac{2RT}{L}$$

where

$W$ is the weight or mass of the load
$R$ is the rise (inches, metres, etc.)
$L$ is the length of one leg (inches, metres, etc.)
$T$ is the permitted tension (SWL) in the leg
$R$ and $L$ are to be in the same units and $W$ and $T$ are to be in the same mass units. (Fig. 19.)

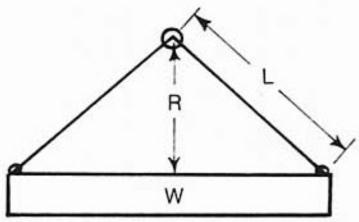



**Figure 19** Safe working angle depicted

*Note:* If at any time $R$ is less than half of $L$, then the included angle exceeds 120° and should not be used.

*Example 1:*

$R = 0.75$ m
$T = 6000$ kg
$L = 1.5$ m

$$\frac{2 \times 0.75 \times 6000}{1.5} = 6000 \text{ kg SLW}$$

Where the sling legs are a fixed length, we may wish to know the minimum rise permissible to lift a known load without an excessive angle. This is given by the formula:

$$R = \frac{LW}{2T}$$

*Example 2:*

$L = 900$ m
$W = 8$ t
$T = 6$ t (mass units)

$$\frac{900 \times 8}{2 \times 6} = 600 \text{ mm rise (minimum)}$$

Where head-room is limited and the rise is known, or is to be kept to a minimum, then the maximum length of leg permissible to safely lift a given load may be obtained from $L = \frac{2RT}{W}$

*Example 3:*

$R = 1$ m
$W = 5$ t
$T = 6$ t

$$\frac{2 \times 1 \times 6}{5} = 2.4 \text{ m maximum length of leg.}$$

Where the leg length and rise are known in advance the minimum SWL required per leg may be calculated from $T = \frac{LW}{2R}$, in order to select the correct sling capacity.

*Example 4:*

$R = 3$ m
$L = 6$ m
$W = 6000$ kg

$$\frac{6 \times 6000}{2 \times 3} = 6000 \text{ kg minimum required per leg.}$$

Therefore a sling or slings having at least this SWL per leg must be selected.

*Note:* This example indicates an included angle of 120°, as the tension in each leg is the same as the load. If the rise were less than half the leg length, then the tension in each leg would be *greater* than the weight of the load being lifted and would increase rapidly at wider angles.

### Single Slings

Where a single sling is reeved around a rectangular load the formula in Example 1 would be $W = \frac{RT}{L}$ as an arbitrary factor to allow for the nip at various points. For example,

$$\frac{0.75 \times 6000}{1.5} = 3000 \text{ kg maximum load}$$

Similarly as in Example 4 (to find minimum sling required)

$$T = \frac{LW}{R} = \frac{6 \times 6000}{3} = 12\,000 \text{ kg min SWL required.}$$

## Other Factors Affecting SWL

Fibre rope slings and knots have been dealt with, and of course wire and chain slings must never be knotted, even though sometimes it may be necessary to join slings.

It is preferable to join wire slings by shackles, although a bad nip may be caused by using a shackle with a small diameter pin (Fig. 20). Pins, lugs and hooks, over which slings may be passed, should be as large in diameter as is reasonable, and be smooth and rounded.

**Figure 20** Rope crushed on small diameter shackle pin

### Sharp Corners

Although left out of the illustrations for clarity, slings passing over sharp corners must be protected, particularly if the sling is likely to slide. It will then shear through like a knife.

A proper corner pad as shown in Figure 21 may be purchased in sets, and is best for protecting both the sling and the load.

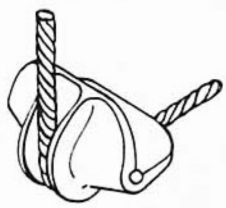


**Figure 21** Typical corner pad

Where these are not available, pieces of split pipe may be used, as shown in Figure 22.

Soft-wood timber sometimes has a use as packing, and even carpet, old conveyor belt material or several layers of sacking may be used, especially on machined surfaces. Rags, cotton waste, etc., are virtually useless.

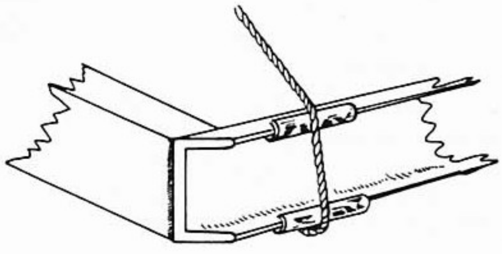


**Figure 22** Split pipe used to protect sling

# Eye-bolts

## Dangers

Eyebolts are fitted for convenience, but if mis-used, can be a great potential hazard. They should only be used for very low lifts, except where they are used to steady the load and not as a means of total support. Common problems with eye-bolts include the following:

- It is possible for a hoist rope to impart spin to the load, with the danger of unscrewing the eye-bolt.
- The eye-bolt may be fatigued from frequent previous lifts.
- It may have come from a machine of even older vintage, with also the possibility of being fatigued.
- It is dependent on its fit in a tapped hole and both it and the thread in the hole may have suffered from over-tightening with a pinch-bar, piece of pipe, etc.
- The threads may be mismatched; for example, an eye-bolt having a $\frac{1}{2}$ in. Whitworth thread of 12 threads per inch is not readily distinguishable from one intended for a $\frac{1}{2}$ in. U.N.C. tapped hole of 13 threads per inch, although in some sizes the pitches may be the same.
- The eye-bolt that must be of the shouldered or collared variety may not be fully inserted so that the collar bears firmly against its mating surface.

## Uses of Eye-bolts

Uncollared eye-bolts have a use where straight pulls are maintained, as in guys for power poles, or in turn-buckles, etc., but they must never be used for load-lifting.

### Collared Types

Their use for load-lifting is not recommended, unless for the lighter types of dies or press-tools where it may not always be possible to get a sling between the die and the press platen. (See Fig. 23.)

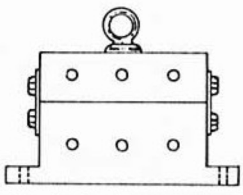


**Figure 23** Press die (note transport plates)

Another example of where an eye-bolt was useful was where a vertical shaft required extracting from a stone-crusher. This was only possible with an eye-bolt and a suitable one was kept in reserve solely for this purpose (Fig. 24). (This particular job was in connection with a specialized machine repair, and not lifting practice in the real sense.)

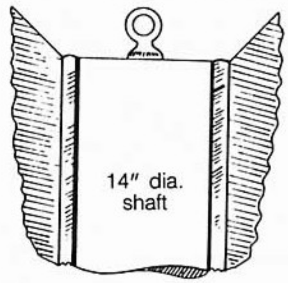



**Figure 24** Vertical shaft

Where eye-bolts are used for lifting, they must be shouldered or collared, be a good fit and be just nipped down until the collar bears against the mating surface, which must be flat, and at least equal in diameter to the collar.

Where two or more eye-bolts are used, a single sling must never pass through more than one eye, and where two-legged or multi-legged slings are in use, the included angle between legs must never exceed 90°. (Fig. 25.) Beyond this angle the SWL for each eye-bolt becomes less than 50% of its strength in straight pull.

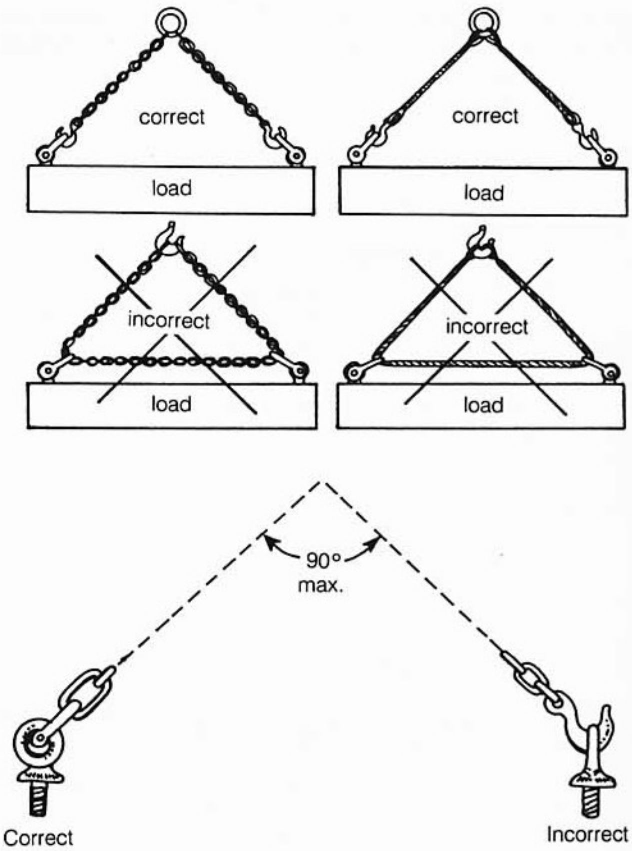



**Figure 25** Safe working sling and eye bolts

Furthermore, the angular pull must only be applied in the plane of the eye and not at right angles to it.

*Note:* Where the use of eye-bolts can be avoided other means should be employed.

The SWL for pairs of eye-bolts at various angles is given below, in contrast to a single eye-bolt in straight pull.

At 90° included angle the SWL for the pair is half that of the single one (Fig. 26).

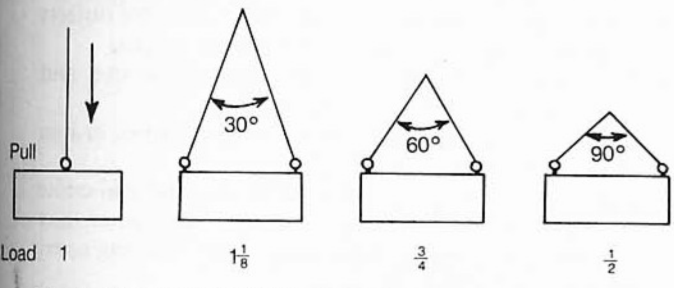



**Figure 26** Load at different angles

## Plate-handling devices

Plate-handling devices fall into two categories:

- those for handling steel or similar plates and sheets, in an upright or vertical position;
- those for handling the above in a flat horizontal position.

*Note:* Some devices can be suitable for both purposes.

### Handling Plates Vertically

In the past vertical plate clamps have ranged from an ordinary carpenter's G-clamp, which is a highly dangerous use, through various home-made devices, to efficient self-locking types.

All, however, depend on a frictional grip of the surfaces to which they are attached and therefore anything that affects this frictional grip must affect the security of the clamp. This may range from paint, grease or scale on the plate, or misuse, over-tightening or overloading of the device, to straight-out incorrect attachment by the user.

#### Problems

Problems encountered with some plate clamps include the following:

- Where a bolt-head is provided, damage can be caused due to overtightening with a long spanner. Where a cross-hole and tommy-bar are provided, the screw might not be sufficiently tightened for a secure grip.
- Fillet welds are in tension and are also subjected to bending when non-vertical plates are being fitted.
- Although a radius in the throat of the clamp is essential for good design, careless use can result in contact with a plate edge, with the result that any plate movement loosens the grip.
- The smooth jaw can result in plate slip, particularly if the plate is slippery from being painted, is oily or polished.
- The jaws are subject to spreading when over-tightened.
- Where a pointed screw is used the point can tear through the plate (particularly if the screw bends) and where a round or flat-ended screw is used mushrooming takes place, tending to increase bending of the screw. Where a cup-pointed screw is used, it tends to fill with paint or scale and becomes less effective.
- The screw always has a tendency to bend, threads become damaged and tight, thus leading the user to think that he or she has a tight grip of the plate with the clamp.
- Except where a single hole in the clamp is placed over a hook fitted with a safety latch, or is shackled to the eye of the hoist-rope, the following can occur.

  After lowering a plate to the floor (particularly with a push-button controlled crane or hoist) if after the plate edge strikes the floor the crane overruns, the hook can keep going and thus come out of the hole and allow the plate to fall. All plate clamps, including the most modern types, should be shackled to a short length of chain.

  With all plate clamps, the included angle between sling legs should never exceed 60°. Beyond this, a spreader beam should be used. Tested and approved locking-type clamps with serrated jaws, properly maintained, should always be used.

## Turning over the Loads

Under certain circumstances a load may need to be turned over. This needs to be done with care. Figure 27 represents the turning over of a steel hopper or bin. If the placing of the attachment point is badly chosen, as drawn, then as the hopper tips over the point of balance, the sling or hoist rope may become dislodged if not firmly shackled on.

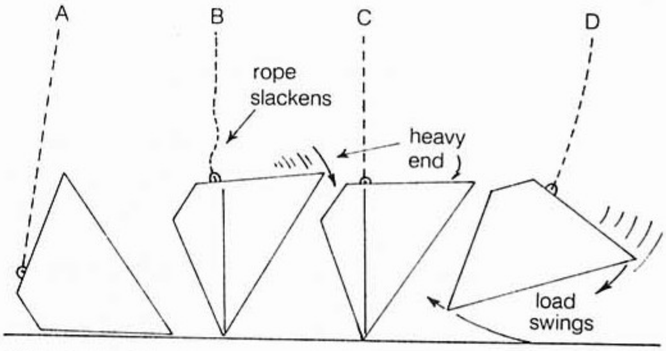



**Figure 27** Turning over a steel hopper or bin

*Note:* A plate clamp or eye bolts must never be used in this situation.

Attachment points must be chosen with care, and where two cranes are not available, two attachment points should be used and, if necessary, slings of unequal length employed to control the load. Each sling or leg should be capable of taking the whole load. (See Fig. 28.)

Loads may be turned as shown in Figure 29. The centre of gravity of the load is shown in the load and it is necessary for this to pass under the centre of the hoist rope before lowering can take place.

The sling leads from the hook straight down to the ground on the side to be lifted. This ensures that the sling remains tight at all times and the load remains under control.

The timber packing is to allow easy placing and removal of the sling. The sharp corners of the load should of course be padded, to protect the sling from damage.

Raising should take place slowly until position 2 is reached, when a gentle push will ensure that the load turns in the desired manner. Finally the load is lowered slowly.

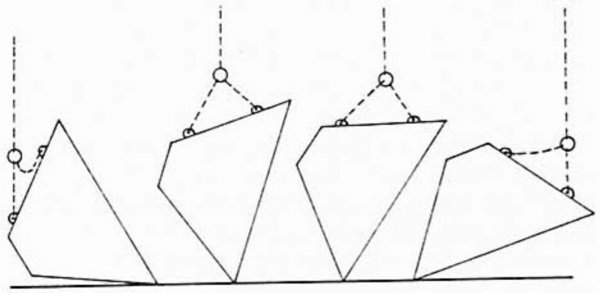


**Figure 28** Load control

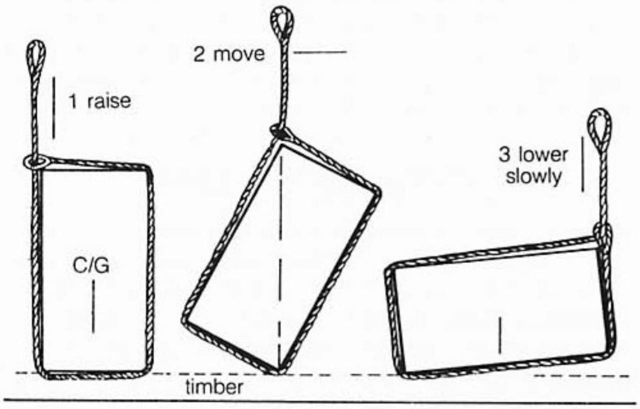



**Figure 29** Load turning

## Points to remember

### DO

While slinging loads, observe the following practices:

- Place packings under loads to allow for each sling removal after setting down and make sure they are firm if loads are to be stacked.
- Use bow shackles where two or more slips are placed on a hook, particularly if the hook is large.
- Remember, when using more than one sling on a load that is heavy at one end, that the sling at the heavy end must be rated accordingly.
- Keep hands and fingers clear when the crane is first taking a strain on a load.
- Check slings, packings and balance, before lifting the load further.
- Carry loads as close to the ground as possible, particularly with mobile cranes, or, at least, only high enough to clear any obstacles.
- Watch out for hazards that the crane driver may not see.
- Wherever possible position yourself so that the crane driver can clearly see you and your signals.
- Stand clear of loads, particularly when mobiling. Heavy loads should be tied, as a person trying to hold them steady may easily be crushed against the crane or other objects. It is absurd to attempt to hold a load of perhaps several tonnes steady as it sways about when mobiling.

### DON'T

- Use worn or broken gear.
- Leave unused sling legs or hooks dangling when the crane is travelling.
- Trail slings along the ground, or pull slings from beneath loads with a crane.
- Use bricks, concrete blocks, or other crushable objects when packing under loads or between stacks.
- Leave the pins out of shackles when not in use, and then use bolts when the pins are lost.
- Knot wire rope, synthetic fibre rope and chains, or join chains with nuts and bolts.
- Leave wire rope slings attached to the load and crane during welding. ('Earthing' through a shop crane may damage both them and the shop crane. Burning operations can damage all slings.)
- Guess at the weights of the loads or the capacities of the cranes, or of any lifting gear. Find out!
- Overload hooks as in Figure 30. Decrease the angle.
- Lift loads on the points of hooks (Fig. 31).
- Reeve slings on wide heavy loads (Fig. 32).
- Impose angular pull on the ferrule of a mechanical splice (Fig. 33).
- Lift a heavy worm reducer box by the eye bolts, provided for the cover. Use the lugs on the lower half (Fig. 34).
- Reeve a sling around on an open top load, without using a spreader to prevent crushing (Fig. 35).

*Important*

Stand clear of the load as soon as slings are tight and before lifting further, for these reasons:

- in case the load tips or becomes detached and injures the slinger (faulty slings or lugs);
- in order to see the hoist rope is vertical, to avoid swing, which may damage the load or injure the slinger, who should not be between the load and the nearby fixed objects;
- to be more easily seen by the crane driver, particularly of small articulated mobiles (poor visibility through boom supports).

## Australian Standards

Recommendations for safe working loads for various types of slings are given in Australian Standards AS 1666–1976, and AS 1380–1972, which should be referred to for safe working conditions.

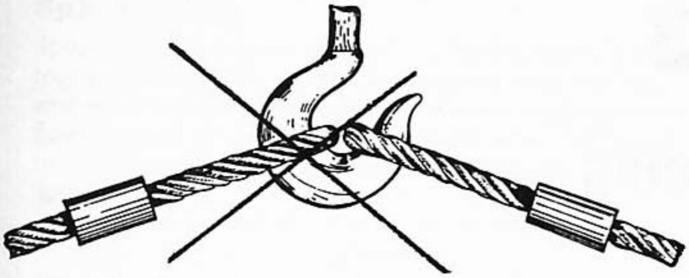


**Figure 30** Bad loading on hook slings

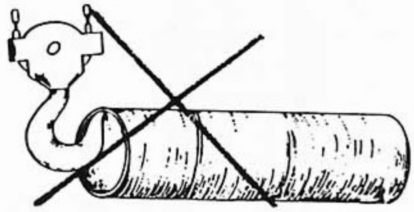


**Figure 31** Don't lift on the point of the hook

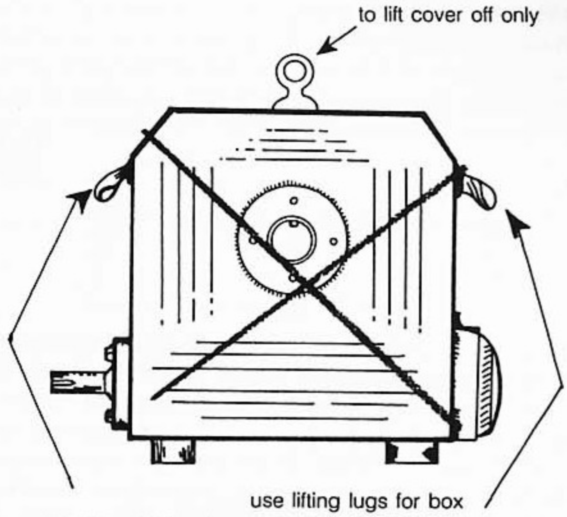



**Figure 34** Use lifting lugs for gear box

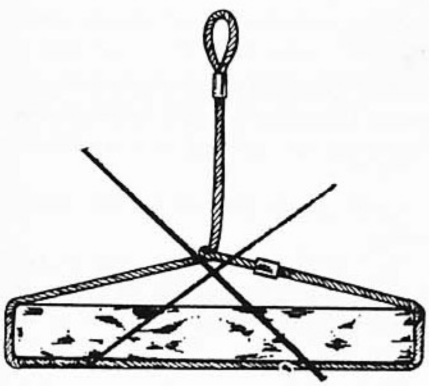


**Figure 32** Don't reeve wide heavy loads

**Figure 33** Bad nip on mechanical splice

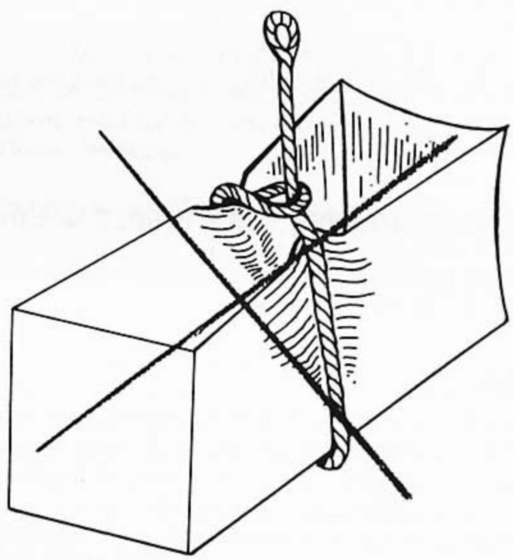


**Figure 35** Reeving crushing an open top load

**Figure 36** How to tie knots

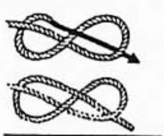
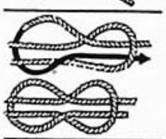
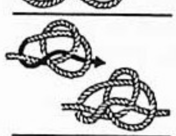


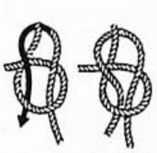
**Figure Eight Knot**
Easier to untie and stronger than the common overhand knot, it is the best knot for stopping a fall that would otherwise run out of a davit or tackle.
TO TIE: Make an overhand loop. Bring the end around and under the standing part. Draw end through loop and tighten.



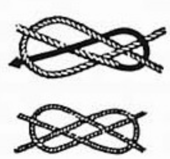
**Square or Reef Knot**
Used aboard ship to secure rope ends. It unties easily if either end is jerked.
TO TIE: Loop the left end under and over the right end, loop the right end under the left standing part and end. Draw back through right loop and tighten.



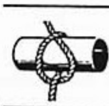
**Bowline**
Often used to secure a mooring line to a post, it never jams or slips.
TO TIE: Make an overhand loop. Bring end under and up through loop, then under and around standing part. Draw end back through loop and tighten.



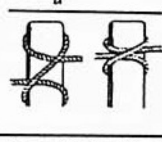
**Sheet Bend**
For light or medium ropes, it is a popular knot aboard ship.
Resembling a bowline, its end is tied to the bight of another rope, instead of its own bight.
TO TIE: Make an overhand loop. Draw the end of the second rope through the loop, under and around the first rope's standing part and back through the loop.



**Carrick Bend**
Used for tying heavy ropes or hawser together, it is one of the strongest knots. Under load, it tightens — an important feature because large ropes cannot be tightened by hand.
TO TIE: Make an underhand loop with end and standing part facing the same direction. Draw second rope end down through loop, under the first end and over the first standing part. Bring the second end up through first loop, over its own standing part and down through loop.



**Half Hitch**
Fastens an object quickly for a right angle pull.
TO TIE: Pass the end around the object and tie an overhand knot loosely. Slop the end under the rope turn.



**Clove Hitch**
For lashing a line around a post or spar.
TO TIE: Wrap end around the object. Make a second loop around the object and draw the end under the standing part.

**Recommended knots for tying Poly Cord.**

# Welding

Welding, as a method of joining metals together, has advantages over riveting or screw fastening. These last two processes require drilling and fitting of rivets or screws—processes that often take longer than the same job completed by welding. Pressure-tight containers are made by welding plate material to produce a stronger product than can be achieved by alternative methods.

Machine parts and framework, which are fabrication-welded sections, are more economical to make than castings.

The extensive application of welding to structural engineering and ship building is a major time-saving factor.

## Soldering, brazing, and bronze welding

Many parts made from sheet or tubing are often soldered together rather than welded.

### Soldering

A common metal used in low-temperature joining is soft solder. It is an alloy of tin and lead, used largely by plumbers on sheetmetal work. Soft solder forms a relatively weak joint.

Stronger jointing is achieved with silver solder. It is chiefly used to join parts made of copper alloys or sheet steel. Because the alloy is expensive its use is usually confined to special work, for example silverware, electrical fittings, or instrument components.

Silver solder contains silver, copper, zinc, and, in some grades, cadmium. Melting points of the different grades are from 600°C to 800°C. The surfaces to be joined must be thoroughly cleaned. A special flux is used in silver soldering. Molten silver solder flows by capillary attraction between the surfaces being joined.

### Brazing

Brazing metal is an alloy of copper and zinc. The process is similar to both silver soldering and bronze welding in that it does not melt the surfaces of the parts being joined.

Brazing is another process that relies on capillary attraction between the molten filler metal and the surfaces being joined. It is applied to closely fitting parts made of steel, copper, and copper alloys.

Figure 1 illustrates a typical brazed joint in copper piping. The parts must be clean and the correct flux used. The whole of the area to be joined is heated to the melting point of the brazing metal.

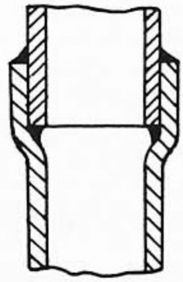


**Figure 1** Typical brazed joint copper piping

### Bronze Welding

Bronze welding is used to join steel (including galvanized steel) and cast-iron parts. It is never used on stainless steel. Often, repairs to castings are carried out by bronze welding.

Manganese bronze and Tobin bronze are the metals used in bronze welding.

The edges of the work to be joined should be dressed to give a bright clean surface. For work 6 mm or more in thickness the edges are chamfered to form a 90° included angle (see Fig. 2).

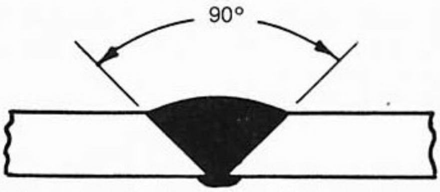



**Figure 2** Example of a bronze welded section

A liberal quantity of suitable flux is necessary to provide a chemically clean base-metal surface. This will ensure strong adhesion between the base metal and the bronze. The work should be carefully preheated and the surfaces coated with a thin layer of bronze in the same way that a surface is tinned in soldering. This is followed by depositing more bronze metal in the manner of fusion welding.

## Pressure welding

Pressure welding is used to join parts without the aid of a pool of liquid weld metal at the joint.

The most common form of pressure welding is found in resistance welding. Three methods are used—spot welding, seam welding and butt welding.

## Spot Welding

Spot welding is extensively used to join sheetmetal parts together. It is widely used in automobile body building and steel furniture manufacture. A very high current flows beween the electrodes to quickly bring the metal to welding temperature. Additional pressure is then applied (see Fig. 3).

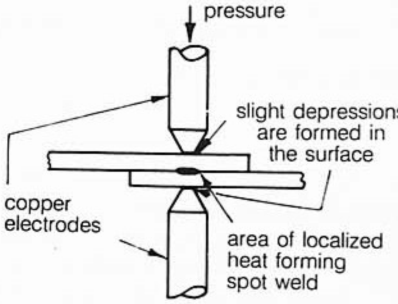



**Figure 3** Spot welding

## Seam Welding

Seam welding is used where a continuous weld is required in joining sheetmetal parts. The copper electrodes are shaped as rollers. The process uses the same principle as spot welding (see Fig. 4).

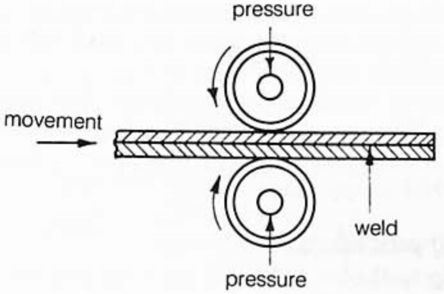



**Figure 4** Seam welding

## Butt Welding

Electric butt welding is employed to join parts made of steel, brass, bronze, and aluminium. Ends to be joined should be of approximately the same cross-sectional area (see Fig. 5).

Butt welding is used to save expensive material when making taper shank drills. The body section of high-speed steel is butt welded to the shank made of cheaper steel (see Fig. 6). A high current flows through the parts being joined. This rapidly brings their ends to welding temperature. Pressure is then applied to bring the ends together and so complete the weld. The current is then switched off.

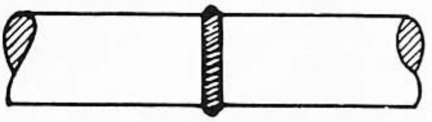


**Figure 6** Finished butt weld

# Fusion welding

During fusion welding the filler rod melts, with the edges of the parts being joined to create a pool of molten metal, which then solidifies. The filler rod or electrode, as it is known in electric-arc welding, is generally similar in composition to the parts being joined. The chief processes of fusion welding are oxyacetylene gas welding and electric-arc welding.

## Oxyacetylene Manual Welding

A high-temperature flame of approximately 3200°C is developed by burning acetylene gas with oxygen in a torch or blowpipe.

### Oxygen and Acetylene Storage

Oxygen is stored at pressures up to 13 800 kPa in black painted steel cylinders. The threads on all fittings connected to the oxygen cylinder are right-handed.

Acetylene is stored at pressures up to 1500 kPa in maroon coloured cylinders. To avoid an explosion, acetylene is dissolved in acetone and absorbed into a porous substance contained in the cylinder. In this state it is safe to transport. As an additional safety measure, the threads on all fittings connected to the acetylene cylinder are left-handed. (Fig. 7.)

### Operating Oxyacetylene Plant

Safety precautions to be observed when operating oxyacetylene equipment are listed in Table 1.

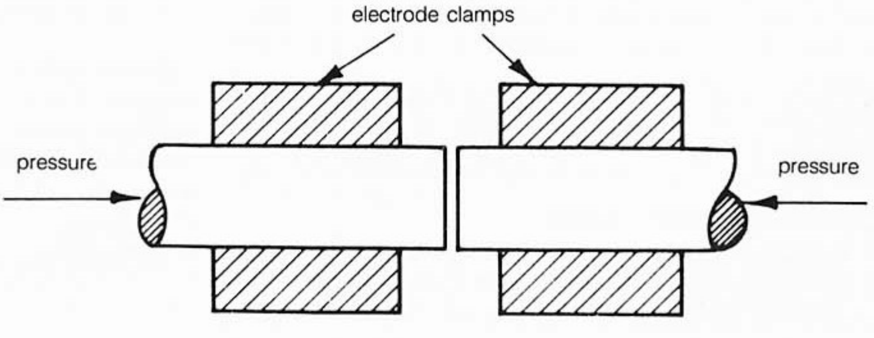



**Figure 5** Butt welding

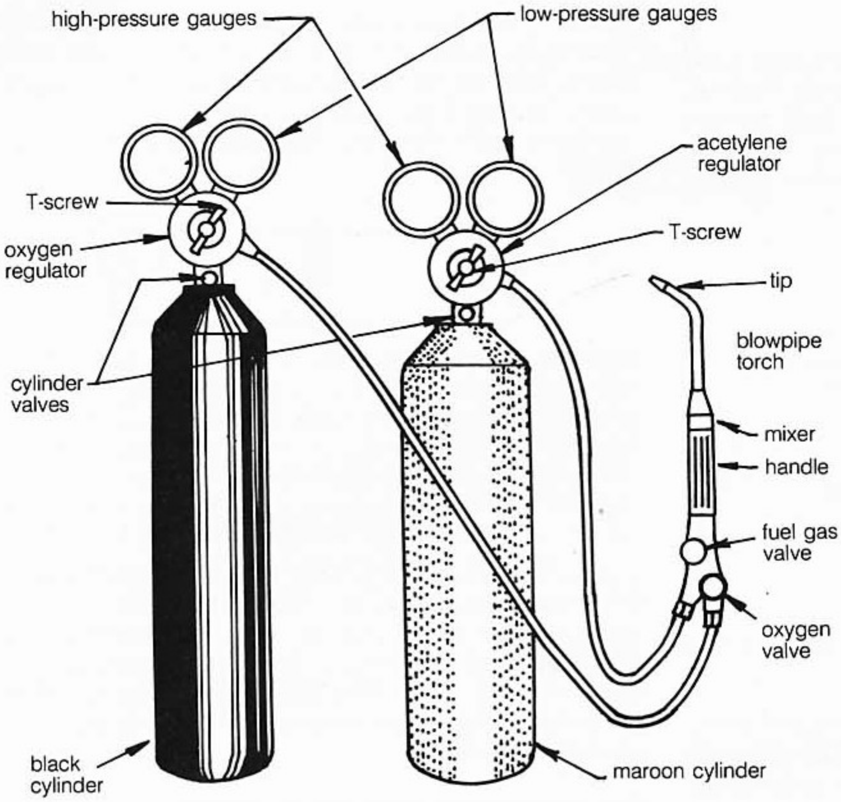



**Figure 7** High-pressure oxyacetylene plant

**Table 1** Safety precautions when operating oxyacetylene

Every possible precaution should be taken to avoid accidents when operating oxyacetylene equipment. The following should ALWAYS be observed.

- FITTINGS MUST BE FREE OF OIL OR GREASE.
- All fittings must be tight.
- Cylinders must be stored securely in an upright position away from hot areas.
- When in use cylinders should be secured by a chain either to some fixed position or to a specially designed trolley.
- Cylinder valves must be opened or closed slowly.
- The key should be left in the acetylene cylinder valve.
- Cutting or welding over the hoses must never be done.
- The correct goggles must always be worn during welding. The lens filter must conform to standards set by the Standards Association of Australia (AS 1336–1338).
- Neat-fitting protective clothing that is free of oil and grease should always be worn.
- Sturdy shoes or boots should be worn.
- ANY CONTAINERS THAT HAVE HELD FLAMMABLE LIQUIDS OR DANGEROUS CHEMICALS MUST NEVER BE WELDED BEFORE BEING THOROUGHLY CLEANED OUT. THIS INVOLVES STEAM TREATMENT AND WASHING WITH A CAUSTIC SODA SOLUTION.
- The nearest fire extinguisher must be located and asbestos cloth placed on hand for use in an emergency, before welding starts.
- If a flashback occurs in a torch, the oxygen must be shut off immediately, followed by the acetylene. The torch is then allowed to cool down. All equipment is then checked.

### *Connecting a fresh cylinder*

1 Remove the cylinder cap if provided.
2 Open the oxygen cylinder valve slightly to blow out moisture and dirt, then close it. The top of the acetylene valve is blown clean by quickly puffing out a little gas. Acetylene cylinders must be stored and used only in an upright position.
3 Connect the regulator to the cylinder, first making sure that the fittings are clean and free from oil and grease.
4 Check for suspected leaks—this may be done with a brush and soapy water.

### *Operating procedure*

1 Fit a tip to the torch to suit the thickness and type of metal to be welded.
2 Open each cylinder valve slowly and note the pressures on the high-pressure gauges. The regulator screws must be loose while this is being done.
3 Operate each regulator screw slowly until the required pressures show on the low-pressure gauges—35 to 70 kPa for both acetylene and oxygen in normal welding.
4 Open the acetylene valve on the torch allowing any air to be blown out and then apply the lighter and adjust the acetylene valve to the point where the flame burns without flaring noisily off the end of the tip.
5 Without wasting time open the oxygen valve until the required flame has been obtained.

## Types of Flame

Accurate flame adjustment is a most important factor in making a success of oxyacetylene welding. There are three types of flame adjustment:

- neutral;
- oxidizing;
- carburizing.

*Neutral flame*

A neutral flame is one that has equal volumes of gases flowing to it. (Fig. 8.) It is the flame most often used for oxyacetylene welding. This flame is recognized by the clear sharp cone at the centre of the flame.

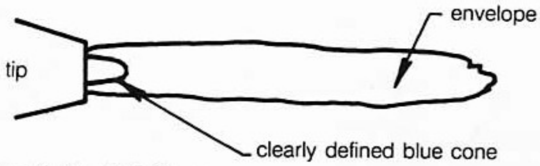



**Figure 8** Neutral flame

*Oxidizing flame*

An oxidizing flame is one that has an excess of oxygen (Fig. 9); it is used for the welding of galvanized work and brass. It is recognized by the short purplish cone and the rather loud hissing noise from the flame.

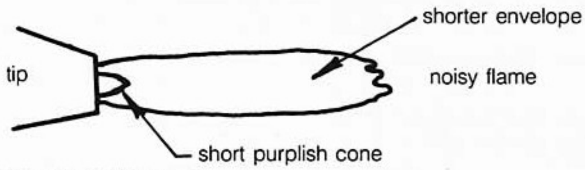



**Figure 9** Oxidizing flame

*Carburizing flame*

A carburizing flame is one with an excess of acetylene (Fig. 10); it is generally used for the welding of aluminium, bronze, and nickel alloys. The flame is recognized by the feather on the end of the cone.

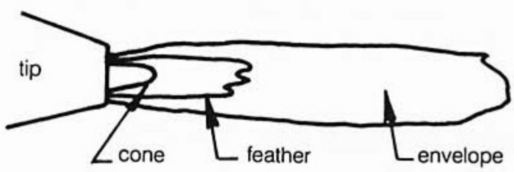



**Figure 10** Carburizing flame

## Closing Down the Plant

If the plant is frequently used during a working day only the first two of the following steps are taken. They should be followed in the order given. For all other occasions the full procedure is adopted:

1 Close the acetylene valve on the torch.
2 Close the oxygen valve on the torch.
3 Close both cylinder valves.
4 Open the oxygen valve on the torch and drain until both oxygen gauges read zero.
5 Release the oxygen regulator T-screw.
6 Repeat steps 4 and 5 for the acetylene line.

*Backfire*

When the flame goes out with a loud 'snap' it is called backfiring. The causes of backfiring are:

- gas pressures too high;
- loose tip;
- blocked tip;
- dirty tip seat;
- allowing the tip to contact the work;
- overheated tip.

It should be noted that the maximum safe pressure for acetylene is 100 kPa (15 p.s.i.).

Flashback Flashback is more serious. The flame burns back in the torch, producing a loud hissing noise. Burning may even reach the hoses or acetylene cylinder. Immediately flashback is detected the following steps must be taken:

1 If confined to the torch, quickly close the oxygen valve. This is followed by closing the acetylene valve and both cylinder valves. The torch should then be cooled and thoroughly inspected before relighting.
2 If in the hose, close all valves and replace the hose.
3 If in the acetylene cylinder, the top of the cylinder will become hot. Close all valves, cool the cylinder with wet bags or water. Move it into the open away from sparks or flame then release the gas. Finally, mark the cylinder and notify the supplier.

## Oxyacetylene Welding Techniques

Leftward or forehand The rod precedes the torch, moving from right to left along the joint. Half circular weaving movements are made with the torch and the rod or with the torch only (see Fig. 11).

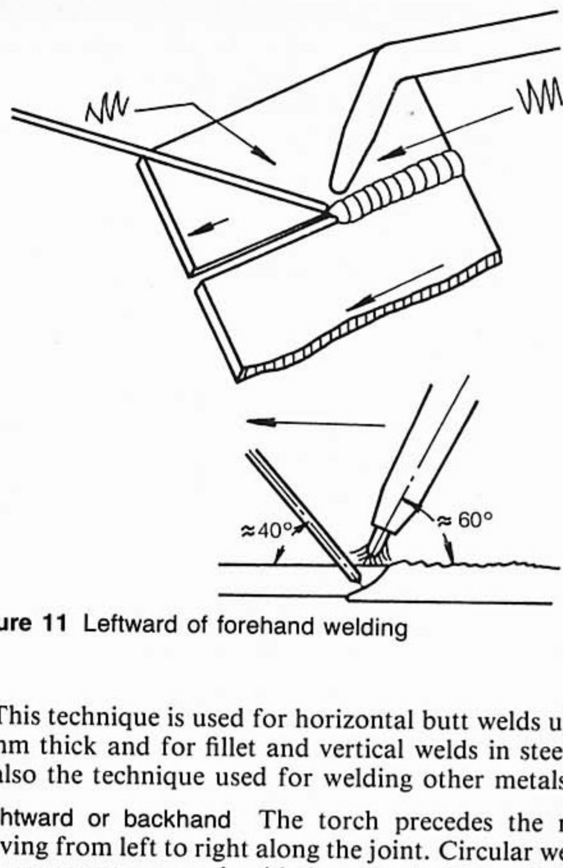



**Figure 11** Leftward of forehand welding

This technique is used for horizontal butt welds up to 6 mm thick and for fillet and vertical welds in steel. It is also the technique used for welding other metals.

Rightward or backhand The torch precedes the rod, moving from left to right along the joint. Circular weaving movements are made with the rod only. The technique is used for horizontal butt welds in steel 5 mm thick and over. (See Fig. 12.)

## Preparation of Material for Oxyacetylene Welding

The metal to be welded must be free of scale, paint, heavy rust, and grease. Cleaning can be carried out with a steel

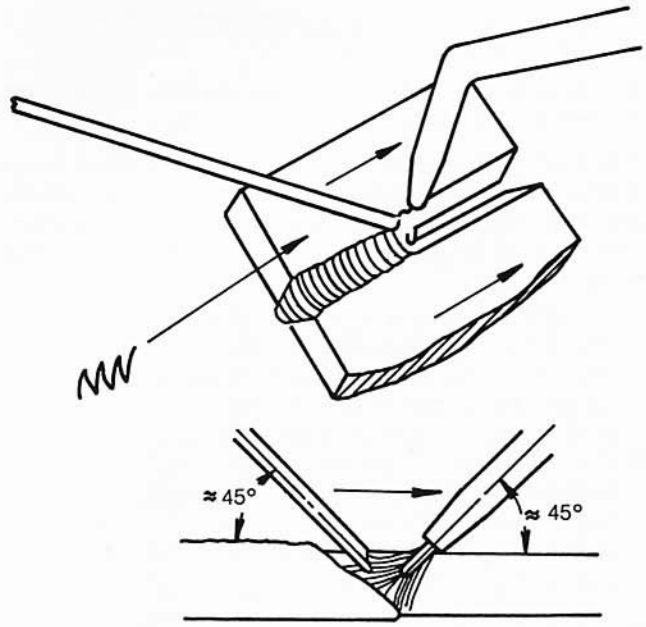



**Figure 12** Rightward or backhand welding

wire brush, old files, or by grinding. Full penetration of the weld depends on section thickness and type of material. For example, in welding low-carbon-steel parts

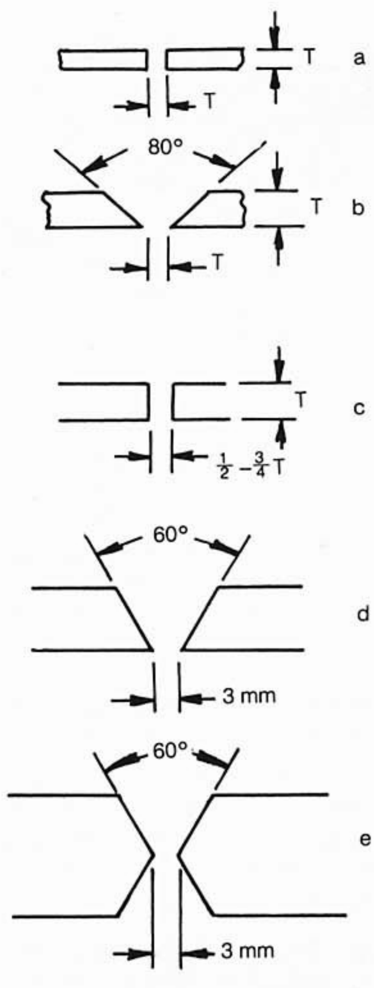



**Figure 13** Butt welds, mild steel (oxyacetylene)

of more than 3 mm thickness, the edges to be joined in a butt weld with the forehand technique require chamfering. (Fig. 13.) They form a single V when placed close together. For sections of more than 13 mm in low-carbon steel a double V is essential. The backhand technique is used in butt welds of more than 6 mm thickness. (See Fig. 12.)

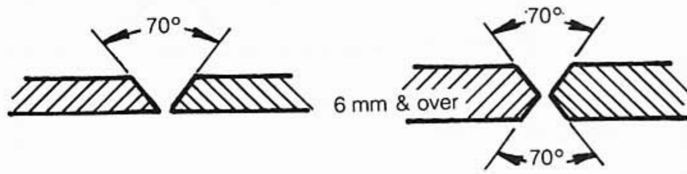



**Figure 14** Material preparation, fusion welding, cast iron

## Types of Oxyacetylene Weld

### *Fillet welds*

The leftward technique is used for fillet welds, care being taken to direct the flame more to the bottom plate, to avoid 'undercutting' the top plate. (Fig. 15.)

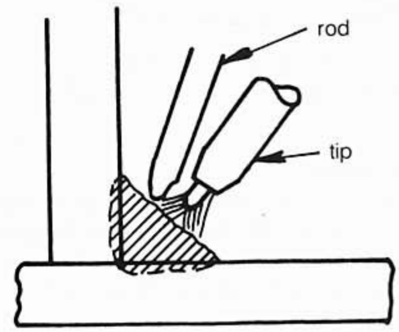



**Figure 15** Angles of torch and rod for fillet welds

## Shielded Metallic Arc Welding

Shielded metallic arc welding, using an electric arc, is a welding process in which the joining of the metals is accomplished by melting the parent metal and the tip of a flux-coated electrode (see Fig. 16). An electric arc between the electrode and the work provides the heat (temperature approximately 6000°C). The electric power source is, in most plants, A.C. (alternating current), but D.C. (direct current) may also be used, and in some applications is a necessity.

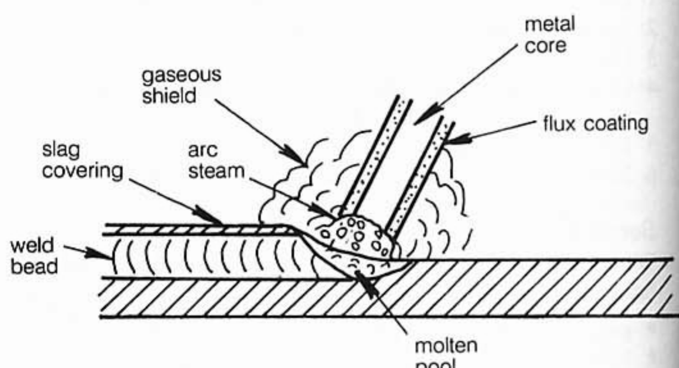



**Figure 16** Shielded arc welding

## Flux Coating

The purpose of the flux coatings are to:

- clean the work by fluxing impurities into the slag;
- provide a gaseous shield for the weld while molten;
- form a protective slag over the weld to shield it during solidification and cooling;
- de-oxidize the weld, reduce porosity, and improve neatness;
- stabilize the arc and minimize spatter;
- help shape the bead and give better penetration.

*Note:* Dampness affects the flux coating on electrodes.

**Table 2** Safety precautions while arc welding

- Wear an apron, gloves, and suitable clothing to avoid burns.
- See that the welding shield is in good condition and that it is used always, or serious eye damage may result.
- Use screens to protect others.
- See that all leads are in good condition and that all fittings are tight.
- In damp situations wear rubber soles or stand on duck-boards.
- Keep all equipment dry.
- Keep a fire extinguisher on hand ($CO_2$ type).
- Do not arc-weld near oxyacetylene welding equipment.
- Check the surroundings to make sure that sparks will not cause fire, explosion, or other damage.
- IF A VESSEL IS SUSPECTED OF HAVING CONTAINED A FLAMMABLE SUBSTANCE OR DANGEROUS CHEMICAL, DO NOT PROCEED WITH WELDING UNTIL IT HAS BEEN THOROUGHLY CLEANED OUT. THE CLEANSING TREATMENT SHOULD INCLUDE STEAM TREATMENT AND WASHING WITH A CAUSTIC SODA SOLUTION.
- In the case of burns, 'arc eyes', or electric shock, seek first aid or medical attention. Infrared rays in the light from an electric arc can cause skin burns. Ultravoilet rays from the same source can burn the retina of the eye.

## Preparations for Metallic Arc Welding

### *Preparation of the metal*

It is essential that the metal is free from scale, rust, galvanizing, plating, paint, and grease, and that the edges are prepared to suit the thickness of the metal and the type of weld.

### *Preparation for butt welds*

This is illustrated in Figure 17. For:

- up to 6 mm thick – use a square butt;
- 6 mm and upwards – use a single V-butt;
- 13 mm and upwards – use a double V-butt.

### *Electrode size and amperage of current*

Electrode size and current amperage increase with the thickness of the metal to be welded. Electrode packets are usually branded with the size and the type of electrode and the amperage required.

### *Identification of electrodes*

To distinguish between different electrodes, the end gripped by the holder may have coloured markings. The markings vary with different manufacturers.

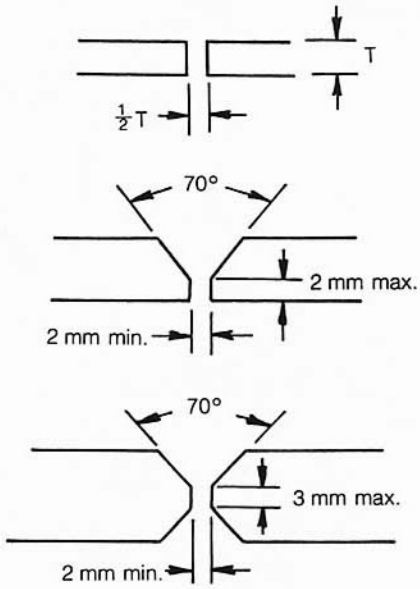


**Figure 17** Butt welds, low-carbon steel (elec.)

## Procedure for Shielded Metallic Arc Welding

1. Fit a suitable flux-coated electrode in the electrode holder.
2. Attach the earth clamp to the work or to the steel table. It is essential that it makes good contact.
3. Set the required amperage, then switch on.
4. Wear an apron and gloves and use the protective shield.
5. Strike the arc by scraping the electrode gently on the work with a circular motion, withdrawing it about 2 to 3 mm. (Fig. 18.) Too short an arc causes sticking and a rough surface on the weld. Too long an arc results in reduced penetration, spatter, and rough surface. A simple rule for proper arc length is – use the shortest arc that will give a good surface to the weld.
6. Proceed to make the weld by moving the electrode along the joint from left to right, at a rate that will allow the formation of a well-shaped bead. (See Figs 19 to 21.)

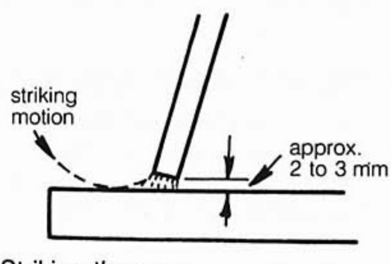


**Figure 18** Striking the arc

### *Multi-run welds*

Small joints may be made with one run, but larger joints may need two or more. The number of runs is also affected by the capacity of the welding plant, some small plants being capable of using only small-gauge electrodes. Between runs the slag should be removed by chipping and cleaning with a wire brush.

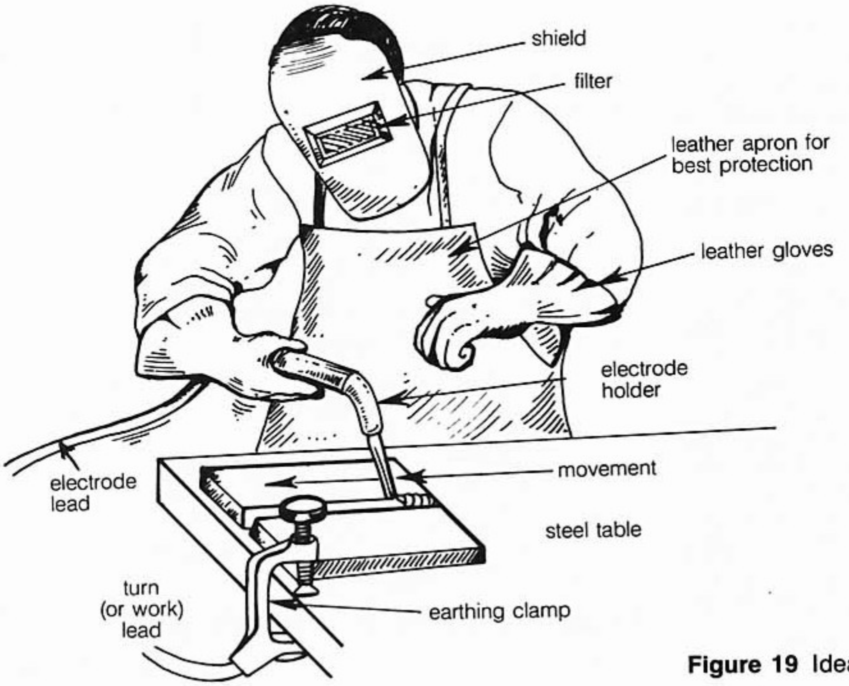



**Figure 19** Ideal arrangement for welding at the bench

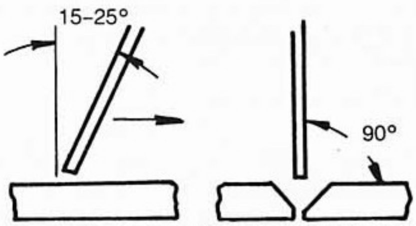



**Figure 20** Electrode angles for single-run butt welds

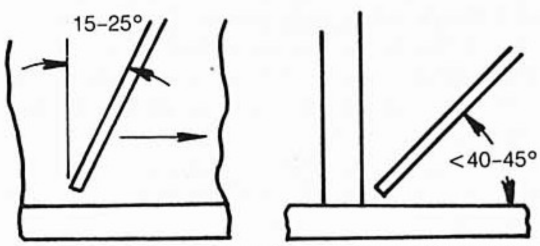



**Figure 21** Electrode angles for single-run fillet welds

## M.I.G. or Metallic Insert Gas Welding

The 'gas metal arc', M.I.G. (metal insert gas) or M.A.G. (metal active gas) process is an arc welding process in which an electric arc is struck between a continuously fed consumable electrode wire and the workpiece. (Fig. 22.) The current is transferred to the wire via a contact tip or contact tube within the welding gun. The electrode is a bare solid wire, which as it is fed to the weld area becomes the filler metal as it is consumed. The wire, weld pool and adjacent area are protected from atmospheric contamination by a shielding gas, fed through the welding torch. This gas shield must provide full protection, even small amounts of entrained air can cause contamination of the weld metal. The shielding gas may be carbon dioxide or argon, or mixtures of argon, $O_2$, $CO_2$ and helium, each of which has characteristic advantages and limitations.

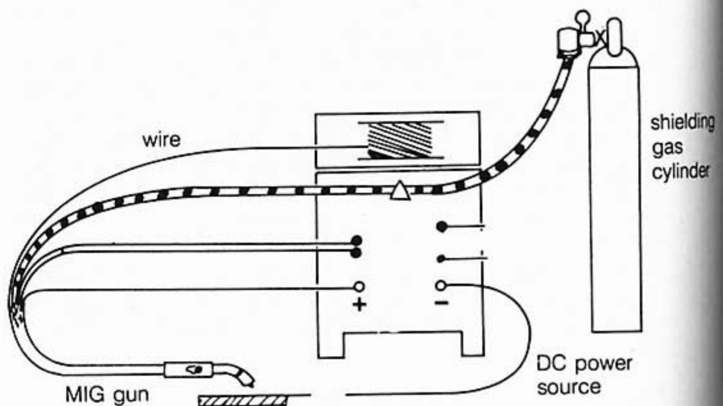



**Figure 22** The MIG welding plant

Like the flux-coated electrode, it is a one-handed process, but covers a far greater range of work. It is capable of welding almost any metal that can be drawn into a thin wire.

The M.I.G. process uses a combination of gas, electrical energy, and consumable filler wire, but the amount of welding that can be achieved in a given time far exceeds that of the other manual processes. It produces no waste, such as stubs of electrodes or slag on the weld.

Features of the process include:

- a clear view of the welding pool;
- continuous welding;
- light-weight torch;
- faster welding speed.

Advantages of using the M.I.G. process are:

- welding can be done in all positions;
- flux powders are not used;
- there is no slag to be removed;
- smoke and fumes are absent;
- 95% of the electrode wire is used;

- up to twice as much welding can be achieved over a given period;
- the process can weld mild steel 0.7 to 5 mm without edge preparation;
- most metals can be welded, by changing the electrode wire and sometimes the shielding gas;
- large gaps in preparation can be tolerated;
- there is less distortion than with other processes;
- spot welds can be performed, with excellent results.

## T.I.G. or Tungsten Inert Gas Welding

The term 'gas tungsten arc welding', or in its abbreviated form T.I.G., has been given to the welding process that employs a heat source in the form of an electric arc between a non-consumable tungsten electrode and the workpiece, and shrouded by an atmosphere of inert gas. (Fig. 23.) The arc, tungsten electrode and weld are shrouded in an atmosphere of inert gas such as argon or helium or mixture of these, which prevents the oxidation and contamination of the electrode and weld pool and allows clean, sound homogeneous, high-quality welds to be made in all weldable metals and alloys without the use of chemical fluxes.

The process is extremely versatile and can be used efficiently in all positions and in a range of thicknesses from 25 mm or more down to materials as thin as 0.25 mm.

Requirements include a power source, a high-frequency unit (usually integrated into the power source), a welding torch, a cylinder of inert shielding gas, a regulator, a flowmeter and a water recirculating cooling unit. With this type of welding, the required heat is provided by an intense electric arc formed between the tungsten electrode and the workpiece.

Argon is usually used in Australia in preference to helium because of its lower cost, and its general suitability for a wide variety of metals.

Argon also exhibits better oxide removal characteristics than helium and helps the welding operation, as heat input to the weld pool is less affected by variations in arc length. Helium provides higher travel speeds and a greater heat input with deeper penetration, and its use is confined mainly to thick aluminium and copper sections. Shielding gas mixtures of argon and helium are used for high-speed mechanized welding of aluminium and copper tube mill applications. Argon–hydrogen mixtures with 6% to 15% hydrogen have been used on stainless steel tube mill work to increase travel speeds.

The T.I.G. process is used with both alternating and direct current welding equipment, the choice of weld current being determined by the material to be welded.

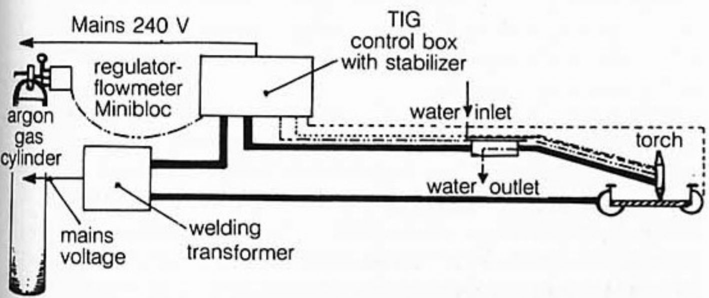



**Figure 23** The TIG welding plant

Metals having refractory surface oxide films, that is, magnesium alloys, aluminium and its alloys, aluminium bronze etc., are welded with A.C. while D.C. is much preferred for carbon steels, stainless and heat-resistant steels, copper, silicon bronze, silver, titanium, nickel alloys etc.

As a result of the 100% protection from atmospheric contamination provided by the inert shielding gas, the T.I.G. process produces welds that are stronger, more ductile and more corrosion resistant than welds made with most other processes. Further advantages include:

- Spatter, sparks and fumes are virtually absent with T.I.G. welding.
- Post-weld cleaning is unnecessary as no flux is used.
- Fusion welds are possible with almost all metals used industrially.
- Because no flux is used, there are very few limits on joint design since corrosion due to flux entrapment cannot occur.
- High welding speeds are obtainable and, when coupled with lack of post-weld cleaning, offer considerable economies.
- The process can be readily mechanized in suitable cases to provide controlled penetration at high welding speeds.
- Use of the correct filler metal gives a deposit of similar composition to the parent metal and so provides a sound, homogenous weld.
- There is less distortion because of localized heat input.
- On pipe welding, the process offers high-quality welds with maximum penetration control of root runs.

# Profile cutting of steel—Hand cutting

## Equipment

### Cutting Torches

Steel may be cut by the oxyacetylene process using an oxyacetylene heating flame and a stream of pure oxygen to burn the steel and thus make the cut. The process may be carried out with a special cutting torch or with an oxyacetylene welding torch to which a cutting attachment has been fitted after removing the mixing chamber and tip. (See Figs 24 and 25.)

**Caution** Care should be taken to see that all joints are gas proof and free from oil and grease.

### Cutting nozzles or Tips

A cutting nozzle has a number of holes to provide heating flames and a central hole for the cutting oxygen.

The size of the nozzle and the gas pressures to use depend on the thickness of the steel to be cut.

It is essential that the end of the nozzle and the holes in it are clean. Cleaning of the end may be carried out with a fine file or emery cloth. The holes should be cleaned with the special cleaning tools provided to ensure that they are not damaged.

### The Flames

The heating flames should be adjusted until neutral, with the cutting lever depressed.

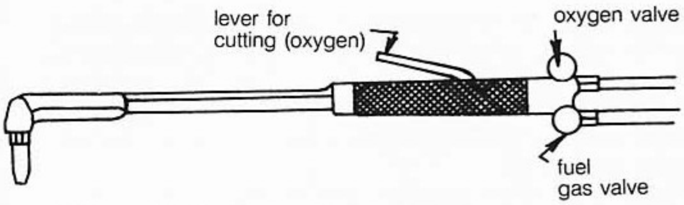



**Figure 24** Cutting torch

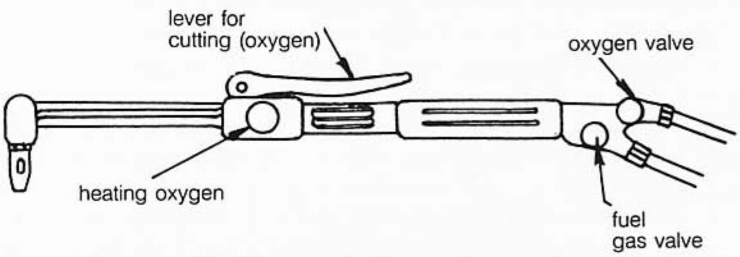



**Figure 25** Welding torch with cutting attachment

## Procedure (Fig. 26)

1 Remove scale along the line of cut, using a wire brush or burning with the torch.
2 Heat the edge to bright red. The inner cones should almost touch the work.
3 Depress the cutting oxygen lever slowly and move the torch along the line of cut keeping the nozzle square to the surface being cut.

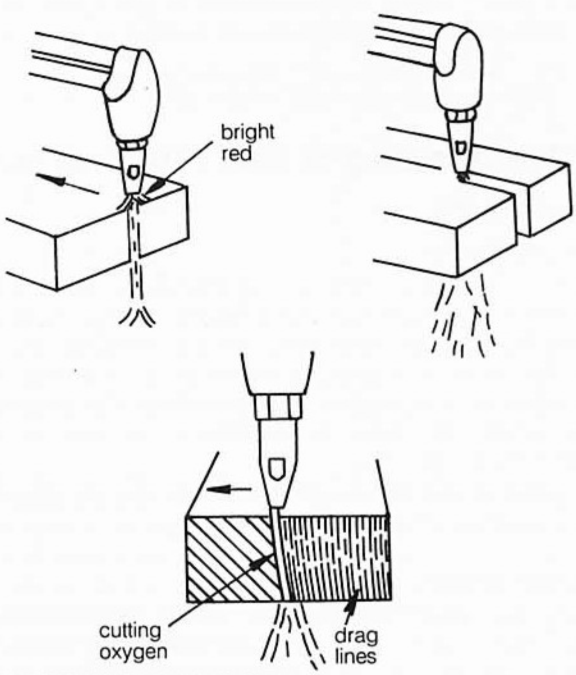



**Figure 26** Cutting procedure

## Defects

It is assumed that the nozzle is clean and correct pressures are set.

If the nozzle is too near to the work the top edges of the cut will be rippled, the surfaces concave, and the flame will tend to backfire.

If the nozzle is too far away the top edges of the cut will melt and the surfaces of the cut will be rough. If the cutting rate is too slow the surface will be undercut and notched at the bottom. If the cutting rate is too fast the drag lines will be steeply sloped and the surfaces of the cut rough.

## Methods of Cutting

### Freehand Cutting

In freehand cutting the torch is guided solely by hand. The method is often used for cutting material to length or cutting sections to be discarded, for example, in repair work or demolition work.

### Guided Cutting

Components of final, or near-final, dimension can be more accurately cut from plate or bar material if the torch is provided with guiding devices. These take the form of guide wheels, trammels, and straight edges.

Guide wheels The bracket holding the guide wheels is fitted to the torch to enable a more accurate cut to be produced when the torch is drawn across the work material.

Straight-edges These are used to direct the guide wheels when producing long straight cuts.

Trammels These are used when cutting discs from plate material. A cleaner cut and a truer circle can be produced when trammels are used to guide the torch.

# Setting up for welding

Parts to be joined by welding should be carefully set and secured in position before taking the first steps in joining them together. This often involves the use of clamps, plates, brackets, and fixtures.

## Welding Fixtures

A welding fixture, or jig as it is more commonly known, is designed to hold the parts to be joined in a set position and to allow for distortion. Fixtures are widely used in production welding for the following reasons:

- They save time in setting up.
- All the finished articles are similar in dimension and shape.
- Distortion control is more effective.

### Design of Fixtures

Welding fixtures are usually built as steel frames. Locating pads or cut-out sections are positioned in the fixture to hold the parts being joined in the right place.

If clamping is considered necessary it is important that clamping pressure on the part is only applied where there is support underneath. If this is not done distortion will occur from this source.

Distortion caused by parts pulling in one direction or another during welding can be eliminated with fixtures. However, distortion can arise from another source.

Residual stresses are present in the materials used. They form during rolling and other operations when the material is made. Heat in the weld areas is sufficient to allow these stresses to bring about distortion. This should be taken into account when designing welding fixtures.

It will require a careful assessment of the amount of welding involved, the actual position of the welds, and the sequence of welding.

## Clamping and Tack Welding

All ends should be carefully formed so that they fit neatly against adjacent faces to be joined.

Where it is practical, parts are lightly clamped in position. Care must be taken that this does not introduce distortion; clamping pressures should only be sufficient to hold the work together until some tack welding has been done.

The work can then be tack welded at regularly spaced intervals along the join to hold the parts together more rigidly.

Clamps should then be removed and the work checked for accuracy before proceeding. If distortion has to be corrected it may be done by tack welding in other positions along the work or by straightening. The welding may then be completed. Magnetic clamps and toggle clamps speed up light jobbing work to be welded.

# Methods of surfacing using welding

## Introduction

Parts of machinery can often be renewed by building up the worn surfaces with weld metal. When the cost of replacement is high or a new part is not available reclamation is necessary.

Some parts require an additional abrasion-resistant surface on critical areas. This can be achieved by depositing suitable metal onto the surfaces by welding. In other cases a corrosion-resistant surface is required and again suitable metal is deposit welded.

The methods adopted in reclaiming worn parts or the provision of protective surfaces are outlined below.

## Reclamation

Teeth of damaged gears, valve seats, worn shafts, tractor treads, and crusher jaws are a few examples of work where reclamation is practical.

The surface to be rebuilt should be cleaned and, in some cases, dressed by grinding. This will provide a satisfactory base for welding.

### Cast-iron Work

Large or comparatively large cast-iron work requires preheating before welding. This is arranged by placing rows of firebricks around the work and then using an oil or gas burner to bring the temperature of the casting up to approxiamtely 300°C to 600°C.

The worn surfaces are then rebuilt by oxyacetylene welding. Slow cooling afterwards will remove thermal stresses.

### Steel Work

Steel parts are often rebuilt by arc welding deposit metal onto the worn surfaces. It is important that electrodes similar to the composition of the part are used in this work.

### Hard Surfacing

Arc welding  When arc welding is used to rebuild a surface that is hard, an intermediate layer of softer metal is first deposited. This will ensure correct keying of the top hard layer. Abrasion-resistant metal is then deposited to form the top layer. The surface of the intermediate layer must be thoroughly cleaned with a chipping hammer and wire brush before the top layer is deposited. Some grinding may also be done to remove a little of the surface unevenness.

Oxyacetylene welding  When oxyacetylene welding is carried out for hard surfacing, a carburizing flame (excess acetylene) is employed. This adds carbon to the deposited metal, enabling it to flow freely at a lower temperature. It also further increases the subsequent hardness.

Before the abrasion-resistant metal is deposited, the temperature is raised at the surface of the base metal until 'sweating' (incipient fusion) is evident.

## Metallizing (Metal Spraying)

Very small globules of liquid metals can be sprayed onto other metal surfaces to improve corrosion or wear resistance. Worn surfaces, for example crankshaft journals, may be reclaimed this way. The process is called metallizing and it can be applied to most metals.

The surface to be sprayed is prepared by sand or shot blasting, rough machining, or grinding. This forms a suitable key for the deposited metal. Depositing metal, in wire or powder form, is melted by the gas flame of the metallizing torch and blown onto the base surface by means of the incorporated spray gun. The molten globules of metal immediately solidify and interlock by flattening.

Where corrosion resistance is required, aluminium or stainless steel deposit metal is used.

Abrasion resistant deposit metals contain chromium or manganese.

# 56

# Fluid power — Industrial pneumatics

The word 'pneumatic' is derived from the Greek word 'pneumos' meaning 'breath'. The science of pneumatics deals with the behaviour of gases (principally air) and their use in transmitting power. Industrial pneumatics is the technology of using compressed air to drive and operate machinery. Pneumatics is considered a branch of 'Fluid power', since gases flow.

Air as a power medium has been used since ancient times, mainly in its normal atmospheric state, for example the use of wind to power sailing ships and windmills. One notable exception, however, was the bellows, which compressed air and blew it into a furnace to melt metals to produce weapons and armour for the Roman Legions, for example.

Pneumatics as we know it today had its formal beginnings in the early 1600s when Blaise Pascal carried out experiments to demonstrate that the atmosphere had pressure. He was very quickly followed by Evangilista Torricelli, who invented the mercury barometer to measure atmospheric pressure, and the Torricellian barometer is still used today.

Around 1650, Otto Von Guericke, mayor of a German town, developed the first true air pump, and demonstrated it in the now famous Magdeburg hemispheres experiment. Some 12 years later, Robert Boyle discovered the relationship between pressure and volume, namely that if temperature is constant, pressure will double if the volume is halved.

Some years later, in 1738, Daniel Bernoulli evolved the theory that changes in pressure were due to changes in molecular energy. He was followed by Jacques Charles, a French physicist, who, in 1738, discovered that gases held at constant pressure expand in proportion to the amount of heat applied.

In 1849, the first real application of modern pneumatics was implemented by using pneumatic power tools to cut coal in a coal mine, the major advantage being that air is inherently explosion proof. This era was well into the Industrial Revolution, and the successful use of air in coal mines led to it being used on a large scale to dig a tunnel through the French Alps. Air as an energy transmission medium finally came of age when a central compressed air plant was built in Paris to supply all of its industry.

Today, most factories have their own air supply, which is used to power the simplest of hand tools, to the most complex machinery, depending on what the factory is manufacturing.

At this point, you may ask 'Why is the use of air so popular?' Well, air has few disadvantages as a transmission medium, and many benefits, as listed below:

- It is explosion proof, so no expensive protection is needed.
- An air system can be rapidly operated, with speeds up to 10 m/sec.
- Air is easily transportable, so can be piped long distances.
- Air is clean, leaving no residues in tooling.
- No return system is needed—used air exhausts to the atmosphere.
- The system has variability—speeds and pressures and infinitely variable.
- A pneumatic system is of low cost.

To help in the understanding of pneumatic systems this section is discussed under three main headings:

- Air and its related laws.
- Compressed air production.
- Components and systems.

## Air and its related laws

The air used in pneumatic systems is free since it comes from the atmosphere, and returns there when we have finished using it. The atmosphere is made up of two main gases, plus some trace elements, as follows:

| | | |
|---|---|---|
| Oxygen | 21% | |
| Nitrogen | 78% | |
| Trace elements | 1% | (argon, helium, krypton, etc.) |

It must be remembered that air is a mixture of gases, which forms an envelope around the Earth, to a height of approximately 50 000 metres. This means that, at any given point in the atmosphere, the air at that point experiences the effects of the air above it, since air has mass. This mass exerts a force over the area of air below it, or the surface of the Earth, thus generating air pressure. This pressure decreases accordingly with increased altitude.

The reference point is sea level, where a pressure of 101.32 kPa is exerted. At 100 m above sea level, the pressure is 100 kPa, indicating that the air pressure drops approximately 1.3 kPa per 100 m. This should be remembered when operating air compressors at high altitudes, as their efficiency drops.

When referring to air in relation to pneumatics, two different terms are used, 'free' air and 'normal' air, which are defined below:

'Free' air is air at atmospheric conditions, and is subject to change of pressure, temperature, and humidity on a meteorological basis.

'Normal' air is a derived term, in which the air pressure, temperature, and humidity are standardized at 101.32 kPa, at 20°C and 36% humidity.

'Normal' air is used for calculations and design of pneumatic components, while 'free' air is used for the calculations of day-to-day efficiencies.

## Pressure Measurement

Due to the design of modern pressure gauges, only pressure above atmospheric is measured. The pressure reading indicated on the gauge scale is therefore known as 'gauge pressure', and is expressed in units kPa.G. True pressure measurement starts at an absolute vacuum, and all readings above this are known as 'absolute pressure', expressed in kPa.abs.

The formulae, and diagram below, show how one measurement may be converted to the other:

Absolute pressure = gauge pressure + atmospheric pressure

Gauge pressure = absolute pressure − atmospheric pressure

Gauge pressure (kPa.G)

| −101.32 kPa.G | 0 kPa.G | 100 kPa.G |
|---|---|---|
| 0 kPa.abs | 101.32 kPa.abs | 201.32 kPa.abs |

Absolute pressure (kPa.abs)

## The Gas Laws

Since gases are compressible, that is, their volumes can be reduced or increased according to the volume changes of their containing vessels, there are certain laws governing the changes that take place. A knowledge of these laws is necessary to be able to understand and develop pneumatic systems.

### Boyle's Law

Boyle's law states that when the temperature of a confined gas remains constant, the volume varies inversely as its absolute pressure. That is:

$$\frac{\text{Initial absolute pressure}}{\text{Final absolute pressure}} = \frac{\text{final volume}}{\text{initial volume}}, \quad \frac{P_1}{P_2} = \frac{V_2}{V_1}$$

### Charles' Law

Charles' law states that when the pressure of a confined gas remains constant, the volume of the gas is directly proportional to its absolute temperature, or, if the volume is constant, the absolute pressure varies directly with absolute temperature. That is:

$$\frac{\text{Initial volume}}{\text{Final volume}} = \frac{\text{initial absolute temperature}}{\text{final absolute temperature}}, \quad \frac{V_1}{V_2} = \frac{T_1}{T_2}$$

or

$$\frac{\text{Initial absolute pressure}}{\text{Final absolute pressure}} = \frac{\text{initial absolute temperature}}{\text{final absolute temperature}}$$

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

### Combination of Boyle's and Charles' Laws

Because pressure, volume and temperature are interrelated, as shown by the above laws, the formulae may be combined into the following general equation:

$$\frac{\text{Initial pressure (abs)} \times \text{initial volume}}{\text{Initial temperature (abs)}} = \frac{\text{final pressure (abs)} \times \text{final volume}}{\text{final temperature (abs)}}$$

or

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

### Abiabatic and Isothermal Compression

Under Boyle's law, when the volume of a confined gas is halved its pressure doubles, and no change in temperature takes place; this is known as isothermal compression or expansion.

However, under normal conditions, a temperature increase is experienced due to the friction generated during compression, and if all the heat is retained in the gas, this is known as adiabatic compression or expansion.

In reality, however, compression takes place somewhere between these two extremes.

The formula for the isothermal cycle is:

$$P_1 \times V_1 = P_2 \times V_2$$

The formula for the adiabatic cycle is:

$$P_1 \times (V_1)^\gamma = P_2 \times (V_2)^\gamma$$

The modification to the formula is to account for the heat factor, and is determined as follows:

Specific heat at constant pressure $= C_p$

Specific heat at constant volume $= C_v$

The ratio $\dfrac{C_p}{C_v} = \gamma$

For air $C_p = 0.24$ and $C_v = 0.17$

So $\gamma = 1.4$

## Compressed Air Production

When air is compressed for use as a power source, the process is one of energy transference as a different power source is used to drive the compressor. This other power source may be an electric motor, where electrical energy is being transformed into air pressure energy, or a petrol engine, where the chemical energy of the petrol is used to drive the compressor.

The industrial requirement for air is that it must be clean and relatively dry, as well as having sufficient volume and pressure for the duties it has to perform. In some cases the air must be perfectly dry, therefore special arrangments must be made to ensure this.

A good air production unit, therefore, must cater for all the requirements discussed above. It follows then that conditioning equipment must be included in the unit, to ensure that the air is produced to the required standard.

## The Air-production Unit

Figure 1 is a schematic diagram of a typical air-production unit.

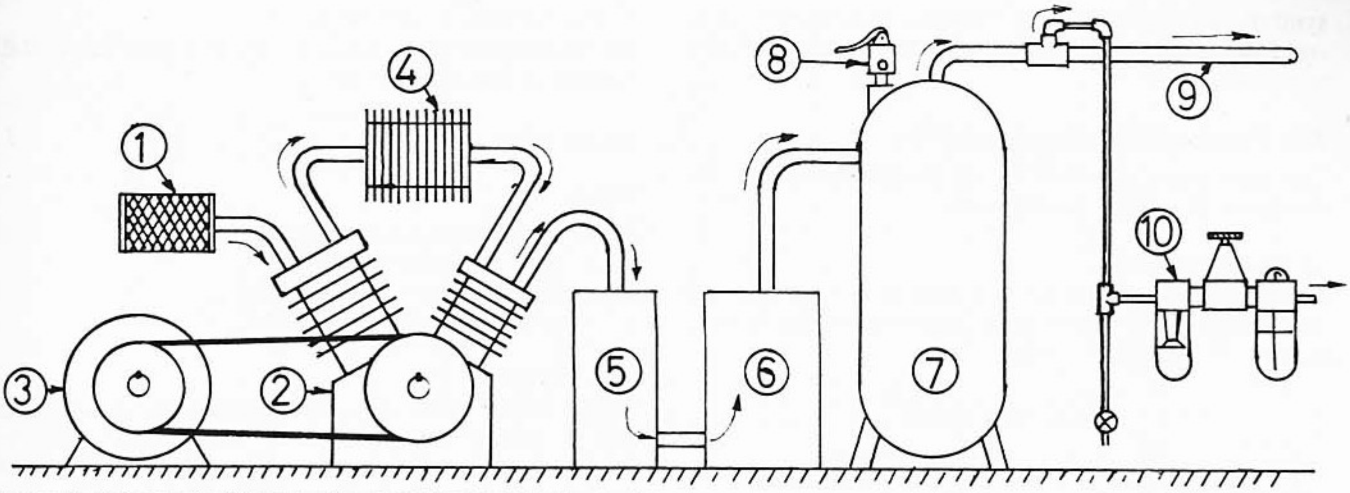



**Figure 1** Schematic diagram of a typical air-production unit

Air is drawn into the system via the air filter (1), which prevents dust and dirt particles from entering the system. It is inducted into the air compressor (2), which is driven by a motor (3), where it is compressed to match the system pressure before being delivered to the system. Compressor types may be reciprocating or rotary operation, single or multiple stage. Usually, larger compressors are multistage, and are fitted with intercoolers (4) to remove the heat of compression, between stages.

When the air leaves the compressor, it is usually hot, and contains an amount of moisture, which will vary depending on the ambient humidity. To cool the air and remove as much moisture as possible, it is then passed through an aftercooler (5). If all the moisture has to be removed, so that the air is completely dry, it is then passed through an air dryer (6), to remove any remaining water.

The air then passes into a receiver tank (7), which acts as an energy storage unit, as well as settling any foreign matter that has managed to enter the system. In small systems without aftercoolers or dryers, the receiver tank also removes water particles. A safety valve (8) is fitted to the receiver to protect the system from overpressure.

From the receiver the air is piped to the mains air line (9), which transports the air to the various points of use throughout the factory. Before the air is allowed to enter any machine, it is passed through an air service unit (10), which has a filter to remove any scale or dirt, a pressure regulator to control the pressure to the machine, and a lubricator, which injects a fine mist of oil into the air to lubricate the pneumatic components of the machine.

The above description is for a typical air production unit, but it should be pointed out that there are many variations to this arrangement.

## Graphic Representation

To simplfy the drawing of air production units and pneumatic circuits, a system of graphic symbols is used. These symbols represent the system components, and when connected together, produce a simple diagram showing the operation of the circuit; this type of diagram is much easier to produce than the complex one shown in Figure 1.

Figure 2 is a graphic symbol diagram of the air production unit shown in Figure 1. (For a full list of all circuit

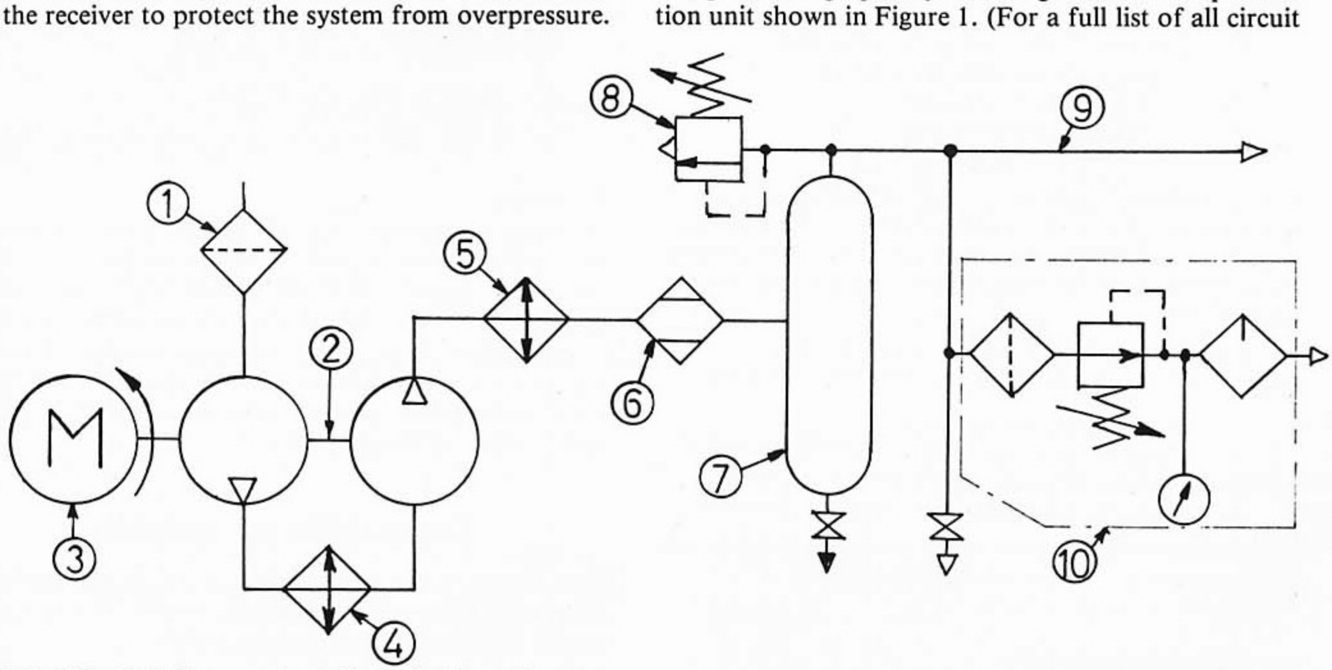



**Figure 2** Symbol diagram of an air-production unit

symbols AS1101 Part 1–1982 Graphic Symbols for General Engineering—Hydraulic and Pneumatic, should be consulted.)

## Air Production Components

The main components of the air production system are discussed in greater detail, below.

### Air Compressors

Air compressors not only vary greatly in size, but also design, Figure 3 shows the classification and types of compressor in general use today.

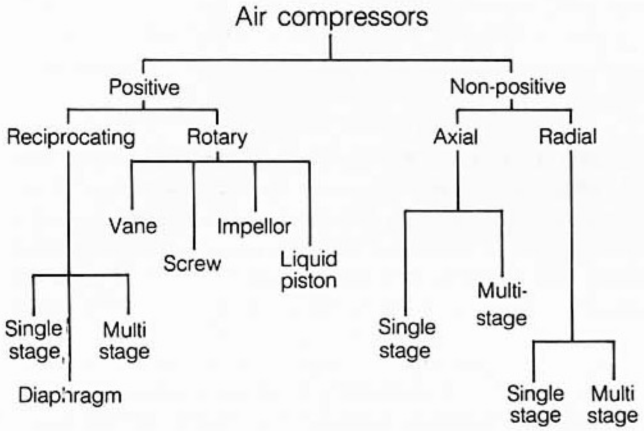



**Figure 3** Types of air compressor

#### *Rating air compressors*

Air compressors are rated as the volume of 'free' air pumped, in cubic metres or litres per second or per minute, and is determined by the formula:

$$\text{'Free' air delivery} = V_1 = \frac{P_2 \times V_2 \times T_1}{T_2 \times P_1}$$

where:

$P_1$ = actual atoms. pressure (kPa.abs)
$T_1$ = intake temp. (degrees kelvin)
$P_2$ = final pressure (kPa.abs)
$V_2$ = delivery volume (litres)
$T_2$ = final temp (degrees kelvin)

This gives the actual delivery of the compressor; however, makers quite often specify compressors by 'displacement', which is the calculated volume delivered using the physical dimensions of the compressor, as shown by the formula below:

$$\text{Displacement} = D = L \times A \times N$$

where:

$D$ = displacement (m³/min)
$A$ = area of cylinder (m²)
$L$ = stroke of piston (m)
$N$ = number of strokes per minute

The 'volumetric efficiency', of the compressor can be calculated from the above ratings, as follows:

$$\text{Volumetric efficiency} = \frac{\text{actual measurement intake air volume}}{\text{theoretical volume}}$$

#### *Power needed to compress air*

Shown below is the formula for the power (in kilowatts) needed to compress air:

$$\text{Power (kW)} = \frac{P_1 \times V}{60\,000} \times \frac{n}{(n-1)} \times \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1$$

Where:

$P_1$ = intake pressure (kPa.abs)
$V$ = 'free' air delivery (l/min)
$P_2$ = discharge pressure (kPa.abs)
$n$ = adiabatic index ($n = C_p/C_v$)

### Air Receivers

As previously stated, air receivers act as energy storages, and as such are pressure vessels, which require Department of Labour and Industry certification. Figure 4 shows a typical horizontal receiver with its normal fittings.

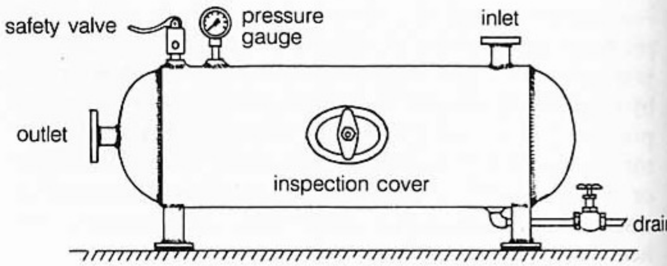



**Figure 4** A typical air receiver

#### *Sizing air receivers*

The size of an air receiver depends on the maximum and minimum pressure in the system, and the number of times the compressor is expected to on-load and off-load per hour, and is calculated from the formula shown below:

$$\text{Volume of receiver} = \frac{15 \times Q \times P_1}{(P_3 - P_2) \times Z} \ (\text{m}^3)$$

where:

$Q$ = delivery volume (m³/hr)
$P_1$ = atmos. pressure (kPa.abs)
$P_2$ = min. operating pressure
$P$ = max. operating pressure
$Z$ = no. switching cycles/hour (15 times max.)

### Air Mains

Air mains are the pipe lines that transport the compressed air throughout a factory, and are divided into two categories, namely 'ring' mains and 'dead-end' mains. Figure 5 shows the two systems incorporated together.

Caculating pipe sizes can be quite complex, depending on the size of the system and the number of outlets; it is therefore easier to use specific manufacturers' tables and graphs for this operation.

## Compressed air systems

This section will deal mainly with pneumatic machine circuits, and the components used in them. Any machine can be divided into three major parts:

- The pneumatic circuit components and plumbing.

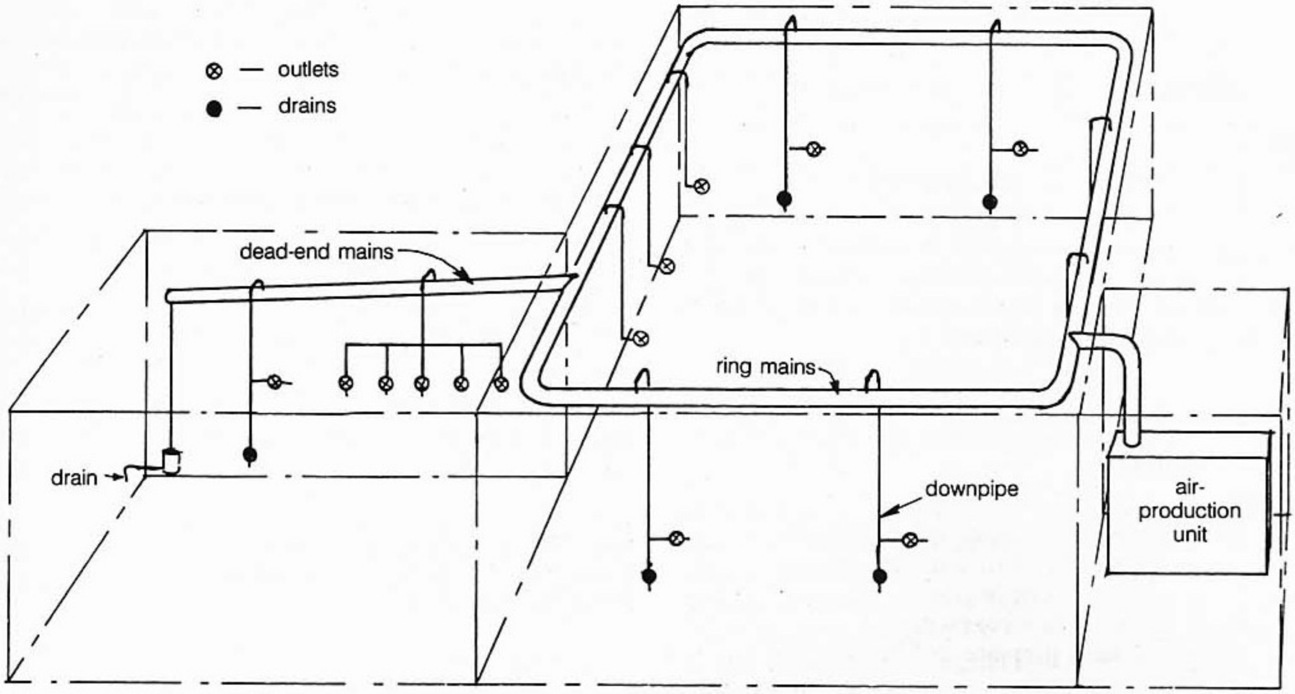



**Figure 5** Typical air mains

- The machine framework.
- Mechanical linkages and toolheads.

For ease of explanation, this section is dealt with in two parts—the basic circuit components and circuit development techniques.

## Basic Circuit Components

Basic circuit components fall into three categories—actuators, directional valves and ancillary valves.

### Actuators

Actuators are the output units or working ends of a pneumatic circuit. They translate the system energy into a usable commodity, by being able to exert forces and create motion, which allows machines to perform their assigned functions.

Actuators are usually classified as linear, rotary, or semi-rotary. There are many varieties of these main types as shown in Figure 6.

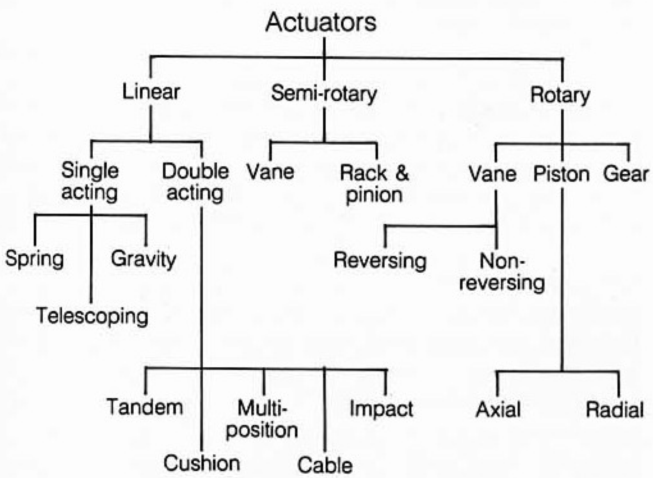



**Figure 6** Types of actuator

Figure 7a is a cross-sectional view of a typical linear actuator, showing its main parts, and Figure 7b is that of a rotary actuator.

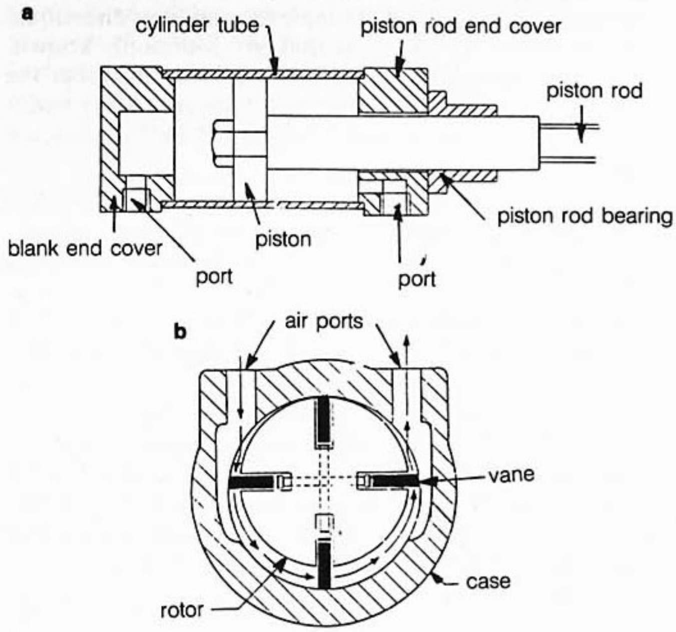



**Figure 7** Linear and rotary actuator in section

#### *Actuator calculations*

In order to choose an actuator for a particular job, the following data must be taken into account:

- Force output and speed, which are determined by calculation or physical test.
- Stroke, which is determined by how far a load has to be moved.
- Working pressure, controlled by factory air supply, which is usually between 600 and 800 kPa.G.

- Actuator diameter, which is calculated from the formula:

$$\text{Diameter} = \frac{F}{3.14 \times P} \text{ millimetres}$$

where:

$F$ = force output in kilonewtons
$P$ = air pressure in kilopascals

- Air consumption, is the amount of air to be compressed per minute to operate the actuator correctly, and for normal double-acting linear actuators, can be determined by the following formula:

$$\text{'Free' air delivery} = \frac{3.14(2D^2 - d^2) \times S \times N \times (P + 101.32)}{4 \times 101.32 \times 1000}$$

(litres/min)

where:

$D$ = diam. of actuator in centimetres
$d$ = diam. of rod in centimetres
$S$ = stroke in centimetres
$N$ = number of strokes/min
$P$ = working pressure in kPa.G

## Directional Control Valves

While actuators are the energy outputs, directional valves are energy directors. It is the job of the directional control valve to channel air to actuators or other directional valves or ancilliary valves, in a pre-determined order, so that the sequence of operations, or function of the circuit may be carried out. In logic terminology directional control valves, or DCVs as they are commonly known, are called 'memories' as it is their job to remember the switching functions of the circuit. There are many variations in type, design, and function, of DCVs; they are normally classified by:

- the number of positions the valve can be put in, or the number of variations in directional output;
- porting, which is the number of main airways entering or leaving the valve;
- actuation, which is the method by which the valve is operated; it may be manual, by air pilot or by solenoid etc.

A typical designation of a valve could be: 3/2, Push button, Spring return, which means that the valve has three ports—Pressure, output, and exhaust—is shifted to position two by a push button, and returned to position one by a spring when the button is released. The symbol diagram of this valve is shown in Figure 8.

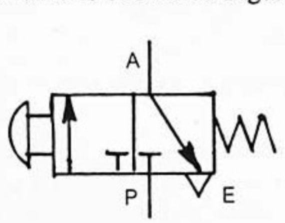



**Figure 8** Push button spring return symbol

There are many ways to actuate a valve, and Figure 9 tabulates these methods.

There are several different ways by which the flow direc-

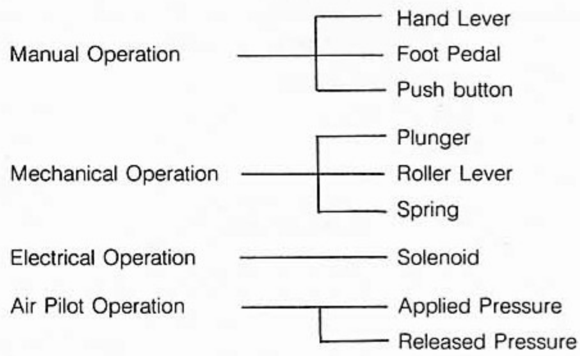



**Figure 9** Methods of actuating a valve

tion can be mechanically changed inside a valve, and cross-sectional views of three of the main methods are shown in Figure 10.

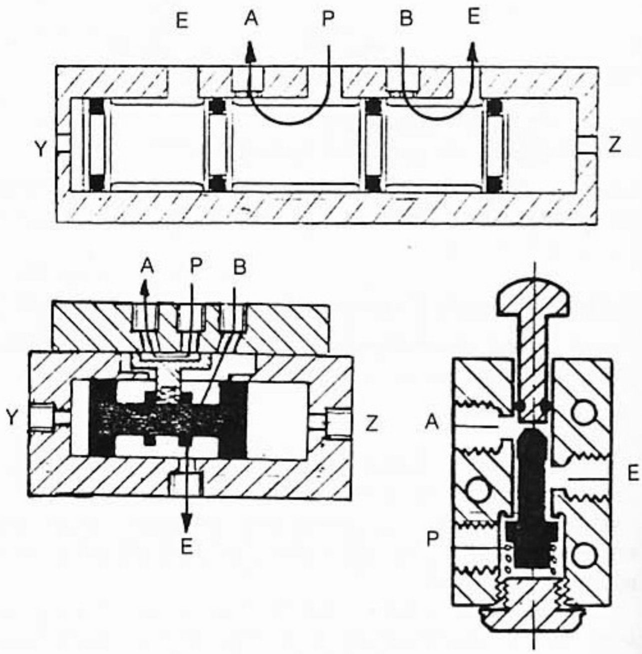



**Figure 10** Typical direction control valves

Sizes of valves depend on their function; if a DCV is operating an actuator, its port sizes will be the same as that of the actuator. If the valve is being used in the sequential part of a circuit, mini-valves can be used with very small port sizes such as $\frac{1}{8}$ or $\frac{1}{4}$ B.S.P.

## Ancilliary Valves

Ancilliary valves are those valves that perform special functions; examples are timers, counters, 'AND' and 'OR' logic gates, and sequence valves, the functions of which are described briefly below.

Timer This valve is initiated by an external pressure signal, and holds its output for the time pre-set on the manual control of the valve.

**Counter** This valve is initiated by an external pulse signal, and counts each pulse, until a manually pre-set number is reached, whereon it produces an output signal, and cancels the count.

**'AND' gate** This is a logic element, which has two inputs and one output and requires a signal at both Input AND Input B, before it will produce an output.

**'OR' gate** This is a logic element, in which a signal at Input A *or* Input B will produce an output.

**Sequence valve** This valve produces an output, when a pre-set pressure input occurs.

## Circuit Development Techniques

For development of a pneumatic circuit for any machine, the circuit can be broken down into three major sections, or sub-circuit groups, as shown in Figure 11. The 'fringe' circuit controls the START/STOP functions, while the 'sequential' or 'memory' circuit controls the sequence of events in the circuit, and the 'power' circuit controls the working end of the circuit.

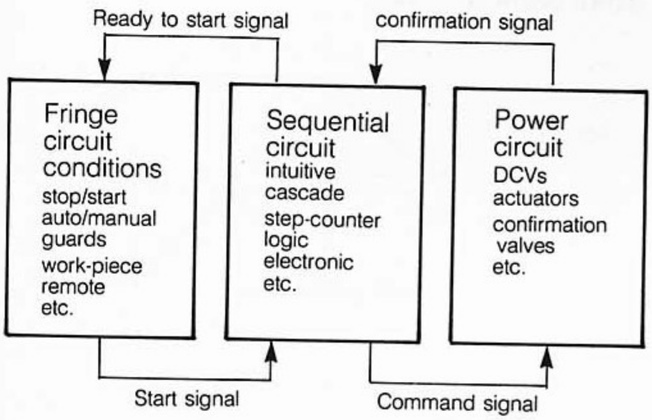



**Figure 11** Major circuit groups

In simple terms, a sequence step command is issued from the sequential circuit to the power circuit to perform a sequence step.

When this is completed, the power circuit sends a confirmation signal back to the sequential circuit to confirm that the step has taken place. These commands and confirmation signals are air pressure signals emanating from valves within each circuit section. On receiving a confirmation signal, the sequential circuit produces another sequence step signal. When the end of the sequence is reached the sequential circuit sends a 'ready to start' signal to the fringe circuit.

If all conditions of the fringe circuit have been satisfied, it will send a 'start' signal back to the sequential circuit, to restart the next cycle.

In small circuits, the sequential circuit may consist of one valve, and so may the fringe circuit. In larger circuits, however, each circuit may contain many valves.

The key to circuit development is in the set-up of the power circuit. Each actuator in the circuit, has a command valve which causes it to extend or retract, and also valves or sensors to indicate its retracted or extended position. Signals to command or confirm are coded, using letters and numbers as shown in Figure 12.

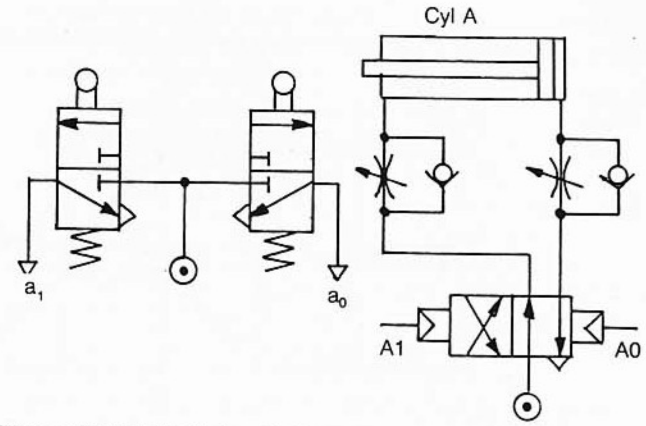



**Figure 12** Typical circuit diagram

Actuators are marked A, B, C, etc., with capital letters denoting command input signals, lower case letters for confirmation signals, and the binary coding '1' for extend, and '0' for retract. Thus a signal coded A1 is a command signal to the A actuator DCV to extend actuator A, and $a_1$ is the confirmation signal that in fact actuator A has extended.

The use of 1 and 0 is a binary number code where:

1 = ON, YES, EXTENDED, OPERATIONAL, etc.

0 = OFF, NO RETRACTED, NON-OPERATIONAL, etc.

In machine circuits, where there are a number of actuators, which extend and retract, in a given order, a 'step sequence statement' can be written; this is a series of command orders, in the following order:

A1 – B1 – C1 – B0 – C0 – A0

This now represents a mathematical statement of the order of actuator movement, and may be read as: 'Actuator A, is to extend, followed by Actuator B, then Actuator C; Actuator B will retract, followed by Actuator C, then Actuator A.'

When two or more actuators move at the same time it is written thus:

A1 – B1 – C1 – B0 – A0/C0

From the sequence statement, a step-displacement diagram can be drawn. This diagram gives an overall picture of the circuit sequence including all the actuator movements, command signals and confirmation signals. The key underneath the displacement diagram is used to indicate the status of the confirmation signals and, as will be seen later, is used to develop the sequential part of the circuit.

This diagram is also known by the following names, 'traverse-time diagram', 'sequence-step diagram', and 'step-motion diagram', and a typical example of this type of diagram is shown in Figure 13.

The letters and numbers in the key represent the status of the outputs of the confirmation valves, and the numbers at the top represent the sequence steps. Thus in step 2, confirmation valve $a_1$, $b_0$, and $c_0$ are producing outputs. The confirmation signals and command signals may be pneumatic or electrical, depending on whether the circuit is purely pneumatic or is electro-pneumatic.

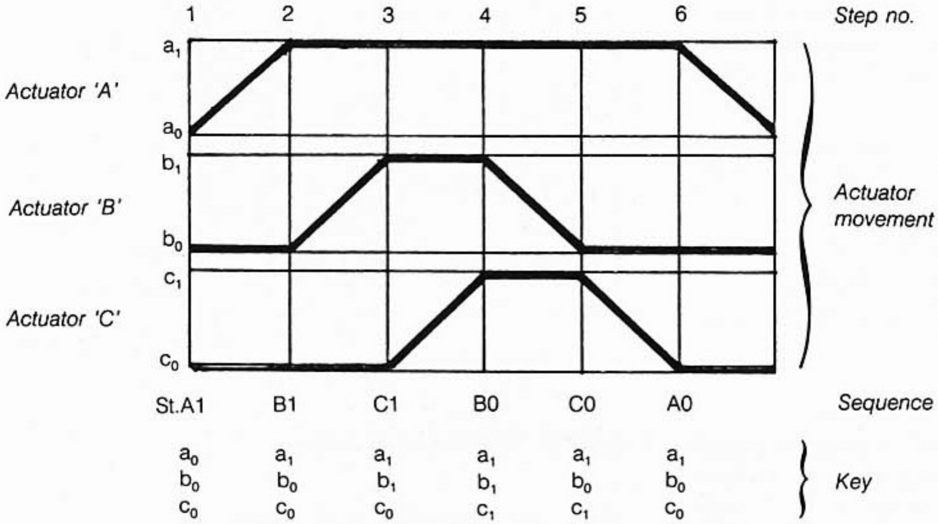



**Figure 13** Step displacement diagram

The step-displacement diagram can now be used to develop the sequential part of the circuit. There are many methods of developing sequential circuits and the diagram is used differently, according to each method, to produce what is known as a 'switching equation'. This is a statement of connection between components, so that the sequence will be carried out in the correct order. An example would be: A1 = $C_0$. Start.

This means that the ouput of confirmation valve $c_0$ is connected through the 'start' valve to the pilot A1, so that, if actuator C is retracted, and the 'START' button is pushed, the command valve for actuator A will shift, and the actuator will extend.

The various methods of developing sequential circuits are as follows:

- Intuitive—this method uses pulse-type confirmation signals to eliminate any possible opposing signals in the circuit.
- Cascade—this method breaks the sequence into groups, where there are no two command letters the same. This avoids possible opposing signals.
- Step-counter (shift-register)—this method uses a memory for each step, which produces a command signal, a pre-setting signal to the next step, and a resetting signal to the last step, so that only one command pilot has pressure at any given time.
- Electro-pneumatic—this method uses electrical micro-switches for confimation, and solenoid-operated command valves, and the above methods can be developed using electrical relays, electronic sequencers, or program logic controllers.

Since it is not possible here to examine in detail all the above methods, an example of circuit development technique will be given using the step-counter method.

*Stage 1—The sequence*

In any sequence, the first actuator to move is designated A, and the second B and so on. From this the sequence can be determined. Using the following sample sequence, the complete circuit will be developed.

Sequence: A1 – B1 – B0 – A0

*Stage 2—The motion step diagram*

The diagram for the above sequence is now drawn, as shown below (Fig. 14).

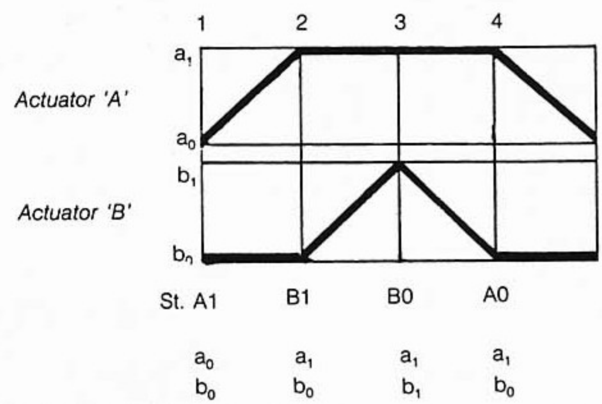



**Figure 14** Motion step diagram

*Stage 3—The switching equations*

The switching equations are now extracted from the above diagram, using the circled confirmations, which gives us all the connections necessary in the circuit.

| *Step counter inputs* | *Command valve inputs* |
|---|---|
| Step 1 = $a_0$. Start | A1 = Output of Step 1 |
| Step 2 = $a_1$ | A0 = Output of Step 4 |
| Step 3 = $b_1$ | B1 = Output of Step 2 |
| Step 4 = $b_0$ | B0 = Output of Step 3 |

*Stage 4—The circuit diagram*

From the motion step diagram and the switching equations, it can be seen that the circuit requires the following components:

- 2 linear actuators
- 2 pilot/pilot 4/2 command DCVs
- 4 pilot/pilot 3/2 counter DCVs
- 4 'AND' valves
- 4 roller/spring 3/2 confirmation DCVs
- 1 push button/spring 3/2 start DCV

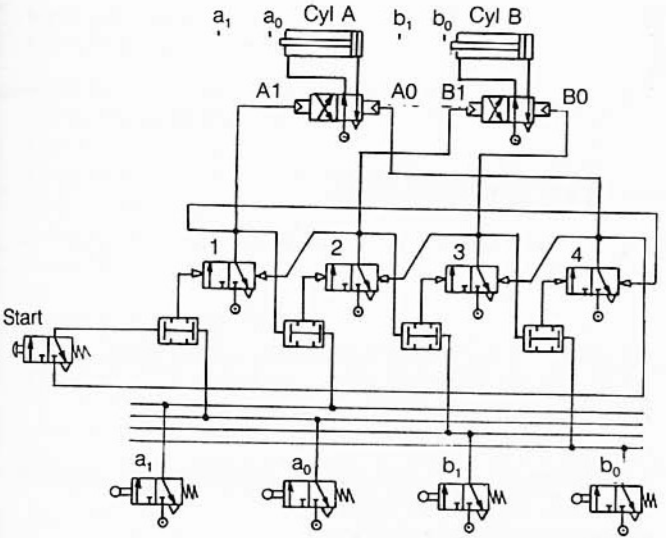



**Figure 15** Circuit diagram

These valves are first neatly drawn, with proper spacing, then connected by using the switching equations, as in the finished circuit shown in Figure 15.

Provided that actuator A is retracted, $a_0$ will produce a signal to the AND valve, and when START is pushed, the AND valve will produce an output to the 3/2 valve. This will create an output to A1, preset Step unit 2 and reset Step unit 4. Actuator A extends to operate $a_1$, which is connected to the AND valve of the second step unit, which already has a signal from the first unit. On arrival of the $a_1$ signal the second step memory switches, producing an output, B1, and also resets Step unit 1, and presets Step unit 3. $b_1$ initiates Step unit 3, which resets 2, presets 4, and gives the command B0. The confirmation signal $b_0$ activates Step 4, making Actuator A retract, thus completing the circuit sequence.

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# Fluid power — Hydraulics

## History

Traditionally, the use of water or air to produce power depended on the movement of vast quantities of fluid at relatively low pressures. Nature supplied this pressure. However, it is only during the past hundred years that pumps and compressors have been developed to produce artificial pressures far in excess of that provided by nature.

Fluid power technology began in 1650 with the discovery of Pascal's law. Simply stated, this law says that pressure in a fluid at rest is transmitted equally in all directions.

Fluid power became prominent as the means of powering presses, cranes, winches and extruding machines (at this stage electrical energy had not been developed to power the tools of industry). The emergence of electricity, in the late 19th Century, resulted in the neglect of fluid power.

Due to certain disadvantages of electrical and mechanical systems for transmitting power, hydraulic systems again were in demand at the end of the 19th century.

Some of the important dates involving the history of fluid power are the following:

1650 Discovery of Pascal's law (Pascal was 27 years old).
1750 Berndulli developed a law concerning the conservation of energy in a flowing fluid.
1790 Joseph Bramah developed the first hydraulic-powered press using water as the means for transmitting power.
1850 Fluid power (water) became prominent in industry (England).
1868 Both London and Manchester had central industrial hydraulic distribution systems (water).
Late 19th Century—emergence of electricity.
1900 It was apparent that electrical systems had certain disadvantages.
1906 Oil was replacing water as the hydraulic medium.
1926 United States developed the direct hydraulic system, that is, self-contained units.

From the 16th and 17th Centuries, hydraulic power has developed, slowly at first, until today, when there is hardly a product available that does not involve the use of hydraulics in either the manufacturing or distribution process.

## Features of hydraulic systems

Hydraulics offer over-all flexibility in power transmission. Hydraulics has had limitations but as the limitations decrease, the applications increase to give today's industry an almost unlimited scope for future developments.

Hydraulic system design features include:

- simplicity in design;
- simplicity of operation, that is, speed control, pressure control, directional control;
- suitability for automation;
- variety of output forces available;
- durability of the system, due to:
  - self lubrication
  - protection under overload conditions
  - minimal vibration
  - indefinite variability of acceleration and deceleration;
- ease of systematic modernization of equipment as technology progresses;
- efficient and economical operation.

With such an array of outstanding features, the full potential of hydraulic power and transmission has not yet been realized and no doubt, in the future, we shall see an ever increasing variety of fluid power and transmission applications. Today's general term 'hydraulic power' commonly refers to power hydraulics in which hydraulic oil is used under controlled pressure and flow to do work in the forming and manufacturing of industrial products. In fact, many people today recognize the precision of today's system to such a degree that they wish to call this area of development 'control engineering'.

Some fields of application are listed below:

Industrial Pressure range 2000 to 35 000 kPa:
- surface grinding machines;
- hydraulic presses;
- transfer machines (sawmills, canneries);
- lathe tool feeding (copy turning);
- cylindrical grinding machines;
- milling machines;
- fork lifts;
- lifting cranes.

Agricultural Pressure range 4000 to 21 000 kPa:
- trench-digging equipment;
- bulldozers
- harvesting equipment;
- tractor attachments;
- front-end loaders;
- post-hole diggers;
- wool presses;
- earth-moving scrapers.

Aeronautical Pressure range 7000 to 56 000 kPa:
- landing gear (mechanisms and covers);
- wing control surfaces;

- rudder control;
- drive brake actuation.

Automotive Pressure range 0 to 14 000 kPa:

- braking systems;
- power steering;
- automatic transmission;
- clutch control;
- convertible hood raising and lowering;
- shock absorbers.

## Properties of Fluids

A fluid is anything that flows—liquid or gas. A fluid:

- is infinitely flexible, yet as unyielding as steel (liquid state);
- is considered incompressible to 7000 kPa or 7 mPa but above this will compress 0.5% for every extra 7000 kPa (liquid state);
- can readily change its shape;
- can be divided into parts to do work in different locations;
- can move rapidly in one place and slowly in another;
- can transmit force in any or all directions and the force acts at right angles to surfaces containing the fluid.

## Advantages of Hydraulic Power

Hydraulic power is used in almost every branch of industry. It is equally at home on a machine tool, a car, a tractor, an aeroplane, a missile or man-made satellite, a boat, or a bread-making machine.

No other medium combines the same degree of positiveness, accuracy, and flexibility of control, with the ability to transmit a maximum of power in a minimum of bulk and weight.

## Some Problems and Limitations

- Fluid power systems need special structural organization.
- Strong tubes and containers need to be used.
- Leaks must be prevented—this problem is acute with high pressure.
- Fluid movement causes friction against containing surfaces and if excessive can lead to loss of efficiency.
- Foreign matter must not be allowed in the system. (Chemical action may produce sludge and corrosion or oxidation; air in oil causes aeration, and oxygen may produce oxidation.)

## Basic Units and Formulae

### Head Pressure

Head pressure is the vertical distance between two levels in a fluid and is expressed in kilopascals (kPa).

Each metre of water is equivalent to 9.8 kPa.
Each metre of oil is equivalent to 8.4 kPa.

### Basic Terms

The basic terms used to categorize hydraulic systems are: force, pressure, area, work, power and efficiency.

Force Force, as applied to hydraulics, may be defined as any cause that tends to produce or modify motion.

To move an object, such as a machine-tool head, force must be applied to it. The amount of force required depends on the object's inertia. Force is commonly expressed in newtons or kilonewtons.

Pressure Pressure is force per unit area, and it is usually expressed in terms of newtons per square metre ($N/m^2$), pascals (Pa), kilopascals (kPa). 1000 $N/m^2$ = 1 kPa.

Area Areas involved in hydraulics are usually measured in square metres.

The relationship between force and pressure may be demonstrated by considering the earth's atmosphere. The blanket of air enveloping the earth's surface is of such a volume that its total weight could be measured in tonnes. However, the force exerted by the weight of a column of air one square metre in cross-sectional area is 101.325 kN at sea level. Thus, atmospheric pressure at sea level is 101.325 kPa.

The relationship between force ($F$), pressure ($P$) and area ($A$) is expressed mathematically by the use of the force triangle (Fig. 1).

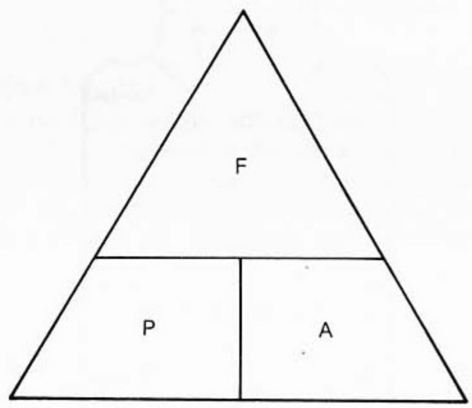



Figure 1 The force triangle

$$F = P \times A$$

$$P = \frac{F}{A}$$

$$A = \frac{F}{P}$$

where:

$F$ = force in newtons
$P$ = pressure in pascals
$A$ = area in square metres.

Work Both force and pressure are primarily measures of effort. Work, however, is a measure of accomplishment.

It describes the application of a force moving through a distance, and is commonly expressed in terms of joules.

Thus, if a force of 3600 N moves a ram 0.5 m, the work accomplished can be calculated as follows:

$$\begin{aligned} \text{Work } (W) &= \text{force } (F) \times \text{distance } (D) \\ &= 3600 \times 0.5 \\ &= 1800 \text{ joules} \end{aligned}$$

This concept of work makes no allowance for the time factor.

Power Power is work per unit time, the kilowatt (1000 watts) is the standard unit of power. One watt is the amount of power necessary to accomplish one joule of work in one second.

In the above example, if the time taken to do the same work was six (6) seconds, then the power required:

$$= \frac{\text{force} \times \text{distance}}{\text{time}}$$

$$= \frac{3600 \times 0.5}{6}$$

$$= 300 \text{ W or } 0.3 \text{ kW}$$

Pascal's law Pascal's law states that pressure at any one point in a static liquid is the same in every direction and exerts equal force on equal areas (see Fig. 2).

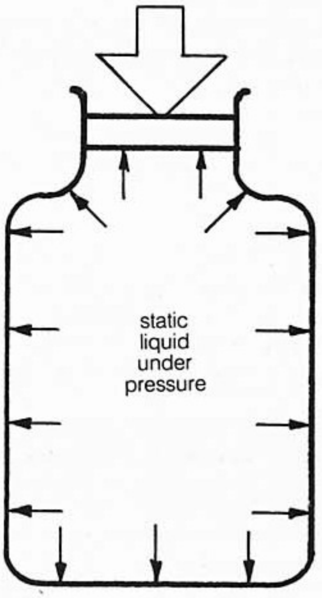



**Figure 2** Liquid under pressure

# Classes and properties of hydraulic fluids

## Classes

Liquids used in hydraulic systems can be classified into three groups:

- water-based liquids;
- petroleum-based liquids;
- synthetic-based liquids.

### Water-based Liquids

Although water was the first hydraulic medium used, its use in present-day industry is usually limited to large commercial hydraulic installations that require high pressures and low operating speeds.

As a hydraulic liquid, water presents many problems, five major problems being:

- rust and corrosion;
- ineffective lubrication;
- temperature variation;
- foreign matter in the water—abrasive action;
- relatively low boiling point.

All of the above factors are detrimental to the operating efficiency and long service life of the equipment.

Water has ideal fire resistance and it may well be beneficial to use it from the standpoint of availability and cost.

Through the addition of soluble oils or other materials, water can be made suitable for special applications where large quantities of fluid are essential, or for working hot materials where a fire hazard exists.

### Petroleum-based Liquids

One of the first oils used as a hydraulic liquid was a petroleum-based automotive brake fluid. However, its use was limited because the natural rubber seals and packings in use were not compatible with petroleum-based oils.

Advancement in packing materials, such as the use of synthetic rubber seals, has permitted the extensive use of petroleum-based liquids in modern industry.

The petroleum refiner is capable of producing oils of almost any viscosity. Additives also provide other desirable characteristics, which prolong the life expectancy of hydraulic machines and increase their efficiencies.

### Synthetic-based Liquids

Petroleum-based oils contain most of the desired properties required of a hydraulic liquid. However, they are flammable under normal conditions and can become explosively dangerous when subjected to high pressures and a source of flame or high temperatures.

In recent years, non-flammable synthetic liquids have been developed for use in hydraulic systems where fire hazards exist. A synthetic material is a complete chemical compound that has been artificially formed by the combining of two or more simpler compounds or elements.

Some of the synthetic liquids currently used as hydraulic mediums are chemically described as phsophate esters, chlorinated biphenyls, or blends of each. Certain synthetic liquids have been found to attack packings used in hydraulic systems, so special packings are normally required when these fluids are used.

## Properties

If incompressibility and fluidity were the only qualities required, any liquid not too thick might be used in a hydraulic system. However, a number of other properties are of prime importance: viscosity, lubricating power, chemical stability, freedom from acidity, ability to resist high temperatures, and minimum toxicity.

### Viscosity

Viscosity is one of the most important properties of liquids used in hydraulic systems and may briefly be defined as a measure of flowability at a given temperature.

Comparing the velocity of two liquids—petrol flows easily, has low viscosity; tar flows slowly and has high viscosity.

#### *Measurement of viscosity*

The viscosity of a liquid can be measured with an instrument called a viscosimeter. Figure 3 shows a Saybolt viscosimeter.

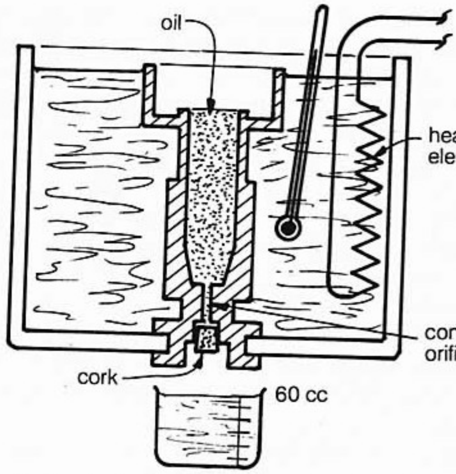



**Figure 3** Saybolt viscosimeter

This instrument measures the time in seconds for a fixed quantity of liquid (60 cm³) to flow through a small orifice of standard length and diameter at a specific temperature. For example, the viscosity of a certain liquid could be 80 seconds, Saybolt Universal (80 SSU) at 55°C.

### *Viscosity index*

One of the properties of an ideal hydraulic liquid would be that of retaining the same viscosity under all temperatures and pressures to which it is subjected. Many liquids, particularly petroleum-based oils, do not have this characteristic. As the temperature increases, the oil becomes thinner, that is, the viscosity decreases; as the temperature decreases, the oil thickens—the viscosity increases.

By adding certain polymers to the hydraulic oil, the viscosity index can be markedly improved, that is, the oil will have the ability to be thin and free flowing when cold but also will not thin out further as the temperature increases and thus will maintain a lubricating film between moving components.

### Lubricating Power

If motion takes place between surfaces in contact, friction tends to oppose the motion. When pressure forces the liquid of a hydraulic system between the moving surfaces, the liquid spreads out into a thin film, which lubricates the area, enabling the parts to move freely. Different liquids vary, not only in lubricating ability, but also in film strength. Film strength is the capacity of a liquid to resist being wiped or squeezed out from between surfaces when spread out in an extremely thin layer. A liquid will no longer lubricate if the film breaks down.

Lubricating qualities and film strength can be improved by the addition of certain chemical agents.

### Chemical Stability

Chemical stability is defined as a liquid's ability to resist oxidation and deterioration for long periods.

One of the major causes of deterioration of hydraulic liquids is excessive temperatures. It is important to realize that the temperature of the oil in the reservoir is not always an indication of all operating temperatures.

Localized hot spots can occur in such places as bearings, gear teeth, or at a point when liquid under pressure is forced through a small orifice.

Liquids may 'break down' if exposed to air, water, salt, or other impurities, especially if they are in constant motion or subjected to heat.

Some metals, such as zinc, lead, brass and copper, have an undesirable chemical reaction on certain liquids.

### Freedom from Acidity

The degree of acidity of a hydraulic fluid when new may be satisfactory, but most liquids cannot remain completely non-corrosive under severe operating conditions.

After use, the liquid may develop corrosive tendencies as it begins to deteriorate. Periodical testing of the liquid is essential.

### Ability to Resist Excessive Rise in Temperature

A liquid's flash point is the temperature at which it gives off vapour in sufficient quantity to ignite momentarily or flash when a flame is applied. A high flashpoint is desirable for hydraulic liquids because it indicates a good resistance to combustion, and a low degree of evaporation at normal temperatures.

### Minimum Toxicity

Hydraulic fluids ideally should have none or minimal toxicity. Most hydraulic liquids are free from toxic materials. However some, for example fire resistant liquids, are toxic. Containers of such liquids must be properly labelled and the liquid itself carefully handled.

# Hydraulic pumps

Fundamentally, the pump's function is to push on the hydraulic fluid and create flow. But to create pressure there must be resistance to flow. Further, if the resistance is a load on an actuator, only enough pressure is created to handle the load.

While the pump causes the fluid to flow, where the flow goes depends on the other parts of the system. A restriction in a pipe will cause pressure in the pipe.

## Types of Pump

There are two basic types of hydraulic pump.

A positive-type pump is one in which the inlet of the pump is sealed from the outlet. This means that there is some kind of valve mechanism between inlet and outlet ports.

A non-positive type pump is one in which the inlet and outlet of the pump are connected hydraulically.

### Positive-type Pumps

Positive-type pumps may be:

- Piston type—radial, axial, in-line, or hand-type (hollow piston).
- Gear type—internal and external.
- Vane type—unbalanced, balanced.
- Gerotor type.

### Non-positive Type Pumps

These may be:

- Centrifugal type—impellor, low-pressure high-volume

flow. The volume delivered depends on speed and resistance at the discharge side.
• Axial flow type—jet boat.

## Pump Displacement

Displacement is the amount of liquid transferred from the pump inlet to the outlet in one revolution or cycle.

For a rotary pump, displacement is expressed in litres per revolution.

For a reciprocating pump, displacement is expressed in litres per cycle.

If the pump has more than one pumping chamber, the pump displacement is equal to the displacement of one chamber multiplied by the number of chambers.

Thus if a rotary pump has eight pumping chambers, each with a displacement of 2.5 ml (millimetres), then the total pump displacement is:

$$2.5 \times 8 = 20 \text{ ml or } 0.02 \text{ L per revolution}$$

## Some Examples of Pump Types

### Gear Pumps

Gear-type pumps operate on the very simple principle that as gears revolve, fluid trapped between the gear teeth and the housing is carried from the suction side to the discharge side of the pump (Fig. 4).

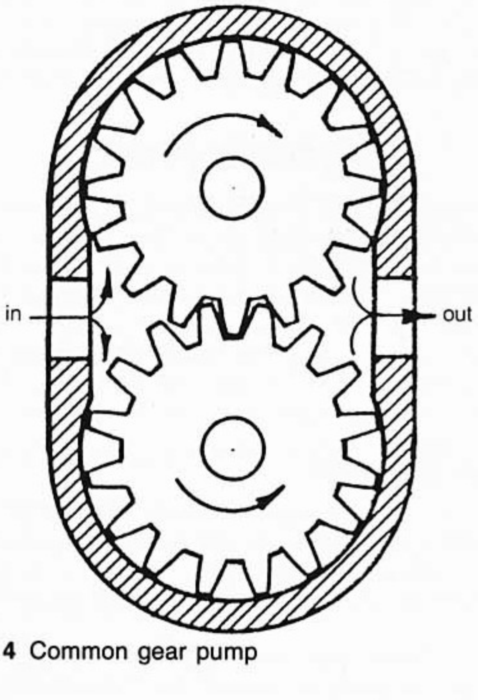



**Figure 4** Common gear pump

Fluid from the discharge side is prevented from returning to the intake side by the close meshing of the two gears, and the small clearances between the gears and housing (0.06 mm).

The maximum pressure that can be developed with gear pumps depends on the design and internal pump clearances—basically, the fit between the gears and the housing. Pumps of this type have been used to produce pressures as high as 30 MPa but normally they operate at pressures of 15 MPa or less. Gear pumps, when driven at constant speed, are capable of discharging only a constant volume of oil. Capacities of currently available pumps range from fractional litres per second to over 10 litres per second.

Spur gears used in pumps tend to give pulsations of fluid and so where a smoothness of flow is required, helical or double helical gears are used.

#### *Gerotor gear pump*

This pump is a special type of gear pump and consists of two lobed gears turning in the same direction around different centres, the small externally toothed gear being located inside the larger internally toothed gear (Fig. 5). The inner driving gear has one tooth less than the outside gear and thus a difference in angular velocity is established.

Fluid enters the pump as the teeth move towards tip-to-tip contact and the fluid is expelled from the unit at the point where the teeth approach tip-to-root contact.

In addition to industrial hydraulic systems the pumps are also used in many applications where good lubrication is necessary.

To determine the delivery per revolution, the volume of the 'missing tooth' multiplied by the number of teeth will give the required information. However, mathematically this is rather involved and a burette may be used to obtain the required volume.

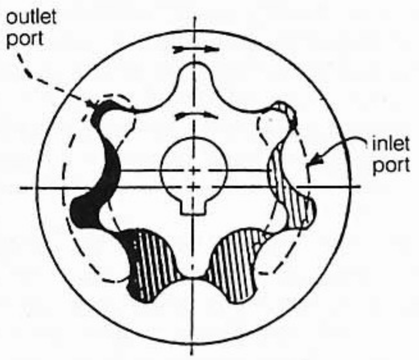



**Figure 5** Gerotor gear pump

#### *Internal gear pumps*

This type consists of an external gear directly coupled to the drive shaft of the pump and placed off-centre in relation to the internal gear (Fig. 6).

The two gears mesh on one side of the pump chamber, between the suction and the discharge.

On the opposite side of the chamber a crescent-shaped form stands in the space between the two gears in such a way as to provide a close tolerance to them both.

The rotation of the centre gear by the shaft causes the outside gear to rotate, since the two are in mesh. Everything in the chamber rotates except the crescent, causing liquid to be trapped in the gear spaces as they pass the crescent. The liquid is carried from the suction to the discharge, where it is forced out of the pump by the meshing of the gears. As the liquid is carried away from the intake side of the pump, the pressure is diminished, and liquid is forced in from the source of supply (by atmospheric pressure).

The size of the crescent that separates the internal and external gears is the determining factor in the volume

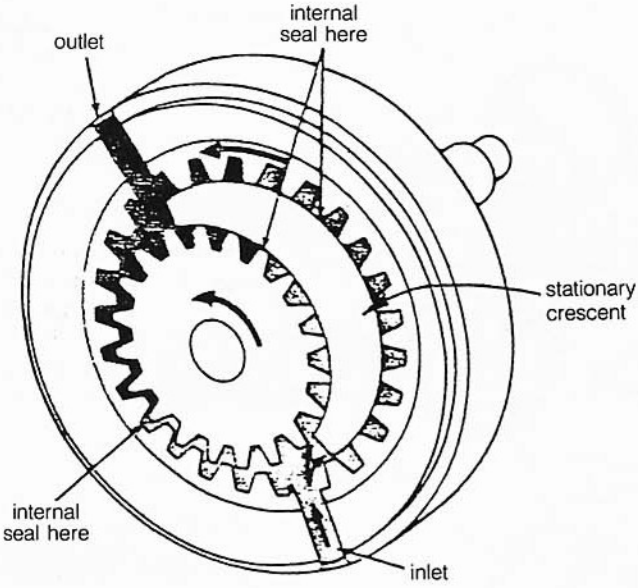



**Figure 6** Internal gear pump

delivery of this pump. A small crescent allows more volume of fluid per revolution than a larger crescent.

One interesting feature of this type of pump is that the direction of flow can be reversed without changing direction of rotation by moving the internal gear so that it bears on the other side of the external gear. The crescent is located on two dowels and may be changed from one side of the pump housing to the other. Flow is then reversed.

## Vane Pumps

In the vane-type pump a slotted rotor splined to a drive shaft rotates between closely fitted side plates, and inside an elliptical or circular shaped ring. Polished, hardened vanes slide in and out of the rotor slots and follow the ring contour by centrifugal force. (Fig. 7.)

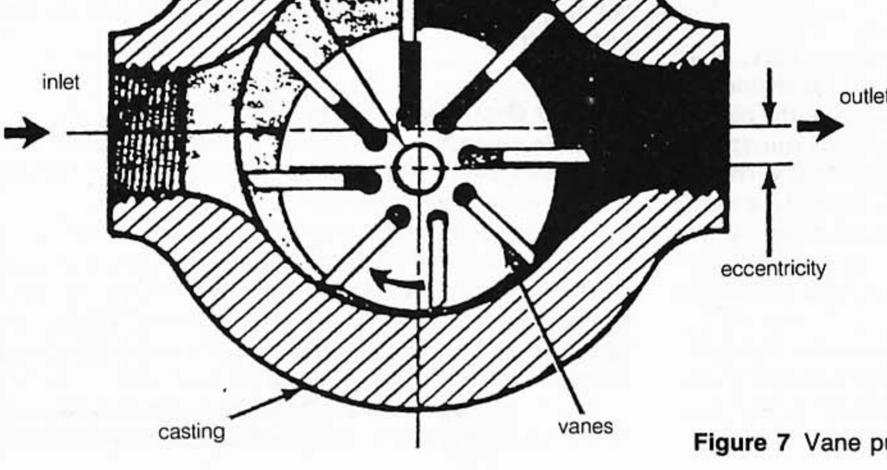



**Figure 7** Vane pump

Pumping chambers are formed between succeeding vanes, carrying oil from the inlet to the outlet. A partial vacuum is created at the inlet as the spaces between the vanes open.

The oil is squeezed out at the outlet as the pumping chamber size decreases.

### *Balanced vane pump*

The balanced vane pump uses a stationary, elliptical cam ring and has two sets of ports internally (Fig. 8).

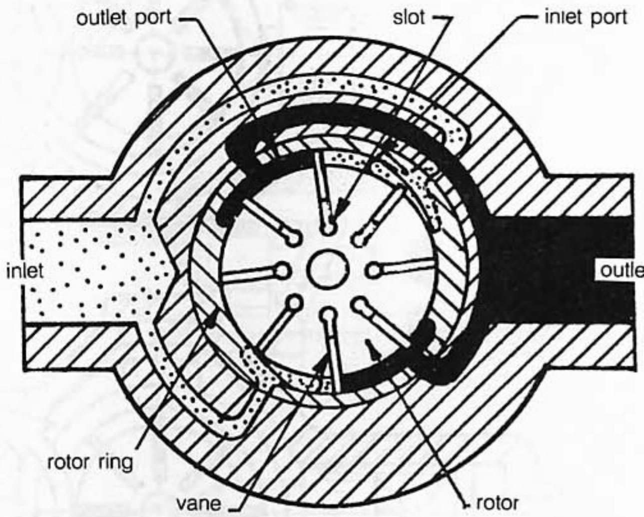



**Figure 8** Blanced vane pump

A pumping chamber is formed between any two vanes twice in each revolution.

The two inlets are 180° apart. The two outlets are also 180° apart. Thus, back pressures against the edges of the rotor cancel each other. Large displacements can be obtained with a relatively small pump assembly size.

*Unbalanced vane pump*

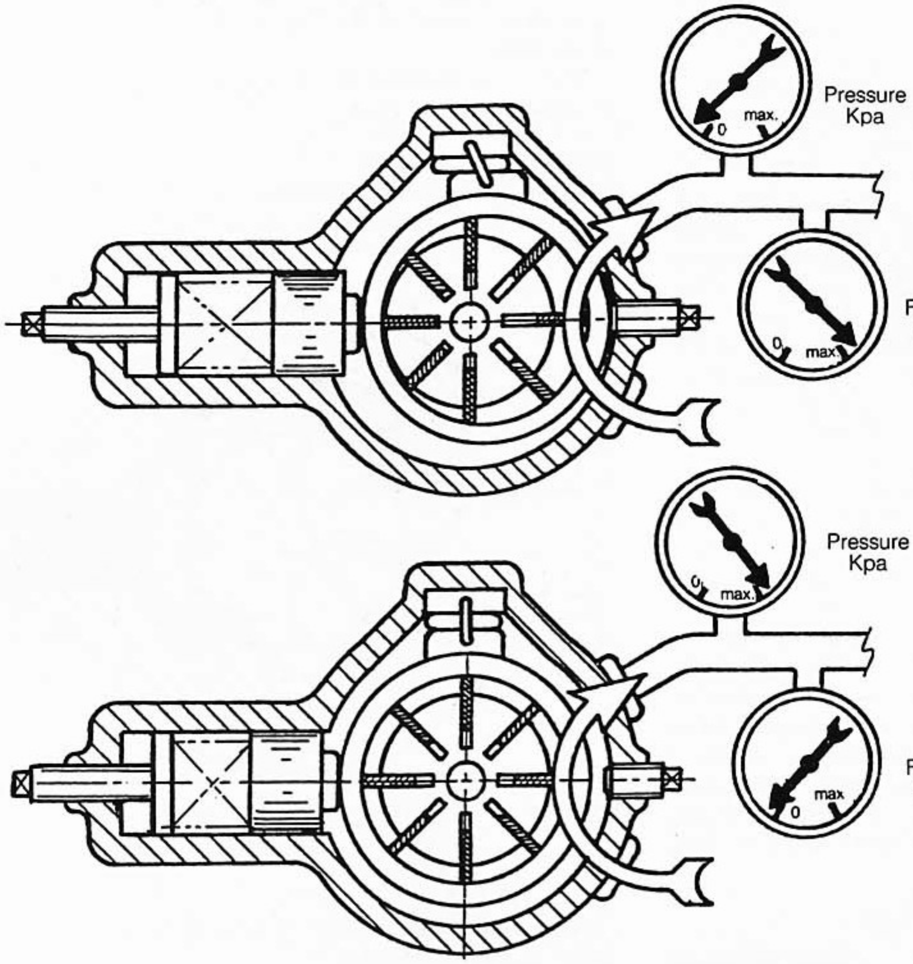



**Figure 9** Unbalanced vane pump

In the variable volume (pressure compensated) unbalanced vane pump shown in Figure 9, a basic principle is involved. In the top diagram, the maximum flow condition is occurring when the restriction flow is at a minimum on the outlet side of the pump. As the restriction builds up due to a cylinder load being applied, pressure is sensed internally in the pump, which pushes the track ring to the left against the spring, until it takes up the position shown in the bottom diagram; maximum pressure is maintained but flow drops off to just enough to cover any leakage at the work cylinder.

## Axial Piston Pumps

In axial piston pumps, the pistons stroke axially, or in the same direction as the cylinder block centerline.

In one type of axial pump, reciprocation of the pistons is caused by a swash plate, which the pistons run against as the cylinder block rotates. The drive shaft turns the cylinder block, which carries the pistons around the shaft.

The piston shoes slide against the swash plate and are held against it by the shoe plate.

The angle of the swash plate causes the pistons to reciprocate in their bores.

At the point where a piston begins to retract, the opening in the end of the bore slides over the inlet slot in the valve plate and oil is drawn into the bore through somewhat less than half a revolution.

Then there is a solid area in the valve plate as the piston becomes fully retracted.

As the piston begins to extend, the opening in the cylinder barrel moves over the outlet slot and oil is forced out through the pressure port.

In this type of pump (Fig. 10), where the cylinder block rotates and the swash plate remains stationary, pressure is limited by the necessity to use plate valves, but the delivery can be varied or reversed by changing the angle of swash.

A bearing plate on the front of the swash plate rotated at the same speed as the cylinder block receives the piston thrust.

### *Variable displacement axial piston pumps*

Variable-volume reciprocating-piston type pumps are commonly used for applications requiring high pressures and accurate control of the discharge volume.

In this type of pump a mechanism is built into the housing in such a way that the angle between the centreline of the cylinder block and drive shaft can be varied. If the angle is fixed, the pump is a constant-delivery type; however, if the angle is adjustable, then the delivery of the pump is variable from zero to its maximum. (Fig. 11.)

To vary displacement from zero to maximum a mechanical hand wheel control may be fitted to the pump

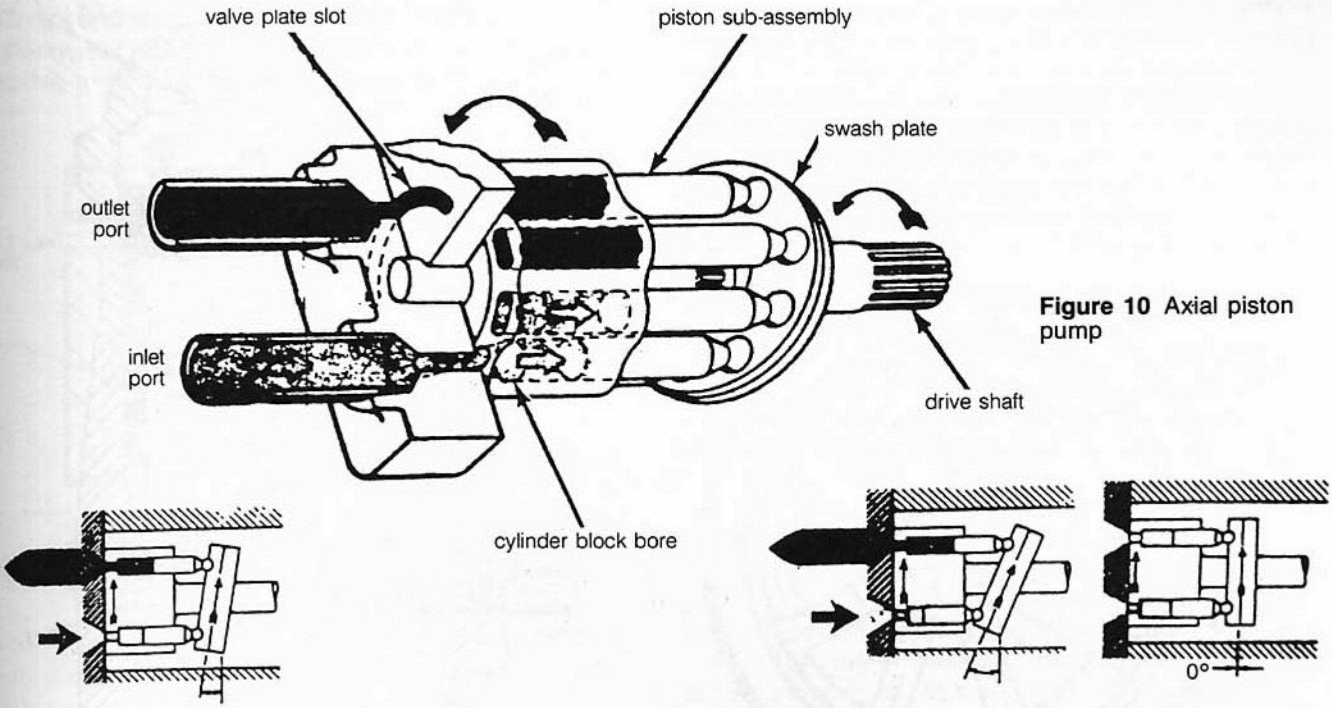



**Figure 10** Axial piston pump

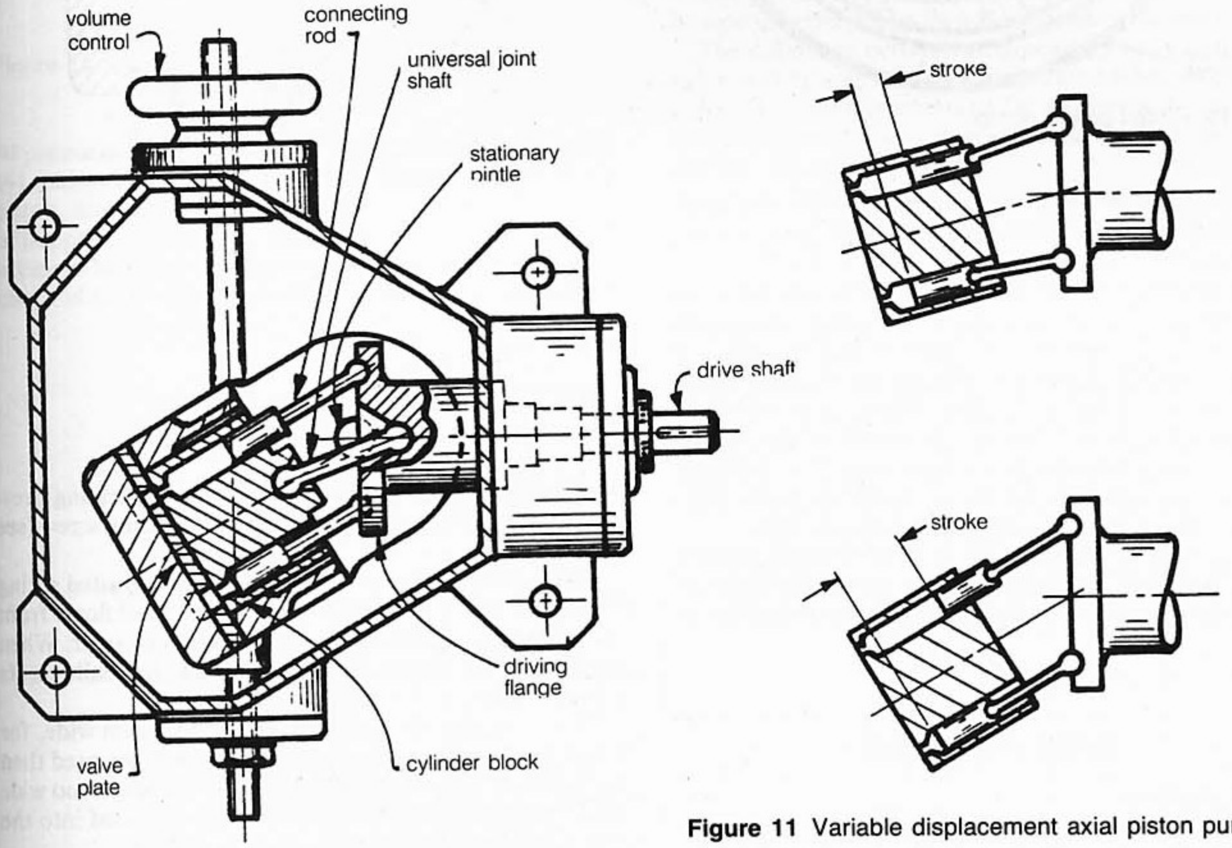



**Figure 11** Variable displacement axial piston pump

and this varies the angle between cylinder block and drive shaft.

A shaft fitted with two universal joints of constant angular velocity connects the drive shaft with the cylinder block.

As the cylinder block is rotating it is necessary to have a valve plate assembly fitted for the oil inlet and the oil outlet. This type of pump is suitable for high pressures depending on effective sealing between the valve plate and the cylinder block.

## Radial Piston Pumps

In a radial piston pump the pistons are arranged like wheel spokes in a short cylinder block.

The cylinder block is rotated by the drive shaft inside a circular housing. The block turns on a stationary pintle, which contains the inlet and outlet ports.

As the cylinder block turns, centrifugal force slings the pistons outwards and they follow the circular housing. The housing centreline is offset from the cylinder block centreline. The amount of eccentricity between the two determines the piston stroke and therefore the pump displacement. (Fig. 12.)

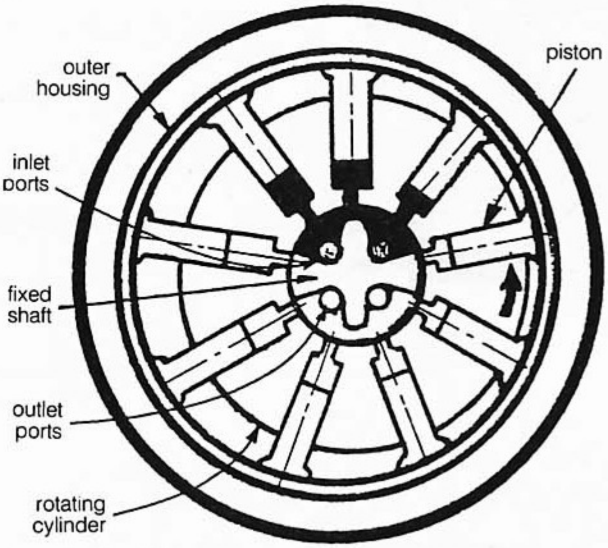



**Figure 12** Radial piston pump

Controls can be applied to change the housing location and thereby vary the pump delivery from zero to maximum.

Quite often a pump of this kind contains an odd number of pistons. This is because no more than one piston is completely blocked by the pintle at any one time. If there were an even number of pistons, for example eight, spaced evenly around the cylinder block, there would be occasions when two of the pistons would be blocked by the pintle, while at other times none would be blocked. This would cause three pistons to discharge at one time and four at one time, causing pulsation in flow.

With an odd number of pistons spaced evenly around the cylinder block, only one piston is completely blocked by the pintle at any one time. This reduces pulsation of flow.

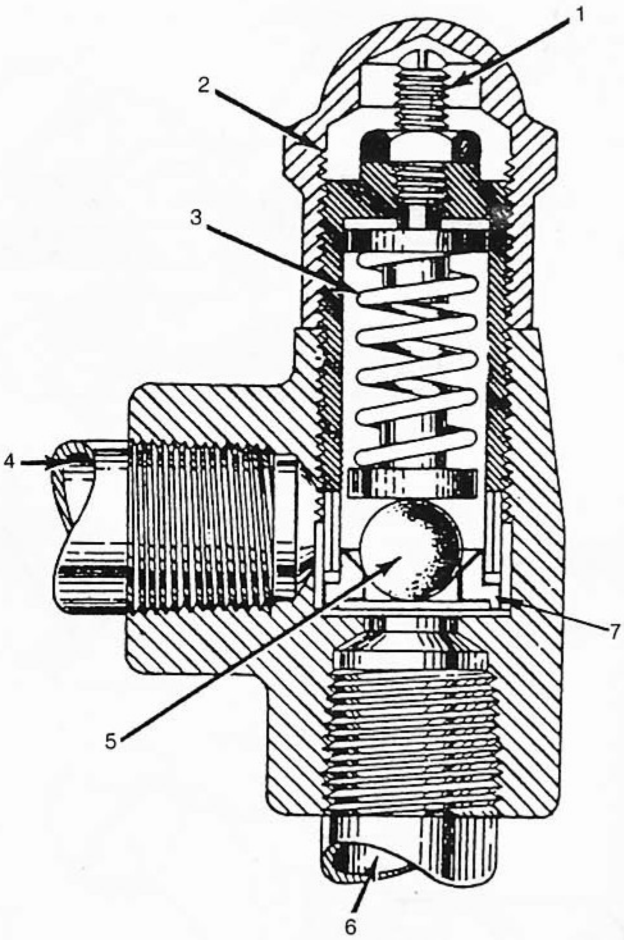
# Hydraulic valves

## Relief Valves

The relief valve is the most common of all pressure control devices. It is used to provide protection against overloading of circuit components or to limit the force or torque that can be exerted by a hydraulic cylinder or motor.

Relief valves are required in almost all hydraulic circuits except where the compensator of a variable-delivery pump is capable of providing this same protection.

A simple relief valve is installed with one port connected to the pressure line and the other to the reservoir.




1 Adjusting screw
2 Cap to seal off adjustment
3 Spring
4 Outlet port
5 Ball
6 Inlet port
7 Replaceable seat

**Figure 13** Relief valve

Spring force holds the ball on its seat. Operating pressures can be changed by turning the adjusting screw (see Fig. 13).

When pressure at the inlet exceeds the adjusted spring force, the ball is forced off its seat and fluid flows from the pressure line through the valve to the reservoir. When pressure drops below the valve setting, the ball reseats and the valve is closed.

The valve seat should be from 0.7 to 1 mm wide, for a ball of 70 mm diameter. If smaller balls are used then the seat may be as small as 0.2 mm. If the seat is too wide then foreign insoluble matter may be pounded into the seat by the ball, causing inefficient sealing.

The pressure at which the valve first begins to pass fluid is called the cracking pressure. As flow through the valve increases, the ball is pushed farther and farther off the seat. Because of the spring rate (the more the spring is compressed the greater the newton force) full-flow pressure is greater than cracking pressure. This condition is referred to as pressure over-ride.

The relatively high pressure over-ride of simple relief valves limits their use in many applications.

### Compound Balanced Piston Relief Valves

This type of relief valve uses pressure and a relatively light spring to hold the piston in the closed position.

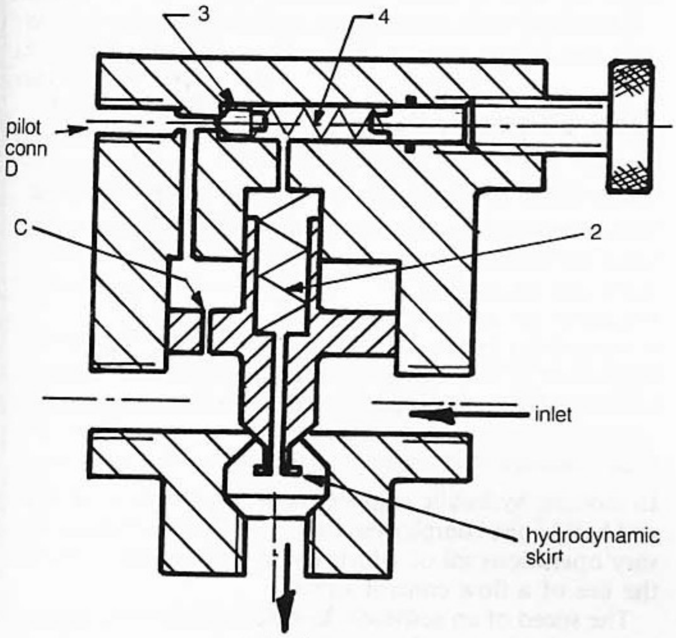



**Figure 14** Compound balanced piston relief valve

At pressures less than the valve setting, passage C (see Fig. 14) maintains balanced pressures above and below the piston, and the light spring holds it closed. The setting of poppet (3) and adjusting spring (4) limits the pressure acting to hold the valve closed, and pressure at the valve inlet and under the piston can increase only slightly more before overcoming the spring (2) and lifting the piston off its seat. This permits flow to the reservoir and prevents further pressure rise.

Since increasing flow through this type of valve results only in additional compression of the low-rate spring (2), over-ride is almost negligible.

Port D can be used for remote control of the valve or to vent the area above the piston, to the reservoir, permitting the valve to unseat when pressure exceeds the light force of the spring (2).

The latter method is often used to unload the pump during periods of idleness.

The skirt on the bottom of the piston is a hydrodynamic 'helper' when pressure drops off.

Flow through the tank port strikes the top of the skirt and makes the piston close faster.

## Unloading Valves

An unloading valve's main function is to unload the pump, that is, to divert pump flow directly to the reservoir in response to an external pressure signal.

Remote control pressure from an external source applies pressure to the small end of the piston.

The piston is forced up against spring pressure thereby opening the pump flow to the reservoir (see Fig. 15).

The difference between an unloading valve and a relief valve is that a relief valve is operated internally and an unloading valve is operated by an external means.

This type of valve is sometimes used to provide a second path for discharging fluid from the large-volume end of a double-acting cylinder on its return stroke.

The circuit shown in Figure 16 demonstrates the use of an unloading valve. By the use of the valve, as shown, the cost of a high-pressure 1.2 litres/second pump can

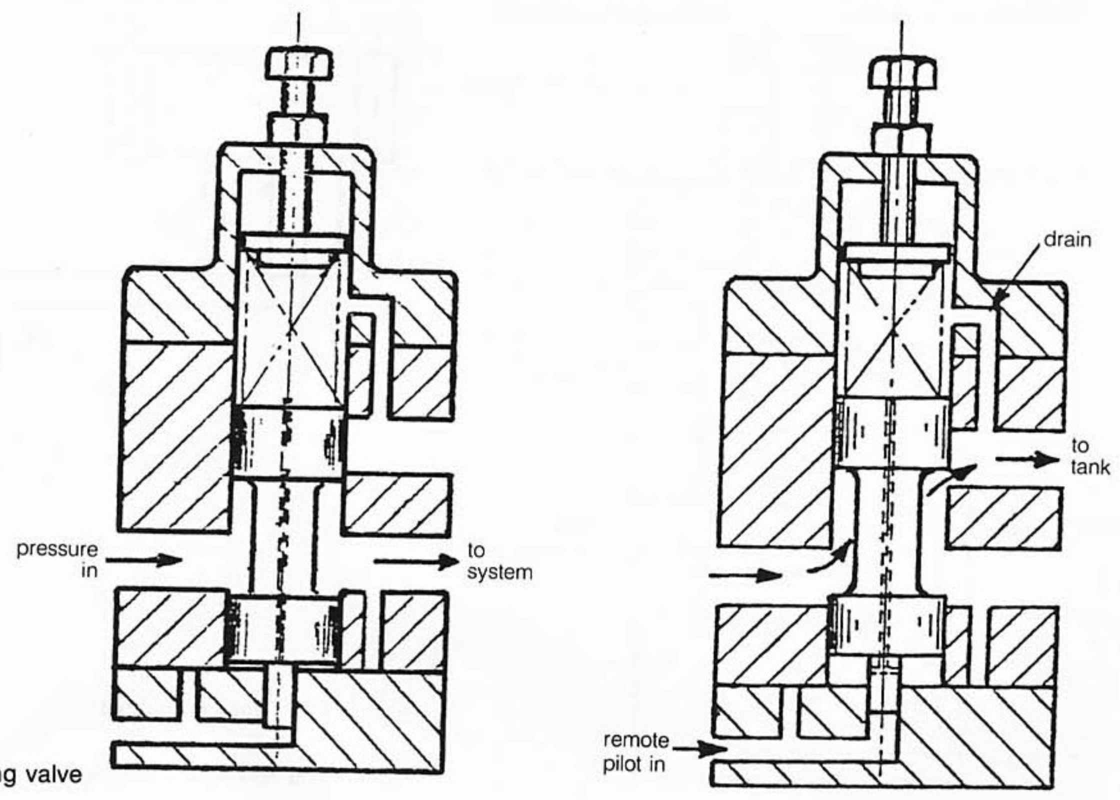



**Figure 15** Unloading valve

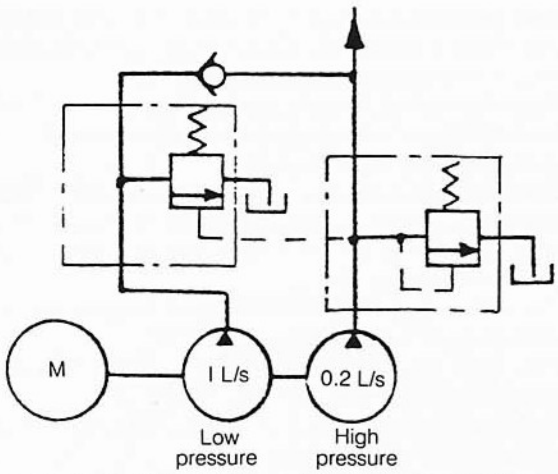



**Figure 16** Unloading valves used with two capacity pumps

be saved. The 1 litre/second pump is unloaded towards the end of the working stroke, so the motor can apply all its power to the 0.2 litres/second pump.

## Sequence Valves

A sequence valve is used to control a sequence of operations, that is, to enable one unit to automatically set another unit into motion. For example, in aircraft landing gear actuating equipment it is necessary for the landing gear doors to open before the landing gear starts to extend. Conversely, the landing gear must be retracted before the doors close.

Suppose two sequence valves are used to control the sequence of operation of three actuating cylinders, as shown in Figure 17.

Fluid from the directional control valve is free to flow into cylinder A. The first sequence valve (1) blocks the passage of fluid until the piston in cylinder A moves to the end of its stroke. At this time, sequence valve 1 opens, allowing fluid to enter cylinder B.

The action continues in sequence until all three pistons move to their respective positions in the cylinders.

## Flow-control Valves

### Factors Governing Rate of Flow

Flow rate in hydraulic systems depends on the following:

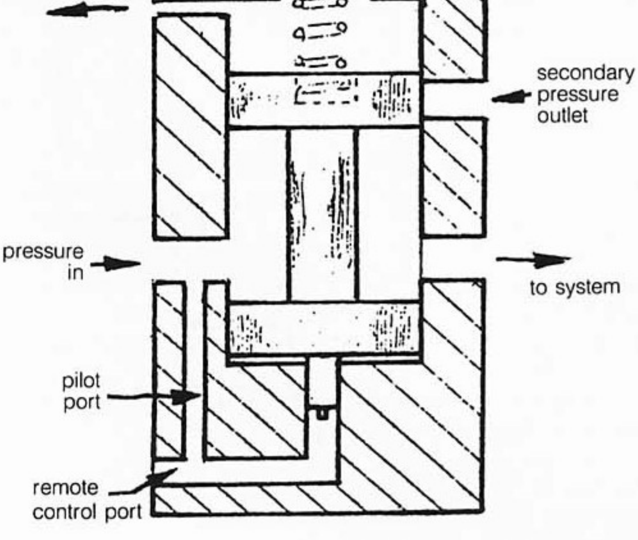
- the size of the pump, that is, the pump's delivery rate;
- the r.p.m. of the pump;
- the size of tubing;
- number of bends in the circuit;
- restrictions in the circuit;
- pressure of the circuit (causing resistance to flow);
- the condition of the pump (wear causes loss of flow as pressure increases);
- oil viscosity.

In modern hydraulic engineering it is possible to design and build quite complex circuits to perform certain necessary operations all of which could not operate without the use of a flow control valve.

The speed of an actuator, hydraulic cylinder or motor is determined by its displacement and the amount of fluid available to it.

If the displacement were changed the pump operating speed would need to be changed, which would have an inverse effect on the force or torque output. To overcome this problem, the rate of flow is controlled by the use of various valve designs.

In relation to piston travel in a cylinder, a larger volume pump would give quicker actuator movement and a smaller pump slower movement. A variable delivery



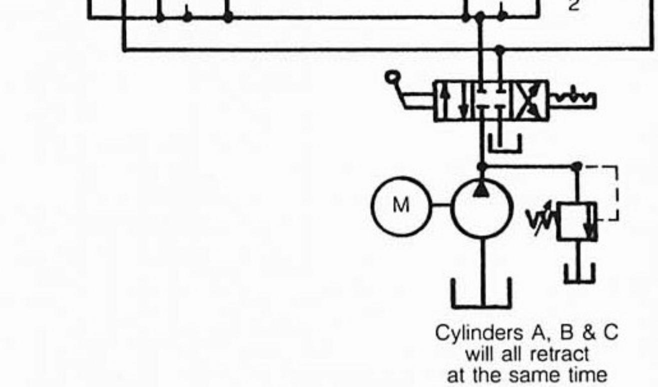




**Figure 17a** Sequence valve

**Figure 17b** Example of use of a sequence valve pump could be the solution to actuator speed, but since circuit pressure would vary with the work load then the efficiency of the pump would determine the feed rate accuracy of the actuator.

One advantage of using the variable delivery pump is that the correct amount of fluid is pumped for the required speed.

If, however, flow is required at more than one location during the feed operation of an actuator, then a separate source of flow is necessary.

The use of fixed delivery pumps and flow control valves allows a more flexible circuit, in that flow not required for feed can be used elsewhere in the system for clamping, indexing and cross-feeding.

### Types of Flow-control Valves

There are a number of different types of flow-control valves as shown in the following list: plug, gate, globe, and needle valves, restrictors, orifice check valves, pressure-compensated and temperature-compensated valves.

## Directional Control Valves

Directional control valves are designed for the specific purpose of directing the flow of fluids in fluid power systems.

### Classification

Directional control valves may be classified according to the type of valving element, for example poppet, rotary spool, sliding spools, etc.

#### *Poppet valve*

This valve consists primarily of a movable poppet, which closes against a valve seat. In the closed position, fluid pressure from the inlet tends to hold the valve tightly closed.

#### *Rotary spool valve*

This type of directional control valve has a round core, with one or more recesses or passages in it.

The core is mounted within a stationary sleeve, and as the core is rotated, the passages or recesses connect or block the ports in the sleeve.

Clearances between the moving parts may be as fine as one thousandth of a millimetre (one micrometre).

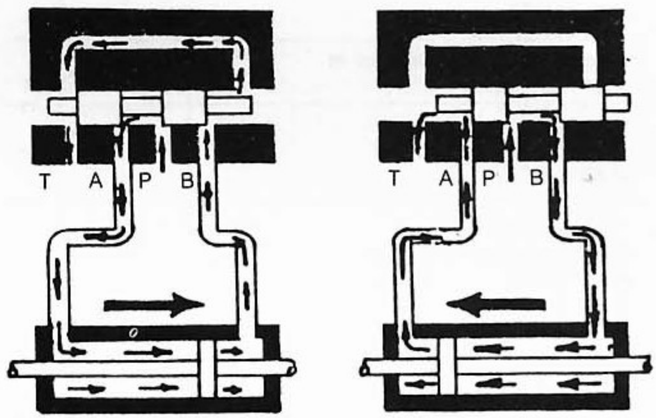
#### *Sliding spool valve*

This directional control valve is extremely popular; the main valve element is a sliding spool.

The spool slides back and forth within its housing and so blocks off or uncovers ports, allowing fluid to travel in a required direction. Clearances are very fine between spool and housing, usually one micrometre, with a surface finish from 0.2 to 0.4 micrometres.

Two-way valves can provide a choice of two flow paths exclusive of the valve's centre position.

In either shifted position, the pressure port is open to one cylinder port, but the opposite cylinder port is open to the tank. (See Fig. 18.)



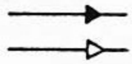
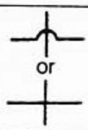
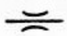
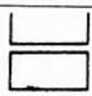
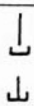
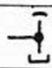
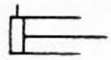
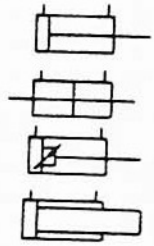
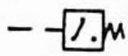
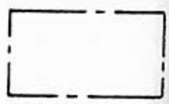
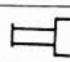
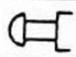
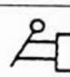

Sliding spool two-way valve

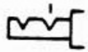
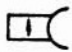
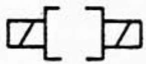
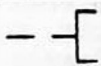
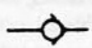
**Figure 18** Spool valve

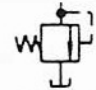
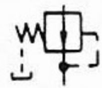
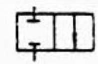
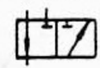
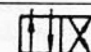
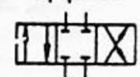
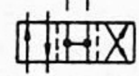
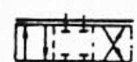
## Basic symbols for fluid power equipment

In design of hydraulic circuits, the use of symbols for lines and pumps makes 'reading' of the circuits much simpler. The standard symbols used are shown in Table 1.

**Table 1** Basic symbols for fluid power equipment

| | |
|---|---|
| **Lines** | |
| Line, working (main) |  |
| Line, pilot (for control) |  |
| Line, liquid drain |  |
| Flow, direction of: hydraulic<br>pneumatic |  |
| Lines crossing |  |
| Lines joining |  |
| Line with fixed restriction |  |
| Line, flexible |  |
| Station, testing measurement or power take-off |  |
| Variable component (run arrow through symbol at 45°) |  |
| Pressure compensated units (arrow parallel to short side of symbol) |  |
| Temperature cause or effect |  |
| Reservoir: vented<br>pressurized |  |
| Line, to reservoir:<br>above fluid level<br>below fluid level |  |
| Vented manifold |  |
| | |
| **Pumps** | |
| Hydraulic pump: fixed displacement<br>variable displacement |  |
| **Motors and cylinders** | |
| Hydraulic motor: fixed displacement<br>variable displacement |  |
| Cylinder, single acting |  |
| Cylinder, double acting:<br>single end rod<br>double end rod<br>adjustable cushion advance only<br>differential piston |  |
| **Miscellaneous units** | |
| Electric motor |  |
| Accumulator, spring loaded |  |
| Accumulator, gas charged |  |
| Heater |  |
| Cooler |  |
| Temperature controller |  |
| Filter, strainer |  |
| Pressure switch |  |
| Pressure indicator |  |
| Temperature indicator |  |
| Component enclosure |  |
| Direction of shaft rotation (assume arrow on near side of shaft) |  |
| **Method of operation** | |
| Spring |  |
| Manual |  |
| Push button |  |
| Push-pull lever |  |

| | |
|---|---|
| Pedal or treadle |  |
| Mechanical |  |
| Detent |  |
| Pressure compensated |  |
| Solenoid, single winding |  |
| Reversing motor |  |
| | |
| Pilot pressure: remote supply |  |
| Pilot pressure: internal supply |  |
| Valves | |
| Check |  |
| On-off (manual shot-off) |  |

| | |
|---|---|
| Pressure relief |  |
| Pressure reducing |  |
| Flow control, adjustable — non-compensated |  |
| Flow control, adjustable (temperature and pressure compensated) |  |
| Two position Two connection |  |
| Two position Three connection |  |
| Two position Four connection |  |
| Three position Four connection |  |
| Two position in transition |  |
| Valves capable of infinite positioning (horizontal bars indicate infinite positioning ability) |  |

# 58

# Steam

Many dates have been recorded as the beginning of the use of steam as a power source. About 200 years ago when the firm of Bolton and Watt sent William Murdock into Cornwall with a prototype steam pumping engine to rid the mines of water, the industrial use of steam power had begun. From this beginning steam power grew and was the biggest asset to the industrialization of England and the civilized world.

Today, industrial machinery is electrically driven, the electricity is generated by a huge high-speed turbine far removed from Watts reciprocating engine.

Many industries still use steam for process and building heating, cooking and food preserving, dry cleaning and clothing manufacture, and many other industrial uses. A fitter may need to replace a boiler gauge glass, service a safety valve, repack a gland or work on many other pieces of plant associated with steam.

Stèam is powerful and dangerous, but very useful and must be treated and approached with care and caution. Before you can work on steam plant, it is necessary to obtain a certificate of competency, which is strictly policed for quality of knowledge and ability to apply it by the Department of Labour (or similar) in your locality.

The reason for this is that when heated water turns to steam it occupies 1600 times its original volume at atmospheric pressure; when this is contained in a closed cylinder the pressure can rise rapidly to dangerous levels, therefore you must know all about boiler operation for safety.

Steam is invisible. The white cloud of so-called steam seen issuing from the boiling kettle is water vapour changing, by condensation, back to water. This is the dangerous part of live steam at pressure, as it leaves an orifice invisible adjacent to it, and then the cloud, at speed and obviously hotter than boiling water, can cause terrible burns.

Never work on installed steam plant unless you are working under supervision of a certified person.

Your college can guide you to obtaining a certificate of competency.

# 59

# Numerical control machine tools

## Introduction

Manufacturers are constantly trying to find a better way to supply their markets in Australia and overseas; or to open new markets. Generally, metal-working industries have found that numerical control (NC) automation can help them to reach these goals. Although numerical control machines are more expensive than their conventional counterparts, the advantage of equipment utilization of machine tools designed to perform such diverse operations as drilling, turning, milling, tapping, grinding, sheetmetal punching, metal forming and folding, flame and laser cutting, spot arc welding, and many more, is significant.

In the case of these varied machine tools, cost savings are obtained through the rapid change over of jobs loaded onto the machine, and through reduction in time lost during the machining operations, which is inevitable with a human operator, who becomes tired and loses concentration. The numerical control machine is suited to medium to small quantity production batches, the significant factor being reduced set-up time. This type of production environment is typical for a large proportion of Australian manufacturers.

In more recent times, with the introduction of computer aided design systems (CAD) into industries, improved efficiency is obtainable in manufacturing with numerical control machines. This can be achieved by utilizing the information (data) used to create the geometry of the part on the CAD system and then, using the same data, the CAD system is able to generate cutter tool paths and a numerical control program for machining. This eliminates the necessity for manual programming, and complex parts can be machined with reduced programming effort and more certain quality.

This is a rapidly growing technology, with extensive job opportunities, and young people entering the metal-working industries will be better equipped if they bring to the job a knowledge of numerical control.

Metal-working industries have found that numerical control automation can assist in reaching their goals, to produce greater quantities of better quality products in less time and at lower cost.

## What is numerical control?

Numerical control can be defined as a form of programmable automation in which the process is controlled by numbers, letters and symbols. In numerical control, the letter and number codes for a program of instructions is specifically designed for a particular work part or job. Change the job on the machine and the program of instructions is changed. It is this capability to change the program for each new workpiece that gives numerical control its flexibility. It is far easier to modify, or write new programs than to make major changes in the production equipment.

When we communicate with a numerically controlled machine tool correctly, it will do exactly what it is told to do at the best possible speed, with great accuracy and a high degree of repeatability, and it will continue to follow our directions for an indefinite period. At the same time, our directions to the numerical control machine must be correct, for it is just as willing to drill a hole in the wrong location as to drill one in the correct location. One must remember that a numerically controlled machine tool can only follow our directions, or reject them and stop work. Our instructions must be correct.

## General features

### Basic Components

An operational numerical control system consists of the following three basic components:

- program of instructions;
- controller unit;
- machine tool or other controlled process.

Program of instructions This is the detailed step-by-step set of directions, which tell the machine tool what to do. It is coded in numerical or symbolic form on some type of input medium that can be interpreted by the controller unit. The most common input medium is 1 inch (25.4 mm) wide punched tape. Other forms of input will be discussed later in the section titled 'Data Input'.

The controller unit The unit consists of the electronics and hardware, which read and interpret the program of instructions and convert it into mechanical actions of the machine tool. The typical elements of the controller unit include the tape reader, a data buffer, signal output channels to the machine tool servomotors and other controls. To ensure that the instructions have been properly executed by the machine, feedback data are sent back to the controller via feedback channels. The most important function of this return loop is to ensure that the table and work part have been properly located with respect to the tool.

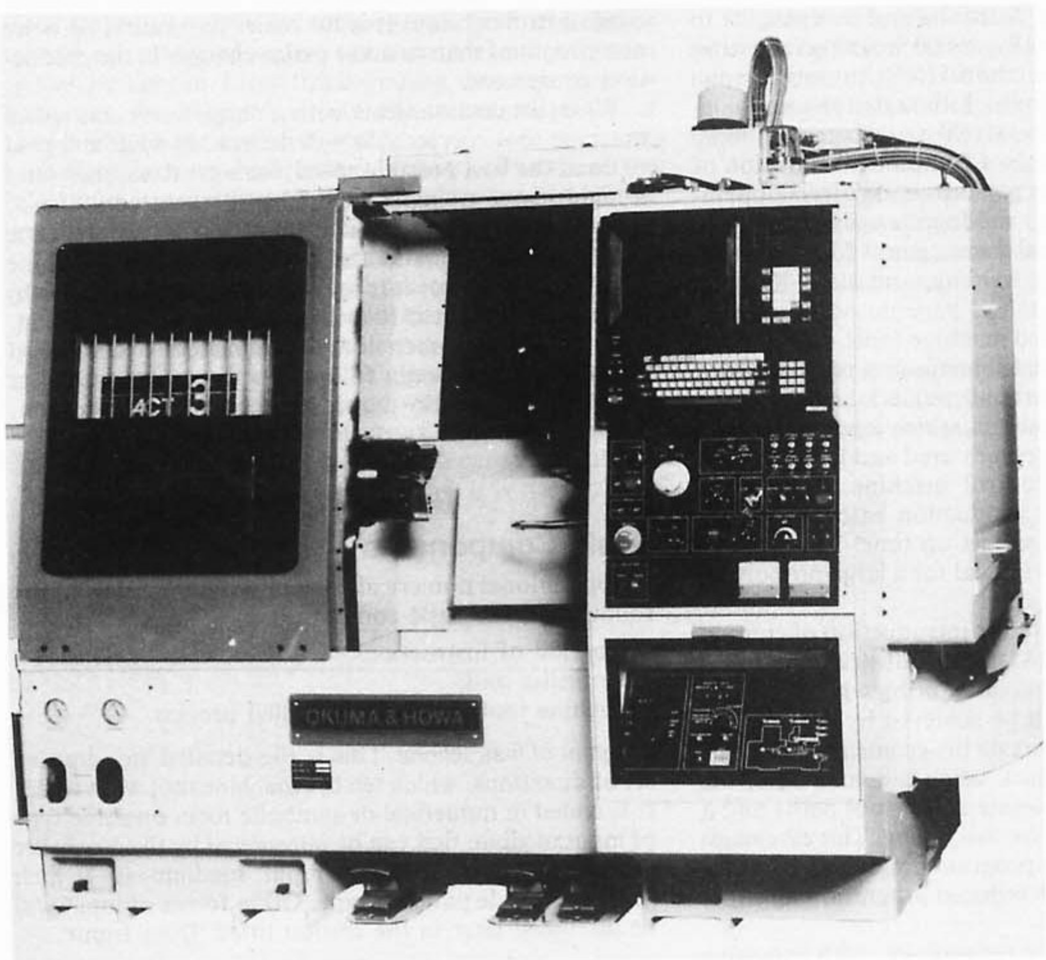
Other elements of the controller unit or console are the dials and switches by which the machine operator runs the NC system. It may also contain data displays to provide information to the operator.

**The machine tool** This is the part of the NC system that performs useful work. In the most common example of an NC system, one designed to perform machining operations, the machine tool consists of the work table and spindle as well as the motors and the controls necessary to drive them.

## Coordinate Systems and Machine Motions

As has been stated earlier, the NC system converts alphanumeric information into machine commands. Since the machine can have several axes of control, a word address letter must be assigned to each axis to ensure that dimensional information is assigned to the correct slide. Plus and minus directions relative to the movement of the tool and the workpiece must also be allocated, or inferred.

Numerical control uses the Cartesian coordinate system to identify each axis. For a vertical milling machine two axes, $X$ and $Y$, are defined in the plane of the table. The $Z$ axis is perpendicular to this plane and movement in the $Z$ direction if parallel to the spindle of the machine. On milling, boring and drilling machines, the $Z$ axis is parallel to the rotating tool. With lathes and cylindrical grinders, the $Z$ axis is parallel to the rotating workpiece. (See Figs 1 and 2).



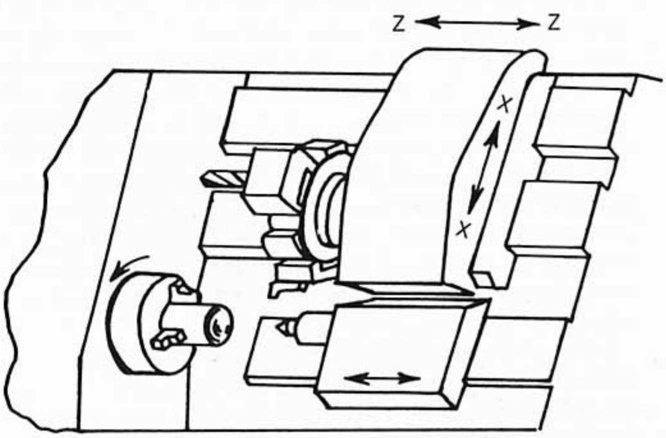




**Figure 1** Illustration of lathe

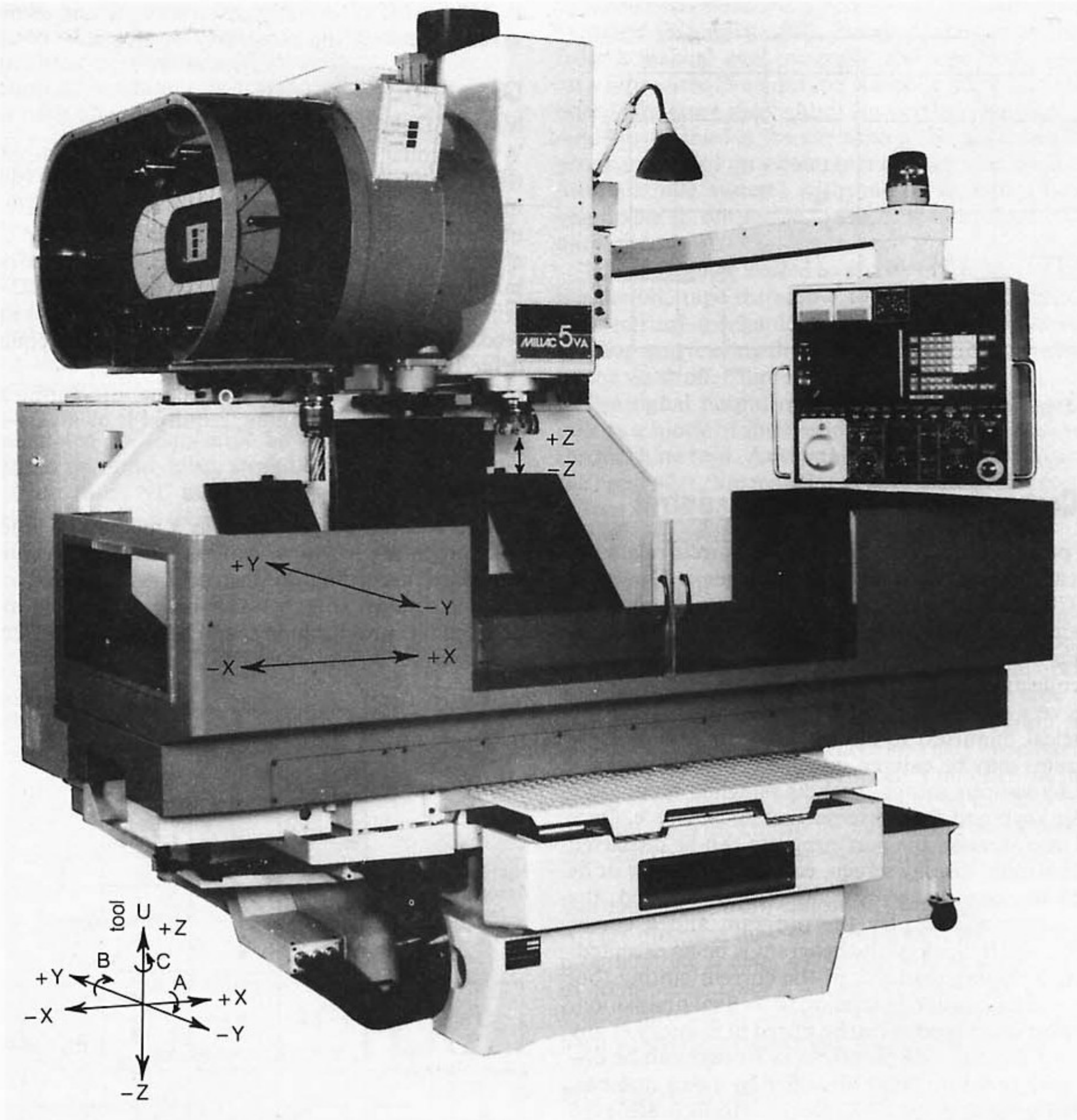



**Figure 2** Illustration of mill

Rotary motions, *A*, *B* and *C* are angles defining rotary motion around the axis, relating to the *X*, *Y* and *Z* axes respectively.

## Absolute and Incremental Positioning

An option available when programming is to use either the absolute system or the incremental system of tool positioning.

The absolute system has the tool locations defined (dimensioned) in relation to a zero point or origin. This point may be located in any position on the workpiece or even outside the workpiece if this is convenient.

The incremental system means that the next tool location must be defined (dimensioned) from the previous tool location. (See Figs 3 and 4.)

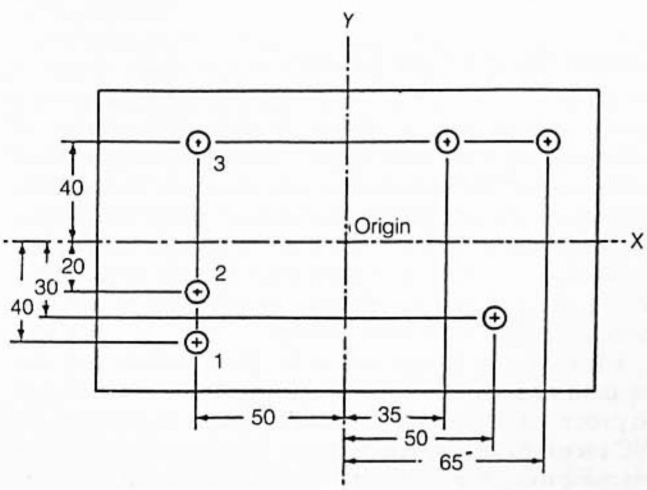



**Figure 3** Absolute system

1 Selection of the coordinate system.
2 Selection of the figure blank and dimensions.
3 Input of the part figure and dimensions.
4 Selection of machining processes.
5 Input of tooling types and parameters.
6 Decisions on cutting conditions.

The operator has only to answer the questions displayed on the screen.

When data is input, the figure blank and part profile are immediately drawn, calculations automatically made, and NC commands inserted, together with a display of the tool path. Different colours are often used in the graphics to show blank detail, part profile, tool path, roughing and finishing detail. Dashed lines represent rapid traverse movements.

On completing the input of part details, the automatically calculated NC data may be punched onto paper tape, stored on floppy disc, stored in memory or transferred direct to an NC machine via external interfaces.

For the component shown in Figure 6 the keys shown in Figure 7 would be input along the profile.

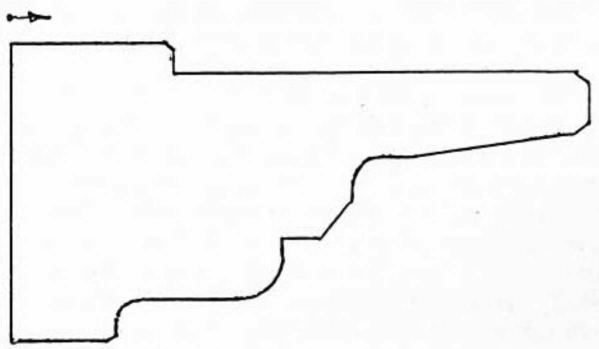


**Figure 6** Sample component

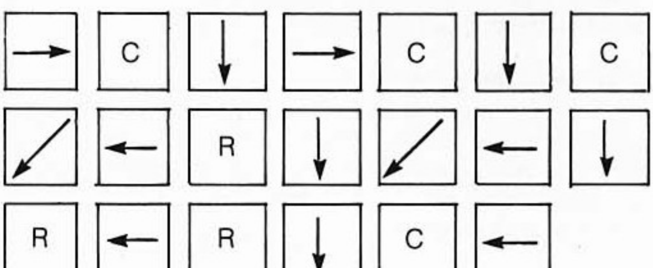



**Figure 7** Input keys for the component shown in Figure 6

After each symbol key is depressed the system asks for the dimensions necessary for the feature, building up data to form the part.

### Punch Tape

The punched tape used for NC is 1 inch (25.4 mm) wide and has eight regular columns or channels of holes, running lengthwise along the tape. The NC program may be coded in either Electronic Industries Association (EIA) Standard or the ISO Standard; many machines systems will read both tape codes and can be switched to whatever format code is being used, or use internal code recognition capability to recognize the code. In Australia, the recommended standard is AS1114–1971 based on the ISO Standard ISO/R840–1968. Punched tape can be produced from a manual part program, the tape being prepared on a typewriter-like machine, which in addition to its keyboard also has a mechanism for perforating blank tapes. Another method is for the tape to be produced from a program created on a computer or computer-assisted part programming system, with one of its many functions being able to output NC tape in the required NC standard code.

The program is loaded to an NC machine tool by feeding the NC tape through a tape reader, which is either an electrical–mechanical or a photoelectric device for winding and reading the part program from punched tape to the controller buffer.

The signal output of data is fed from the controller unit as a block of instructions to command and activate the machine tool. As the tape is read and interpreted by the controller, the machine is activated by the controller output. At the conclusion of the job the tape may then rewind, ready to machine the next part.

### Memory Input

Input of data into a controller with a computer memory device, as discussed earlier with CNC machine tools, can be either entered through the keyboard of the operator's controller or from punched tape through the tape reader, and is loaded into memory. The part program is identified by a part program number and may be selected from memory, by entering the program's number on the keyboard. The program is then able to be run any number of times from the controller without the use of tape. Editing, and revisions can be made directly at the controller.

### Memory Input from External Computer

A part program may be created by a computer assisted programming system, a CAD system, or saved and stored in computer memory. These programs are then downloaded into the memory of a CNC controller, or can be used to drive the machine, through a DNC link.

## NC Tape Codes

NC tapes are punched using a binary code; this coding system uses the base 2 number system, which can represent any number of the more familiar base 10 or decimal system.

The binary system has only two numbers, 0 and 1. The successive digits in the binary system are based on the number 2 raised to successive powers. The first digit is $2^0=1$, the second is $2^1=2$, the third is $2^2=4$ and so on. The two numbers, 0 or 1, in successive digit positions indicate either the presence or absence of the value. Figure 8 shows the binary system and its equivalent numbers in the decimal system.

| | $2^3$ | $2^2$ | $2^1$ | $2^0$ | |
|---|---|---|---|---|---|
| | 8 | 4 | 2 | 1 | Decimal value |
| Binary numbers : | 0 | 0 | 0 | 0 : | 0 |
| : | 0 | 0 | 0 | 1 : | 1 |
| : | 0 | 0 | 1 | 0 : | 2 |
| : | 0 | 0 | 1 | 1 : | 3 |
| : | 0 | 1 | 0 | 0 : | 4 |
| : | 0 | 1 | 0 | 1 : | 5 |
| | etc. | | | | |

**Figure 8** Binary example

Eight channels are needed on the tape to facilitate other symbols to be coded, in addition to numbers, for example plus or minus signs, or alphabetical letters. Five of the channels represent values of 0, 1, 2, 4 and 8, allowing any numerical digit to be designated on one row of the tape. One channel in each of the standard codes, EIA and ISO, is reserved for a parity check (see Figure 9).

Whenever the EIA standard code is being used, and the particular number or symbol being punched calls for an even number of holes, an extra hole is punched in the parity channel, making the total an odd number.

If a particular ISO value generates an odd number of holes in the row, the parity channel is then used, to make up an even number.

Each row of holes on the NC tape is a character, such as a letter, number, or symbol. A collection of characters, called a word is used to describe an instruction. A block of information is a collection of words, which makes a complete NC instruction; for example, a milling operation block might contain information locating the *x* and *y* coordinate and speed feed values for the cutter.

Each block is separated by a symbol indicating end of block (EOB) as shown in Figure 9 for ISO and EIA. The tape reader feeds the data from tape into the buffer of the controller in blocks.

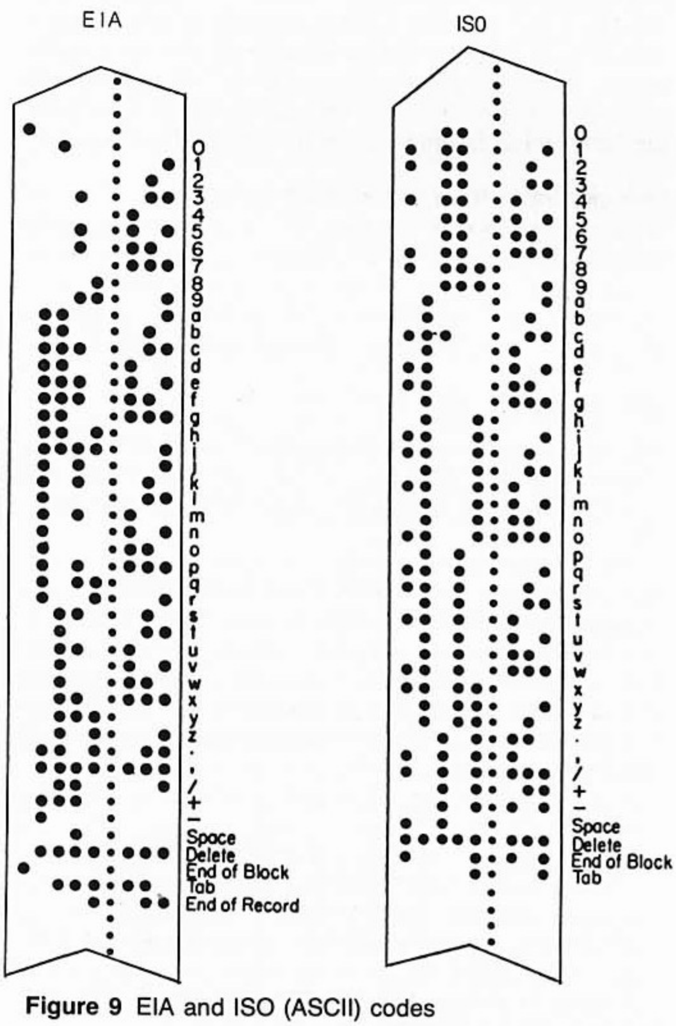



**Figure 9** EIA and ISO (ASCII) codes

## Block Format

The following list of functions and their identifying letter are used in the formation of a block.

### *Sequence number*

The sequence number N is used to identify the block.

### *Preparatory function (G)*

This function (often called the geometric function G) is used to prepare the machine for instructions that are to follow. The preparatory function is needed so that the controller can correctly interpret the data following it in the block. For example, G01 is to prepare the controller for linear interpolation movement with respect to the coordinate values to follow. Some examples of typical G functions are shown in Table 1 in the 'Manual programming' section of this chapter.

### *Feed rate control function*

The feed rate control function (F) specifies the feed rate in a machining operation and may be expressed in units per minute or units per revolution of the spindle.

Most controllers can be switched to metric or inch mode by the use of the appropriate G function.

### *Cutting speed control function*

This function specifies the cutting speed, for an operation, by controlling the spindle rotation rate. Units are revolutions per minute (r.p.m.) or by specifying the relative surface speed of the tool to the workpiece. Units may be in inches per minute (r.p.m.) or millimetres per minute (mm.p.m.). It is usual when operating an NC lathe to specify the cutting speed in terms of surface speed rather than r.p.m. due to the changing diameter of the workpiece as machining progresses. This means the r.p.m. varies as the machining diameter changes, thereby maintaining a constant surface cutting speed (when the constant surface speed function is available).

### *Tool selection control*

This function (T) is used when the NC machine tool requires a tool change. The function indicates the tool specified for an operation within the program and corresponds to the relative location of the tool in the automatic tool change turret.

### *Miscellaneous function*

The miscellaneous (M) function is used to specify miscellaneous functions available on the machine tool, and varies from machine to machine.

These functions are machine-related commands such as spindle on, spindle stop, coolant on, coolant off, tool change etc.

Reference should be made to the machine tool handbook for the specific miscellaneous functions available and their relevant codes.

A representative list of M functions is shown in Table 2 in the 'Manual programming' section of the chapter.

### *Canned cycles*

These are preparatory G functions unassigned by standards specifications and can be used for repeated cutting cycles such as drilling, tapping and roughing. This can save the programmer time and reduce the amount of data in a program, when the same tool is to perform a repeated operation. As an example, consider 6 to 10 mm diameter holes to be drilled 25 mm deep at 40 mm centres. A canned drilling cycle to perform this operation would require only one block of instructions.

To summarise the block format:
A block is a collection of words containing characters that represent a command with a sequence number (N) and other functions as required, such as a preparatory function (G) and corordinates. The information within a block is varied and need only contain those commands and data required to instigate change from the previous block, as defined between carriage return commands.

## Manual programming

Manual programming is predominantly used where the workpiece is relatively simple or where the coordinates required are not too numerous or are easily obtained.

One of the main duties of the programmer in the process of producing a program is to provide documentation for setting and operating the machine tool.

The process of producing a program is as follows:

1 Examine the part drawing:
  - Determine the size and shape of the raw material.
  - Determine a suitable manufacturing process and finished profile.
2 Determine the sequence of operations and work-holding methods to achieve the shape and size of the component to the accuracy stipulated on the drawing.
3 Select and detail the tooling required. This includes shape, size, turret positions and offset details if applicable.
4 Show on the documentation, details of positioning the workpiece, for example work-holding process, work datum and start point in relationship to machine datum where necessary. (Refer to Figure 10.)
5 Calculate coordinate points for the profile about the work datum.
6 Write the program in the format appropriate to the machine tool and controller being used, for example mill, punch, press, Fanuc or ANCA control, etc.

### Preparing the Program

Machine tools operate by directing and controlling a range of functions. In NC programming these functions are addressed by a letter. Details of that function are represented by numerals immediately following the letter.

Some of the functions indicated by a letter are:

D: Depth of cut in a cycle.
E: Screwcutting lead.
F: Feedrate.
G: Preparatory code.
H: Tool offset indicator.
I: Parameter on *X* axis in a cycle.
J: Parameter on *Y* axis in a cycle.
K: Parameter on *Z* axis in a cycle.
L: Repeat.
M: Miscellaneous functions e.g. turning M/c on etc.
N: Sequence number.
P: Time in seconds.
Q: Parameter.
R: Radius.
S: Speed.
T: Tool call-up.
U: A parameter associated with *X* axis.
V: A parameter associated with *Y* axis.
W: A parameter associated with *Z* axis.
X: axis.
Y: axis.
Z: axis along work spindle.

The intention of the program after the selection of tool, speed, etc. is to direct the cutting tool to a destination along a prescribed path. The prescribed path code is called a preparatory code or G code, for example G03 X50.0 Y0 R20.0. This 'block' says move in a circular path in the C.C.W. direction to the coordinates X50.0 Y0 producing a radius of 20.0 mm.

Table 1 Some typical G codes

| | |
|---|---|
| G00 | Rapid traverse (positioning) |
| G01 | Linear interpolation, e.g. feed in a straight line |
| G02 | Clockwise movement (CW) |
| G03 | Counterclockwise movement (CCW) |
| G04 | Pause or dwell |
| G20 | Imperial format (inch) |
| G21 | Metric format (mm) |
| G28 | Return to machine zero |
| G90 | Absolute dimensions |
| G91 | Incremental coordinates |
| G92 | Programming of absolute zero point |

Table 2 Some typical M codes

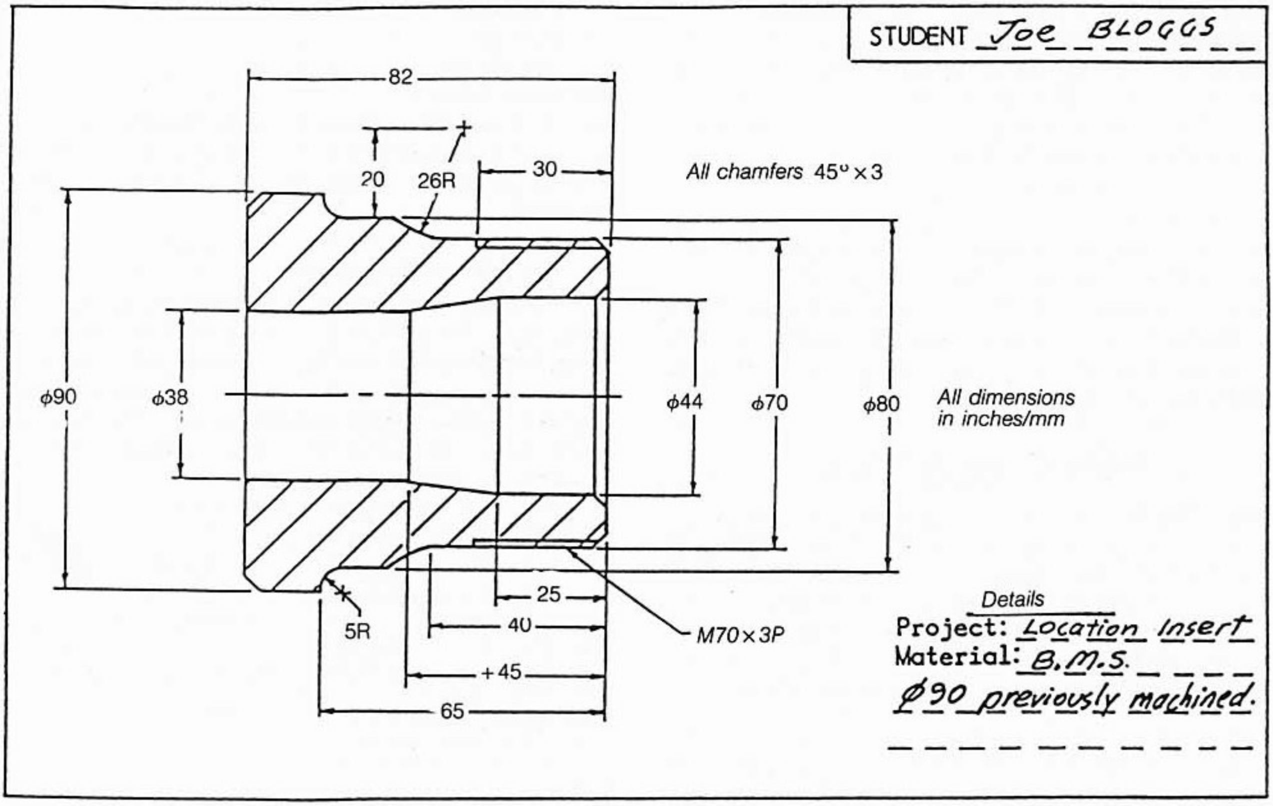
| | |
|---|---|
| M00 | Program stop |
| M02 | End of program |
| M03 | Spindle on CW rotation |
| M04 | Spindle on CCW rotation |
| M05 | Spindle stop |
| M06 | Tool change |
| M08 | Coolant on |

A program usually consists of three basic sections:

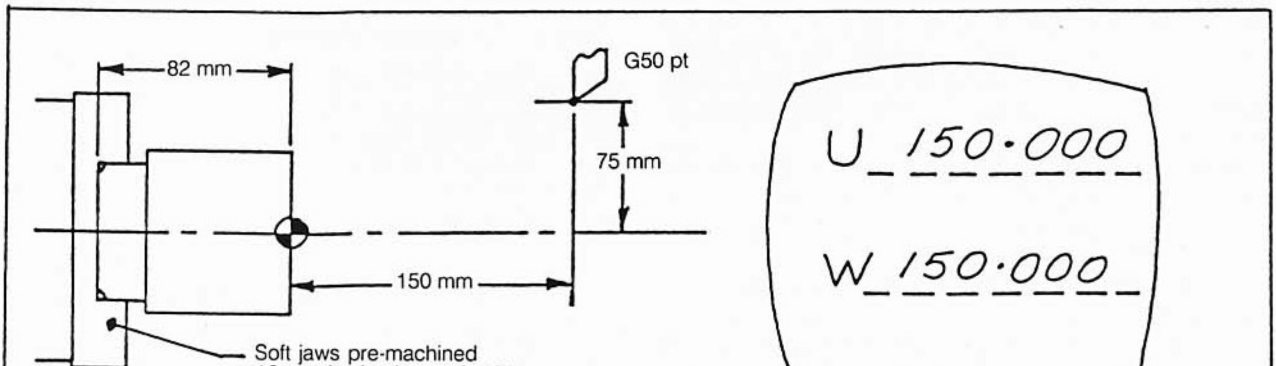
- the start-up or preparatory section;
- the main program;
- the shut-down or end of program.

A typical program to cut the profile shown on a milling machine with 6M controller would be:

01234 (program number)
N5 G21 (metric programming)
N10 G91 G28 Z0 (driving to *Z* axis machine zero) (Fig. 11)
A /N15 G28 X0 Y0 (driving to *X* and *Y* axis machine zero)
/N20 G00 X-? Y-? (driving to start point on *X* and *Y* axis; to be edited at set-up).
N25 G90 G92 X−30.0 Y70.0 Z210.0 (establishing work datum).
N30 T01 M06 (calling tool and loading).
N35 T02 S1000 M03 (calling next tool setting r.p.m. and turning spindle on).
N40 G90 G000 X−20.0 Y0 (moving to start of machining).
N45 G43 Z1.0 H01 (approaching on *Z* axis and adjusting length offset).




Initial set-up




TOOLING DETAILS

| TOOL | R | T | G50 POINT |
|---|---|---|---|
| T01 R/Turning tool | – | – | X150·000 Z150·000 |
| T03 F/Turning tool | 0·8 | 3 | X150·000 Z150·000 |
| T05 R/Boring tool | – | – | X250·000 Z40·000 |
| T07 F/Boring tool | 0·8 | 2 | X250·000 Z40·000 |
| T09 60° Screwing tool | – | – | X150·000 Z150·000 |

**Figure 10** NC documentation

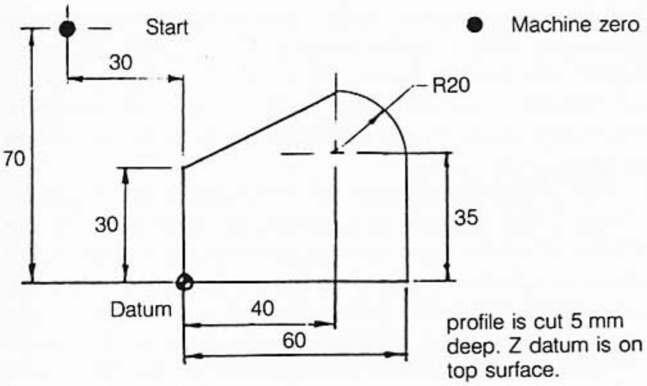



**Figure 11** Machine zero

N50 G01 Z-5.0 F150 M08 (feeding down on *Z* axis coolant on).
B N55 G41 X0 Y0 D11 F200 (feeding to profile start allowing for tool radius on left-hand side of work).
N60 Y30.0
N65 X40.0 Y55.0
N70 G02 X 60.0 Y35.0 I0 J-20.0 (circular interpolation).
N70 G01 Y0
B80 X0
N85 G40 Y-20.0 M09
N90 G91 G28 G49 Z0 (driving *Z* axis to machine zero).
C N95 G90 G00 X-70.0 Y30.0 M05
N100 M30

As a general rule, programs for other controllers do not vary dramatically. The difference often occurs in the start and the end of the programs. As an example, a program for an ANCA controller start would be:

N5 G71 G90
N10 M00 (load tool)
A N15 M03 (spindle on)
N20 G50 X-150.0 Y150.0
N25 G00 X0 Y0
N30 X5.0 T0101
B G00 Z0 T0100
G51
C G00 X0 Y0 M05
M02

## Program Verification

Collision avoidance, correct data format, general shape definition, and the actual path taken by the machine or tools can be verified by what might be termed first-order checking, as opposed to second-order checks to verify accuracy of profile, or sizes produced by the NC process.

First-order checking can take place by careful manual examination of the finished program and documentation, or by graphic verification on a computer's visual display unit or plotter, if suitable software exists to read, translate and graphically represent the respective tool paths.

During the initial entry of the program into the controller, format errors will be registered and displayed by the controller. Further checking in the 'dry run' mode, with the tool well clear of the workpiece and holding devices, will allow verification of the general movements and order of operations.

Accuracy of profile and sizes can be verified together with cutting conditions during the cutting of first, and subsequent parts on the NC machine tool, using optional stops to allow the operator to measure and correct where required.

Compensation for variations to tooling such as length or cutter diameter can be used to advantage during the verification process, by deliberately setting the offset parameters on the controller to ensure parts produced will have excess metal remaining. By measuring the actual part produced and adjusting the offsets to accommodate for the resultant variation from the desired dimensions, even the first component may be produced within tolerance requirements.

## Machine Operation

Detailed information concerning machine operation must occur with interaction on the machine and with reference to the specific manufacturing process and controller and machine tool instructions.

The safety of the operator and the machine demands that extreme care in setting parameters, and in program verification, takes place prior to operating in automatic mode. 'Dry run' mode, with the tool well clear of possible obstructions, should be followed by 'single block' operations during the cutting of the first component, with control of 'rapid traverse' over-ride, where appropriate. The operator can then step through the program, checking the expected motions from the program information, with the drawing or component information, prior to executing the next block, verifying sizes and making appropriate adjustments, or program editing where necessary.

Good communication between the operator and NC programmer is important, not only in receiving instructions to assist setting up the machine for each task, but in reporting any required variations to the programs, and refining the manufacturing process.

# Computer assisted programming

More complex profiles, and contoured surfaces may require computer assistance to reduce the effort of programming, and increase the accuracy and reliability of the NC programs.

The geometry of the part may be defined using 'automatic program tooling' language (APT) or other languages to describe points, lines, circles, and other geometric shapes to define the surfaces of the component. Commands to describe the tool and the motions to machine around the respective portions of the geometric shapes can be entered into the computer together with desired feeds etc. and the processed cutter location data is then post-processed to change the data into the correct format for the particular NC machine and controller.

## Computer Aided Design/Computer Aided Manufacturer CAD/CAM

The ability to reuse the information stored in the computer during creation of the computer model of the part in the design process allows the CAD data to be used in the CAM process, creating NC programs for the geometric profiles required.

The model displayed on the visual display unit (VDU) permits the surface to be machined to be identified by the NC programmer, in the correct sequence for the specified tool, and generates the information for the NC machine tool to perform the required NC operations.

Considerable productivity gain can occur through the combined CAD and CAM process.

## Computer Integrated Manufacture

The integration of the CAD/CAM process with other processes and information systems is gradually being applied to many manufacturing enterprises to enable the further reuse of data to improve design and manufacture and management processes, and consequently improve productivity and marketing.

Many elements of CIM already occur in separate processes, such as robots loading NC machines, or groups of NC machines fed by robots or other transverse devices in flexible manufacturing cells (FMC) or extensive machines coupled into a flexible manufacturing system (FMS).

The electronic transfer of information generated by CAD/CAM possibly using group technology (GT), the family of similar parts grouping process, will allow a CIM system to automatically plan the production process and send appropriate NC programs and instructions to the machine tools and controlling computers to produce components in a 'just in time' (JIT) environment. These and other procedures are part of the factory of the future, but each component is becoming more visible in current manufacturing practice.

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# Portable power tools

## Power tool safety

Power tools may look harmless and safe to use; because of this, many accidents occur with this type of equipment.

Some basic rules that must be observed when using portable power tools are listed below.

- When using electrical power tools always use the nearest power point available and make sure the lead or extension lead is not interfering with other machinery. **(Carefully layout leads.)**
- When using pneumatic tooling always use the nearest air supply point and make sure the supply hose is not interfering with other machinery. **(Carefully layout leads, air hoses, ensure dry air and lubricator working.)**
- Before using portable electric tools, inspect the casing, switch, lead and plug to ensure they are not broken or damaged.


Figure 1 Piston grip electric drill

- Never carry a portable tool by its lead.
- Securely hold work to be drilled or ground.
- Hold the portable tool firmly when switching on, as some tools have a tendency to spin around as they start. Also, be prepared to resist the turning effort of a large capacity portable drill in the event of the drill jamming or when the drill bit breaks through the material.
- **Do not use metal-cased electrical power tools in wet areas** as electrocution could occur. **Use a double-insulated** type of tooling in these areas or air-driven tools for safety.
- Avoid getting the portable power tool wet and take extra care in a damp situation (e.g. do not drag leads through water, do wear rubber soled shoes and rubber gloves).
- **Consider the safety of others** when using these tools
  - take care not to trip people with leads;
  - check behind partitions before drilling through them;
  - check building wiring plans before drilling into walls;
  - make sure others will not be hit by flying sparks, hot metals, etc. (use screens);
  - **Do not leave unattended tools plugged in.**
- Use pneumatic tooling when working in explosive areas, but remember that hot metal or sparks can be produced by the grinding or drilling operation (e.g. drilling holes inside petrol tanks).
- Use appropriate protective clothing and/or equipment for personal safety (e.g. glasses, shields, spats, apron, etc.).
- Avoid using the switch in the locked 'ON' position, especially when performing operations where tools such as drills may become jammed, causing the power tool to rotate.
- Do not disconnect the lead of an electrical tool by pulling on the lead. Grasp the plug to pull from the power outlet.
- Ensure you have adequate footing when using power tools. Try to avoid using these tools when working from ladders or other insecure positions.

### Work Holding

To prevent damage to the machine or material and injury to the operator, it is necessary to restrain the work from moving when using hand-held power tools.

## Power sources for portable power tools

### Mains Supply 240 Volt

Electric portable power tools operating from 240 V mains supply require care in use to prevent stalling, which will rapidly burnout the electric motor. Double-insulated tools do not require an earth wire. Metal-cased older-type tools must be earthed. Low-voltage electrical supply is used where mains supply is unavailable or for safety reasons.

### High-frequency Electricity Supply

A separate electricity supply, provided by an electric motor–generator combination, delivering electricity at a higher frequency per second than mains supply (three-phase 200 V; 200 cycle) is an alternative power supply.

Equipment designed to operate on high frequency is smaller in size for the same power output, hence provides easier operational handling.

## Compressed Air

Power tools operated by compressed air (pneumatic) are not damaged by stalling. The air supply must be clean, dry and lubricated. Protective glasses must be worn to avoid particles being blown by the air exhaust onto the operator.


**Figure 2** Typical range of portable power drills

# Drills

Portable power drills are available with either electrical or pneumatic (air) power supply; they are available in a variety of types (Fig. 2):

- *Single-speed pistol drill* used for small holes, up to 10 mm diameter.
- *Multiple-speed drill* used for small and larger type holes, up to 24 mm diameter.
- *Variable-speed drill* used for drilling into a variety of materials (e.g. timber — fast, stainless steel — slow).
- *Impact drill* used for producing holes in concrete or masonry.
- *Reversible drill* used for tapping threads into thin material. This drill can also be used with a screwdriver attachment.

The selection of the correct power drill is governed by:

- the r.p.m. required;
- the power of the motor;
- the chuck capacity.

## Accessories

Two types of press stand are available as accessories (Figs 3 and 4):

- *Light press stand* used to simulate a small drill press for drilling small components.
- *Magnetic base press stand* used to mount a larger portable drill for drilling holes into girders or machine components that are too large to put onto a drilling machine. This base is located in the correct position for drilling the hole and is held onto the surface magnetically. This will enable the holes to be drilled at right angles to the surface.

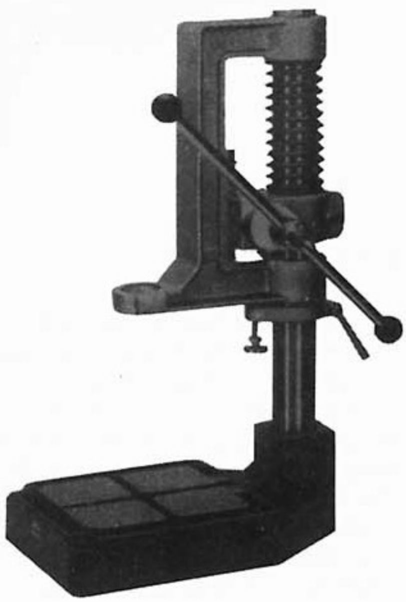


**Figure 3** Press stand to accept a portable drill

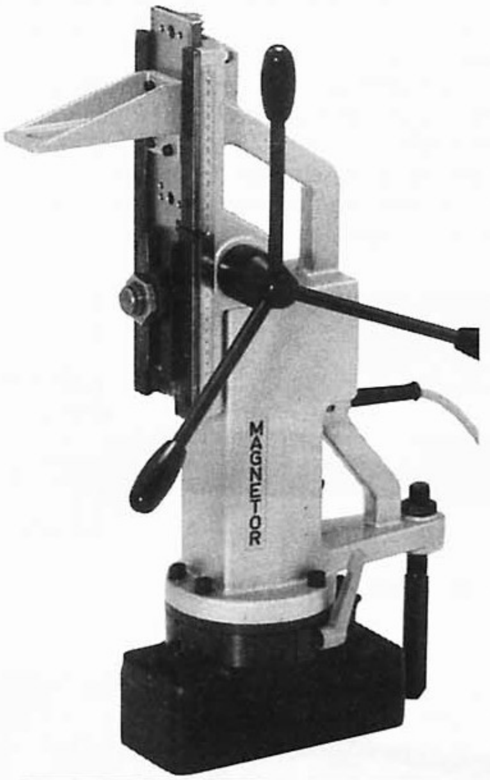



**Figure 4** Press stand with magnetic base

## Grinders

Grinders are powered either electrically or pneumatically. They are similar in shape, and safety must be observed at all times.

There are three types of portable grinder:

- angle grinders;
- straight grinders;
- die grinders (pencil grinder).

### The Angle Grinder

The angle grinder is used for rapid removal of weld beads and similar work on flat or external shapes, using a disc wheel. Also, a suitable flaring cup wheel can be mounted for similar applications. With a suitable cut-off wheel, bar tube and plate can be readily and quickly cut, and in the foundry, risers and runners can be efficiently cut from castings. Using the flexible backing pad with a cloth-backed abrasive disc many grinding operations can be achieved where a smoother finish is required.

#### Attachments

The following attachments are available for the angle grinder.

- a flexible backing pad and nut;
- cup wheel flanges;
- cup wheel guard;
- a disc wheel flange and nut;
- a spacer cut-off wheel;
- a grooving and cutting guide;
- side handles;
- a cut-off stand – with this attachment the work is well supported for safe use; the material may be cut with accurate straight or angular cuts. (See Figs 5 and 6.)


**Figure 5** Portable grinder—angle type

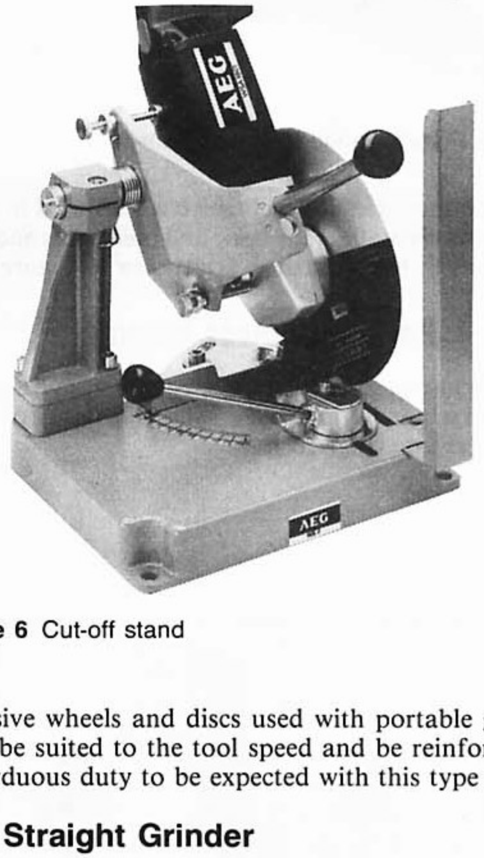



**Figure 6** Cut-off stand

Abrasive wheels and discs used with portable grinders must be suited to the tool speed and be reinforced for the arduous duty to be expected with this type of tool.

### The Straight Grinder

The straight grinder is used for similar operations to those of the angular grinder, but, where a straight wheel is desirable, can also be fitted with a pot ball wheel. This type of grinder is not as well suited to cut-off operations. (Fig. 7.)

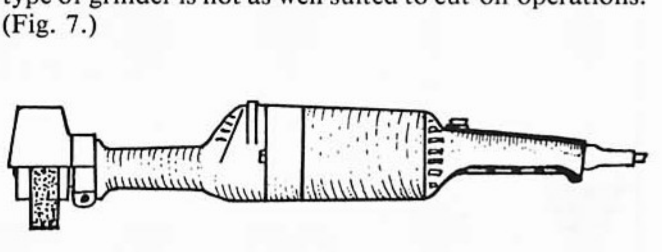


**Figure 7** Portable grinder—straight type

## The Die Grinder

The die grinder (pencil grinder) (Fig. 8) is either electrically or pneumatically driven. The grinding wheels are cemented to a shank, commonly called mounted points. They fit into a collet in the grinder, which can be either 6.35 mm ($\frac{1}{4}$ inch) or 3.18 mm ($\frac{1}{8}$ inch) depending on the size of the unit. Speeds of up to 64 000 r.p.m. are obtainable on the small unit and are necessary for small mounted points.


**Figure 8** Portable grinder—small die type

Several mounted point abrasive wheels used in finishing operations of dies for plastic and press tools and many other uses in the workshop are shown in Figure 9.

## Portable power hammers

Portable hammers are used for chipping, cutting sheet metal, riveting, driving bushes, shearing light bolts, and bursting rivets. (Fig. 10.)

Demolition hammers are used for larger work, such as cutting grooves into concrete, breaking concrete and shearing bolts, etc. (Fig. 11.)

Tools available are for: descaling boilers, etc., pavement breaking, shearing steel plates, general purposes, peening rivets.

Special cutting chisels made from copper alloys will not produce sparking and are used in power hammers where danger from explosion exists.

**Figure 10** Portable power hammer—air driven


**Figure 11** Portable power hammer—electric

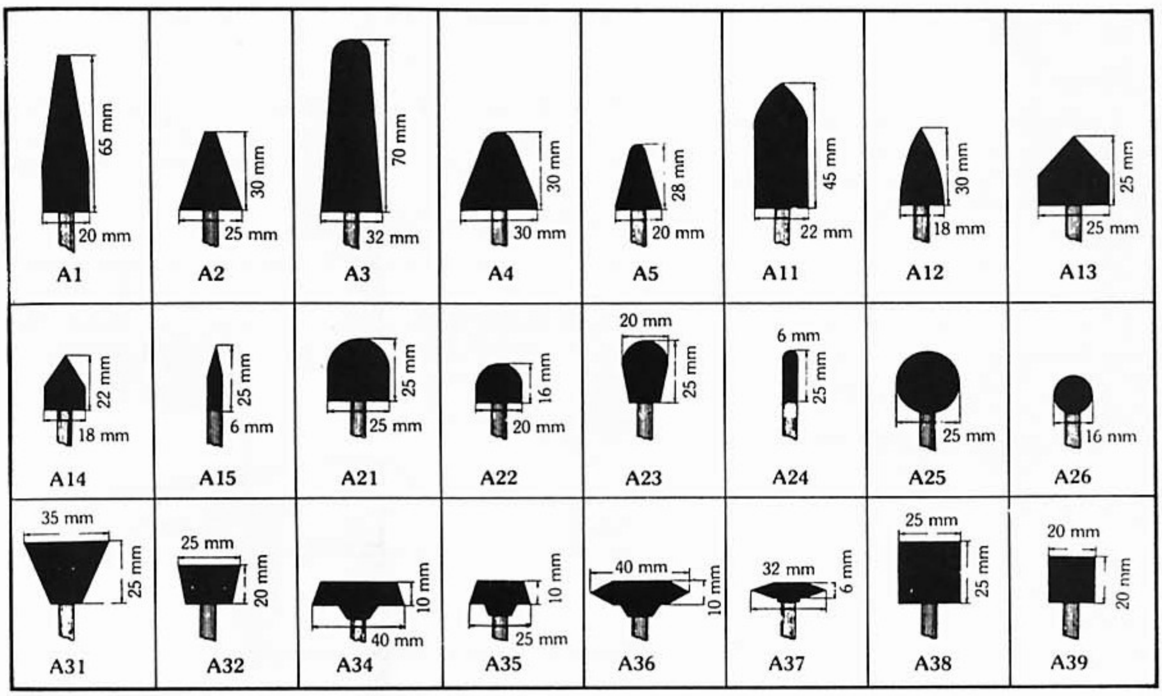



**Figure 9** Standard shapes of mounted points

## Nibblers and shears

Nibblers These cut a continuous slot, a slug being removed at each stroke, and no problems arise in cutting into and across wide and thick sheets. There is no distortion to flat, convex or concave surfaces. (Fig. 12.)


**Figure 12** Electric nibbler

The larger machines are made with narrow and wide punches. The narrow punch machines have a greater capacity to weight ratio, but have limited radii. Wide punch machines can produce very small radii.

Nibbler punches and dies (and shear cutters) can be reground on a freehand grinding wheel.

Shears These work with a scissor-like action without loss of material. They are particularly suitable for trimming work and on thinner sheets are very fast in operation, depending on material thickness. (Fig. 13.)


**Figure 13** Electric shear

## Circular saws

Cutting blades are available for circular saws in toothed cutting or toothed friction types. (Fig. 14.) It is necessary to select a blade with an appropriate tooth pitch. Thin sheet material should never be cut with coarse tooth blades. A cut-off reinforced grinding wheel can also be used, which then makes it suited to cutting almost any materials.

Electrically driven circular saws are available as:

- single speed;
- multi speed;


**Figure 14** Portable circular saw

- variable speed;
- angular tilt.

Pneumatically driven types are either:

- variable speed; or
- angular tilt.

## Jig saws

Jig saws (Fig. 15) are suitable for cutting profiles on flat or curved surfaces. Adjustable guides permit cutting parallel to an edge, or cutting a circle from a central point. Cutting blades are available to cut:

- ferrous metal
- non-ferrous metal
- masonry
- ceramics
- wood
- plastics
- rubber
- cloth
- paper
- fibre glass.

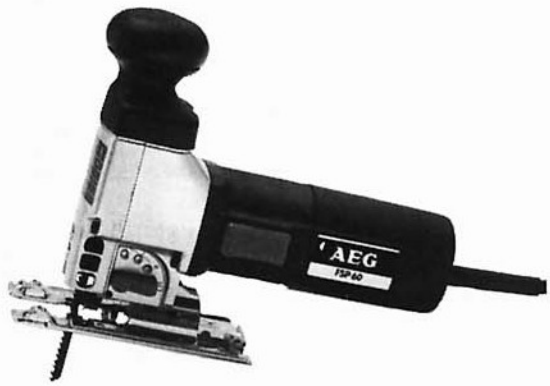



**Figure 15** Jig saw

# Power wrenches

Power wrenches are either electrically or pneumatically powered. (Figs 16 and 17.)
Types available are:

- variable torque; or
- reversible.

Hexagon sockets to suit a complete range of nut sizes are available. Power wrenches may also be used to tap threads in thin material.

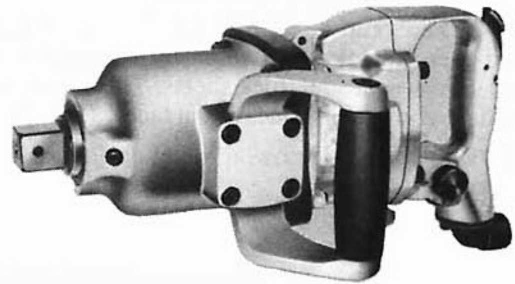
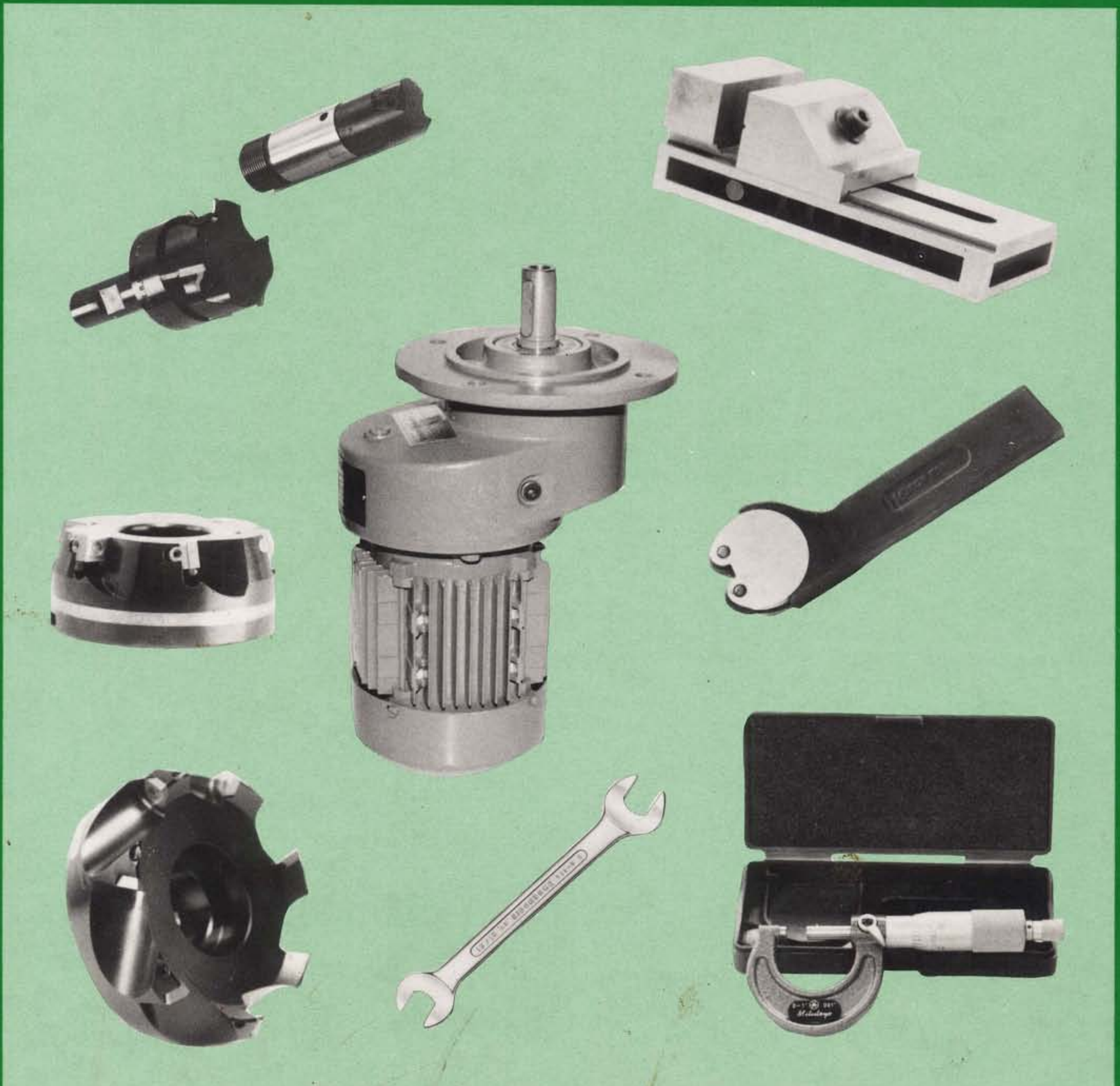


**Figure 17** Power wrench-large impact type

**Figure 16** Power wrench-pistol grip reversible

# Fitting and Machining



# Fitting and Machining

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Ron Culley

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# Useful facts and figures

## 1 Mathematical signs and common abbreviations

| | |
|---|---|
| + | Plus sign of addition |
| + | Positive number >0 |
| − | Minus sign of subtraction |
| − | Negative number <0 |
| × | Multiplied by |
| ÷ | Divided by |
| : | Is to, in proportion |
| = | Equals |
| $a$ | Numerator |
| $b$ | Denominator |
| % | Per cent |
| $\pi$ | Pi 3.1416 |
| > | Greater than |
| < | Less than |
| ∴ | Therefore |
| ∵ | Because |
| $\sqrt{a}$ | Square root of $a$ |
| $\sqrt[3]{a}$ | Cube root of $a$ |
| $\sqrt[4]{a}$ | 4th root of $a$ |
| $\sqrt[n]{a}$ | $n$th root of $a$ |
| $a^2$ | $a$ squared (2nd power of $a$) |
| $a^3$ | $a$ cubed (3rd power of $a$) |
| $a^4$ | 4th power of $a$ |
| $a^n$ | $n$th power of $a$ |
| $\frac{1}{a}$ | Reciprocal value of $a$ |
| $\mu$m or $\mu$ | Micrometre ($10^{-6}$, 0.000001 m) |
| mm | Millimetre ($10^{-3}$, 0.001 m) |
| cm | Centimetre ($10^{-2}$, 0.01 m) |
| m | Metre |
| km | Kilometre (1000 m) |
| $mm^2$ | Square millimetre |
| $cm^2$ | Square centimetre |
| $m^2$ | Square metre |
| $km^2$ | Square kilometre |
| g | Gram |
| kg | Kilogram (1000 g) |
| t | Tonne (1000 kg) |
| mL | Millilitre |
| L | Litre (1000 mL) |
| ML | Megalitre (1000 L) |
| p.s.i. | Pounds per square inch, unit of pressure |
| Pa | Pascal, unit of pressure = 1 $N/m^2$ |
| kPa | Kilopascal |

| | |
|---|---|
| N | Newton |
| Nm | Newton metre |
| g | Acceleration due to gravity, 9.81 m/sec (32.16 ft/sec) |
| ∠ | Angle |
| ∟ | Right angle |
| ⊥ | Perpendicular to |
| ° | Degree (angle or temperature) |
| ′ | Minute ($\frac{1}{60}$ of degree) |
| ″ | Second ($\frac{1}{60}$ of minute) |
| ( ) | Parentheses |
| [ ] | Brackets |
| sin | Sine |
| cos | Cosine |
| tan | Tangent |
| cot | Cotangent |
| sec | Secant |
| cosec | Cosecant |
| V | Volt |
| A | Ampere |
| W | Watt V X A |
| Hz | Hertz, Frequency |
| $p$ | Diametral pitch in gearing (commonly DP) |
| $m$ | Module pitch in gearing |
| CLA | Centre line average |
| Ra | Roughness average, in $\mu$m units |
| UTS | Ultimate tensile strength |
| TSI | Tons per sq inch, Tensile strength imperial |
| $N/mm^2$, MPa | Newtons per sq millimetre, Tensile strength metric |
| HRC, Rc | Hardness number Rockwell read on C scale |
| HRB, Rb | Hardness number Rockwell read on B scale |
| HRA, Ra | Hardness number Rockwell read on A scale |
| VHN, HV | Number, Hardness Vickers |
| BHN, HB | Number, Hardness Brinell |
| AS | (followed by a number) Australian Standard |
| BS | (followed by a number) British Standard |
| ISO | (followed by a number) International Standard |
| ANSI | (followed by a number) American Standard |

See Chapter 3 for all abbreviations used on drawings.

# II Conversion factors for common engineering units

| Quantity | To convert | Into | Multiply by |
|---|---|---|---|
| Length | inches | millimetres | ×25.4 |
| | feet | metres | ×0.3048 |
| | yards | metres | ×0.9144 |
| | miles | kilometres | ×1.6093 |
| | millimetres | inches | ×0.039 37 |
| | metres | feet | ×3.2808 |
| | kilometres | miles | ×0.6213 |
| Area | square yards | square metres | ×0.836 13 |
| | square feet | square metres | ×0.0929 |
| | square inches | square millimetres | ×645.16 |
| | square metres | square yards | ×1.195 99 |
| | square metres | square feet | ×10.7639 |
| | square millimetres | square inches | ×0.001 55 |
| Volume | cubic inches | cubic centimetres | ×16.3871 |
| | cubic inches | litres | ×0.016 387 |
| | cubic feet | cubic metres | ×0.028 31 |
| | cubic feet | litres | ×28.3168 |
| | UK gallon | litres | ×4.546 |
| | cubic centimetres | cubic inches | ×0.0610 |
| | litres | cubic inches | ×61.0237 |
| | litres | cubic feet | ×0.035 31 |
| | litres | UK gallons | ×0.219 969 |
| | cubic metres | cubic feet | ×35.3147 |
| Velocity | feet per second | metres per second | ×0.3048 |
| | feet per minute | metres per minute | ×0.3048 |
| | miles per hour (mph) | kilometres per hour (km/h) | ×1.609 344 |
| | metres per second | feet per second | ×3.280 84 |
| | metres per minute | feet per minute | ×3.280 84 |
| | kilometres per hour (km/h) | miles per hour (mph) | ×0.621 371 |
| Mass | pounds | kilograms | ×0.453 59 |
| | UK tons | tonnes (1000 kg) | ×1.016 05 |
| | kilograms | pounds | ×2.2046 |
| | tonnes (1000 kg) | UK tons | ×0.9842 |
| Density | pounds per cubic foot | kilograms per cubic metre | ×16.0185 |
| | kilograms per cubic metre | pounds per cubic foot | ×0.062 42 |
| Force | pound-force | newton | ×4.4482 |
| | kilogram-force | newton | ×9.806 65 |
| | newton | pound-force | ×0.2248 |
| Moment of a force | pound-force foot | newton metre | ×1.3558 |
| | pound-force foot | kilogram-force metre | ×0.138 255 |
| | newton metre | pound-force foot | ×0.737 56 |
| Stress | UK ton-force per square inch | newton per square millimetre | ×15.4443 |
| | UK ton-force per square inch | meganewton per square metre | ×15.4443 |
| | UK ton-force per square inch | megapascal | ×15.4443 |
| | newton per square millimetre | UK ton-force per square inch | ×0.064 749 |
| | meganewton per square metre | UK ton-force per square inch | ×0.064 749 |
| | megapascal | UK ton-force per square inch | ×0.064 749 |
| Pressure | pound-force per square inch | newton per square metre | ×6894.76 |
| | pound-force per square inch | pascal | ×6894.76 |
| | newton per square metre | pound-force per square inch | $\times 1.450\,38 \times 10^{-4}$ |
| | pascal | pound-force per square inch | $\times 1.450\,38 \times 10^{-4}$ |
| Temperature | degrees F | degrees C | $(F° - 32) \times \frac{5}{9}$ |
| | degrees C | degrees F | $(\frac{9}{5} \times °C) + 32$ |

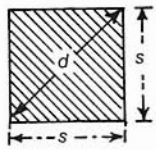
# III Converting millimetres to inches

This chart can be used when converting the dimensions on metric drawings to the settings on English machine tools. For example: required depth of cut is 6 mm; setting on cross-slide dial is 0.236 in.

| mm | in. | mm | in. | mm | in. | mm | in. |
|---|---|---|---|---|---|---|---|
| 0.001 | 0.000 039 4 | 6 | 0.236 220 5 | 38 | 1.496 063 0 | 70 | 2.755 905 5 |
| 0.002 | 0.000 078 7 | 7 | 0.275 590 6 | 39 | 1.535 433 1 | 71 | 2.795 275 6 |
| 0.003 | 0.000 118 1 | 8 | 0.314 960 6 | 40 | 1.574 803 1 | 72 | 2.834 645 7 |
| 0.004 | 0.000 157 5 | 9 | 0.354 330 7 | 41 | 1.614 173 2 | 73 | 2.874 015 7 |
| 0.005 | 0.000 196 9 | 10 | 0.393 700 8 | 42 | 1.653 543 3 | 74 | 2.913 385 8 |
| 0.006 | 0.000 236 2 | 11 | 0.433 070 9 | 43 | 1.692 913 4 | 75 | 2.952 755 9 |
| 0.007 | 0.000 275 6 | 12 | 0.472 440 9 | 44 | 1.732 283 5 | 76 | 2.992 126 0 |
| 0.008 | 0.000 315 0 | 13 | 0.511 811 0 | 45 | 1.771 653 5 | 77 | 3.031 496 1 |
| 0.009 | 0.000 354 3 | 14 | 0.551 181 1 | 46 | 1.811 023 6 | 78 | 3.070 866 1 |
| 0.01 | 0.000 393 7 | 15 | 0.590 551 2 | 47 | 1.850 393 7 | 79 | 3.110 236 2 |
| 0.02 | 0.000 787 4 | 16 | 0.629 921 3 | 48 | 1.889 763 8 | 80 | 3.149 606 3 |
| 0.03 | 0.001 181 1 | 17 | 0.669 291 3 | 49 | 1.929 133 9 | 81 | 3.188 976 4 |
| 0.04 | 0.001 574 8 | 18 | 0.708 661 4 | 50 | 1.968 503 9 | 82 | 3.228 346 5 |
| 0.05 | 0.001 968 5 | 19 | 0.748 031 5 | 51 | 2.007 874 0 | 83 | 3.267 716 5 |
| 0.06 | 0.002 362 2 | 20 | 0.787 401 6 | 52 | 2.047 244 1 | 84 | 3.307 086 6 |
| 0.07 | 0.002 755 9 | 21 | 0.826 771 7 | 53 | 2.086 614 2 | 85 | 3.346 456 7 |
| 0.08 | 0.003 149 6 | 22 | 0.866 141 7 | 54 | 2.125 984 2 | 86 | 3.385 826 8 |
| 0.09 | 0.003 543 3 | 23 | 0.905 511 8 | 55 | 2.165 354 3 | 87 | 3.425 196 8 |
| 0.1 | 0.003 937 0 | 24 | 0.944 881 9 | 56 | 2.204 724 4 | 88 | 3.464 566 9 |
| 0.2 | 0.007 874 0 | 25 | 0.984 252 0 | 57 | 2.244 094 5 | 89 | 3.503 937 0 |
| 0.3 | 0.011 811 0 | 26 | 1.023 622 0 | 58 | 2.283 464 6 | 90 | 3.543 307 1 |
| 0.4 | 0.015 748 0 | 27 | 1.062 992 1 | 59 | 2.322 834 6 | 91 | 3.582 677 2 |
| 0.5 | 0.019 685 0 | 28 | 1.102 362 2 | 60 | 2.362 204 7 | 92 | 3.622 047 2 |
| 0.6 | 0.023 622 0 | 29 | 1.141 732 3 | 61 | 2.401 574 8 | 93 | 3.661 417 3 |
| 0.7 | 0.027 559 1 | 30 | 1.181 102 4 | 62 | 2.440 944 9 | 94 | 3.700 787 4 |
| 0.8 | 0.031 496 1 | 31 | 1.220 472 4 | 63 | 2.480 315 0 | 95 | 3.740 157 5 |
| 0.9 | 0.035 433 1 | 32 | 1.259 842 5 | 64 | 2.519 685 0 | 96 | 3.779 527 6 |
| 1 | 0.039 370 1 | 33 | 1.299 212 6 | 65 | 2.559 055 1 | 97 | 3.818 897 6 |
| 2 | 0.078 740 2 | 34 | 1.338 582 7 | 66 | 2.598 425 2 | 98 | 3.858 267 7 |
| 3 | 0.118 110 2 | 35 | 1.377 952 8 | 67 | 2.637 795 3 | 99 | 3.897 637 8 |
| 4 | 0.157 480 3 | 36 | 1.417 322 8 | 68 | 2.677 165 4 | 100 | 3.937 007 9 |
| 5 | 0.196 850 4 | 37 | 1.456 692 9 | 69 | 2.716 535 4 | | |

# IV Areas and related formulae of plane figures

### Square




$A$ = area

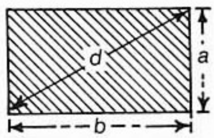
$A = s^2$

$A = \frac{1}{2} d^2$

$s = 0.7071d = \sqrt{A}$

$d = 1.414s = 1.414\sqrt{A}$

### Rectangle




$A$ = area

$A = ab$

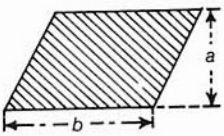
$A = a\sqrt{d^2 - a^2} = b\sqrt{d^2 - b^2}$

$d = \sqrt{a^2 + b^2}$

$a = \sqrt{d^2 - b^2} = A \div b$

$b = \sqrt{d^2 - a^2} = A \div a$

### Parallelogram




$A$ = area

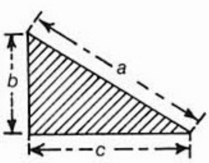
$A = ab$

$a = A \div b$

$b = A \div a$

Note that dimension $a$ is measured at right angles to line $b$.

### Right-angled triangle




$A$ = area

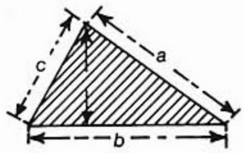
$A = \frac{bc}{2}$

$a = \sqrt{b^2 + c^2}$

$b = \sqrt{a^2 - c^2}$

$c = \sqrt{a^2 - b^2}$

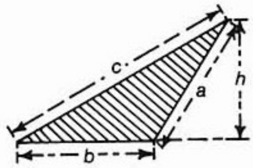
### Acute-angled triangle




$A$ = area

$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2}$$

### Obtuse-angled triangle



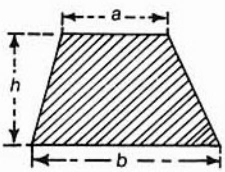

$A$ = area

$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{c^2 - a^2 - b^2}{2b}\right)^2}$$

If $S = \frac{1}{2}(a + b + c)$, then

$$A = \sqrt{S(S-a)(S-b)(S-c)}$$

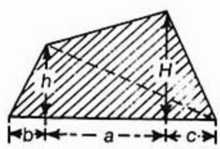
### Trapezoid




$A$ = area

$$A = \frac{(a+b)h}{2}$$

### Trapezium



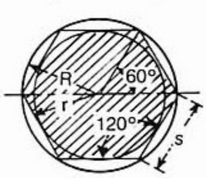

$A$ = area

$$A = \frac{(H+h)\,a + bh + cH}{2}$$

A trapezium can also be divided into two triangles as indicated by the dotted line. The area of each of these triangles is computed, and the results added to find the area of the trapezium.

# Useful facts and figures

## Regular hexagon




$A$ = area;

$R$ = radius of circumscribed circle;

$r$ = radius of inscribed circle.

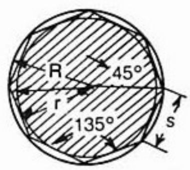
$A = 2.598s^2 = 2.598R^2 = 3.464r^2$

$R = s = 1.155r$

$r = 0.866s = 0.866R$

$s = R = 1.155r$

## Regular octagon




$A$ = area;

$R$ = radius of circumscribed circle;

$r$ = radius of inscribed circle.

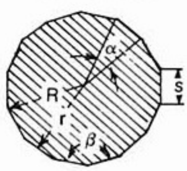
$A = 4.828s^2 = 2.828R^2 = 3.314r^2$

$R = 1.307s = 1.082r$

$r = 1.207s = 0.924R$

$s = 0.765R = 0.828r$

## Regular polygon



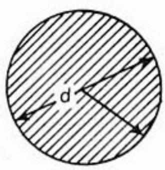

$A$ = area; $n$ = number of sides.

$\alpha = 360° \div n$ $\quad \beta = 180° - \alpha$

$A = \frac{nsr}{2} = \frac{ns}{2}\sqrt{R^2 - \frac{s^2}{4}}$

$R = \sqrt{r^2 + \frac{s^2}{4}};\ r = \sqrt{R^2 - \frac{s^2}{4}};\ s = 2\sqrt{R^2 - r^2}$

## Circle




$A$ = area; $C$ = circumference

$A = \pi r^2 = 3.1416r^2 = 0.7854d^2$

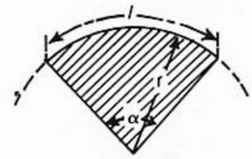
$C = 2\pi r = 6.2832r = 3.1416d$

$r = C \div 6.2832 = \sqrt{A \div 3.1416} = 0.564\sqrt{A}$

$d = C \div 3.1416 = \sqrt{A \div 0.7854} = 1.128\sqrt{A}$

Length of arc for centre-angle of $1° = 0.008727d$
Length of arc for centre-angle of $n° = 0.008727nd$

## Circular sector



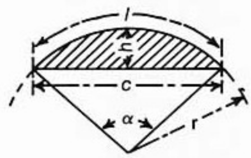

$A$ = area; $l$ = length of arc; $\alpha$ = angle, in degrees

$l = \frac{r \times \alpha \times 3.1416}{180} = 0.01745r\alpha = \frac{2A}{r}$

$A = \frac{1}{2}rl = 0.008727\alpha r^2$

$\alpha = \frac{57.296l}{r} \quad r = \frac{2A}{l} = \frac{57.296l}{\alpha}$

## Circular segment



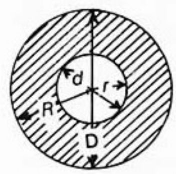

$A$ = area; $l$ = length of arc; $\alpha$ = angle, in degrees.

$c = 2\sqrt{h(2r-h)}$ $\quad A = \frac{1}{2}[rl - c(r-h)]$

$r = \frac{c^2 + 4h^2}{8h}$ $\quad l = 0.01745r\alpha$

$h = r - \frac{1}{2}\sqrt{4r^2 - c^2}$ $\quad \alpha = \frac{57.296l}{r}$

## Circular ring



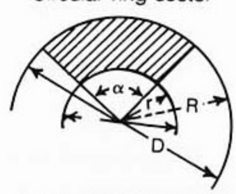

$A$ = area

$A = \pi(R^2 - r^2) = 3.1416(R^2 - r^2)$

$= 3.1416(R + r)(R - r)$

$= 0.7854(D^2 - d^2) = 0.7854(D + d)(D - d)$

## Circular ring sector

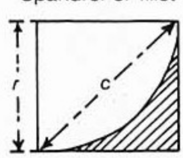



$A$ = area; $\alpha$ = angle, in degrees.

$A = \frac{\alpha\pi}{360}(R^2 - r^2) = 0.00873\alpha(R^2 - r^2)$

$= \frac{\alpha\pi}{4 \times 360}(D^2 - d^2) = 0.00218\alpha(D^2 - d^2)$

## Spandrel or fillet



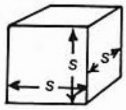

$A$ = area

$A = r^2 - \frac{\pi r^2}{4} = 0.215r^2$

$= 0.1075c^2$

# V Volumes

### Cube

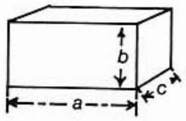



$V$ = volume

$$V = s^3$$

$$s = \sqrt[3]{V}$$

### Square prism

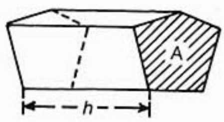



$V$ = volume

$$V = abc$$

$$a = \frac{V}{bc} \quad b = \frac{V}{ac} \quad c = \frac{V}{ab}$$

### Prism

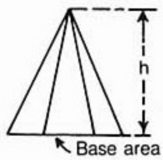



$V$ = volume; $A$ = area of end surface

$$V = h \times A$$

The area $A$ of the end surface is found by the formulas for areas of plane figures on the preceding pages. Height $h$ must be measured perpendicular to end surface.

### Pyramid



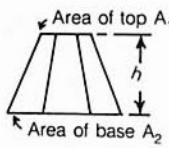

$V$ = volume

$V = \frac{1}{3}h \times$ area of base.

If the base is a regular polygon with $n$ sides, and $s$ = length of side, $r$ = radius of inscribed circle, and $R$ = radius of circumscribed circle, then:

$$V = \frac{nsrh}{6} = \frac{nsh}{6}\sqrt{R^2 - \frac{s^2}{4}}$$

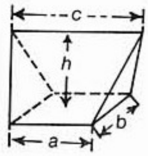
### Frustrum of pyramid




$V$ = volume

$$V = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 \times A_2})$$

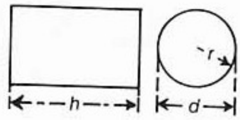
### Wedge




$V$ = volume

$$V = \frac{(2a + c)bh}{6}$$

### Cylinder




$V$ = volume; $S$ = area of cylindrical surface

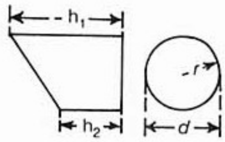
$$V = 3.1416r^2h = 0.7854d^2h$$

$$S = 6.2832rh = 3.1416dh$$

Total area $A$ of cylindrical surface and end surfaces:

$$A = 6.2832r\,(r + h) = 3.1416d\,(\tfrac{1}{2}d + h)$$

### Portion of cylinder

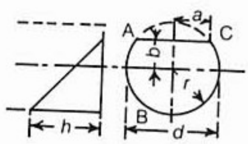



$V$ = volume; $S$ = area of cylindrical surface

$$V = 1.5708r^2\,(h_1 + h_2) = 0.3927d^2\,(h_1 + h_2)$$

$$S = 3.1416r\,(h_1 + h_2) = 1.5708d\,(h_1 + h_2)$$

### Portion of cylinder



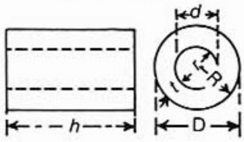

$V$ = volume; $S$ = area of cylindrical surface

$$V = \left(\frac{2}{3}a^3 \pm b \times \text{area } ABC\right)\frac{h}{r \pm b}$$

$$S = (ad \pm b \times \text{length of arc } ABC)\,\frac{h}{r \pm b}$$

Use + when base area is larger, and − when base area is less than one-half the base circle.

### Hollow cylinder




$V$ = volume

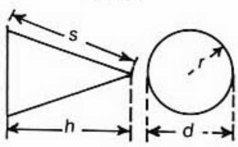
$V = 3.1416h\,(R^2 - r^2) = 0.7854h\,(D^2 - d^2)$

$= 3.1416ht\,(2R - t) = 3.1416ht\,(D - t)$

$= 3.1416ht\,(2r + t) = 3.1416ht\,(d + t)$

$= 3.1416ht\,(R + r) = 1.5708ht\,(D + d)$

### Cone



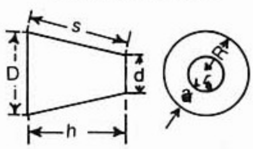

$V$ = volume; $A$ = area of conical surface

$V = \dfrac{3.1416r^2h}{3} = 1.0472\,r^2h = 0.2618\,d^2h$

$A = 3.1416\,r\,\sqrt{r^2 + h^2} = 3.1416\,rs = 1.5708\,ds$

$s = \sqrt{r^2 + h^2} = \sqrt{\dfrac{d^2}{4} + h^2}$

### Frustum of cone



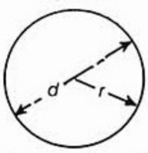

$V$ = volume; $A$ = area of conical surface

$V = 1.0472\,h(R^2 + Rr + r^2) = 0.2618\,h(D^2 + Dd + d^2)$

$A = 3.1416\,s(R + r) = 1.5708\,s(D + d)$

$a = R - r \quad s = \sqrt{a^2 + h^2} = \sqrt{(R - r)^2 + h^2}$

### Sphere



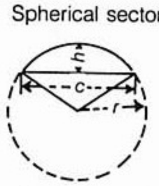

$V$ = volume; $A$ = area of surface

$V = \dfrac{4\pi r^3}{3} = \dfrac{\pi d^3}{6} = 4.1888\,r^3 = 0.5236\,d^3$

$A = 4\pi r^2 = \pi d^2 = 12.5664\,r^2 = 3.1416\,d^2$

$r = \sqrt[3]{\dfrac{3V}{4\pi}} = 0.6204\,\sqrt[3]{V}$

### Spherical sector



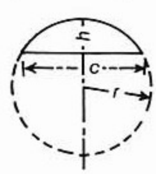

$V$ = volume; $A$ = total area of conical and spherical surface

$V = \dfrac{2\pi r^2h}{3} = 2.0944r^2h$

$A = 3.1416\,r\,(2h + \tfrac{1}{2}c)$

$c = 2\sqrt{h(2r - h)}$

### Spherical segment



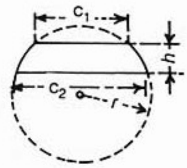

$V$ = volume; $A$ = area of spherical surface

$V = 3.1416h^2\left(r - \dfrac{h}{3}\right) = 3.1416\,h\left(\dfrac{c^2}{8} + \dfrac{h^2}{6}\right)$

$A = 2\pi rh = 6.2832\,rh = 3.1416\left(\dfrac{c^2}{4} + h^2\right)$

$c = 2\sqrt{h(2r - h)}$; $r = \dfrac{c^2 + 4h^2}{8h}$

### Spherical zone



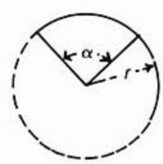

$V$ = volume; $A$ = area of spherical surface

$V = 0.5236\,h\left(\dfrac{3c_1^2}{4} + \dfrac{3c_2^2}{4} + h^2\right)$

$A = 2\pi rh = 6.2832\,rh$

$r = \sqrt{\dfrac{c_2^2}{4} + \left(\dfrac{c_2^2 - c_1^2 - 4h^2}{8h}\right)^2}$

### Spherical wedge

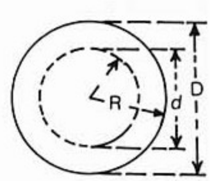



$V$ = volume; $A$ = area of spherical surface;
$\alpha$ = centre angle in degrees

$V = \dfrac{\alpha}{360} \times \dfrac{4\pi r^3}{3} = 0.0116\alpha r^3$

$A = \dfrac{\alpha}{360} \times 4\pi r^2 = 0.0349\alpha r^2$

### Hollow sphere




$V$ = volume

$V = \dfrac{4\pi}{3}\,(R^3 - r^3) = 4.1888\,(R^3 - r^3)$

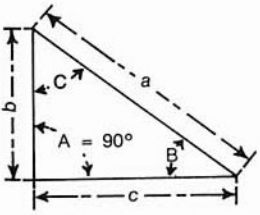
$= \dfrac{\pi}{6}\,(D^3 - d^3) = 0.5236\,(D^3 - d^3)$

# VI Geometrical propositions

- The sum of three angles in a triangle always equals 180°; then if two angles are known the other can be found.
- If three sides of a triangle are of equal length then the three angles enclosed are also equal, i.e. it is an equilateral triangle. A line bisecting an angle also bisects the side opposite.
- If only two sides of a triangle are equal in length, then the angles opposite them are also equal, i.e. it is an isosceles triangle. A line bisecting the angle formed by the two equal sides bisects the other side at right angles to it.
- In any triangle the angle opposite the longest side is the largest angle, and the sum of the length of two sides is greater than the third.
- When two lines intersect then the opposite angles are equal and the sum of the four angles = 360°.
- Any plane figure having four sides has a total of 360° in the four angles formed.
- If a chord in a circle is bisected and a line drawn from it to the centre of the circle a right angle is produced.
- A tangent to a circle is at right angles to a line from the tangent point to the circle centre.
- In any triangle inscribed in a semicircle the angle opposite the diameter is a right angle (90°).
- A right angle (90°) can be produced by using a triangle where the sides are in the proportion of 3:4:5.

# VII Right-angled triangles

## Solution of right-angled triangles




As shown in the illustration, the sides of the right-angled triangle are designated *a*, *b* and *c*. The angles opposite each of these sides are designated *A*, *B* and *C* respectively.

Angle *A*, opposite the hypotenuse a is the right angle, and is therefore always one of the known quantities.

| Sides and angles known | Formulae for sides and angles to be found | | |
|---|---|---|---|
| Sides *a* and *b* ... | $c=\sqrt{a^2-b^2}$ | $\sin B=\frac{b}{a}$ | $C=90°-B$ |
| Sides *a* and *c*... | $b=\sqrt{a^2-c^2}$ | $\sin C=\frac{c}{a}$ | $B=90°-C$ |
| Sides *b* and *c*... | $a=\sqrt{b^2+c^2}$ | $\tan B=\frac{b}{c}$ | $C=90°-B$ |
| Side *a*; angle *B*... | $b=a\times\sin B$ | $c=a\times\cos B$ | $C=90°-B$ |
| Side *a*; angle *C*... | $b=a\times\cos C$ | $c=a\times\sin C$ | $B=90°-C$ |
| Side *b*; angle *B*... | $a=\frac{b}{\sin B}$ | $c=b\times\cot B$ | $C=90°-B$ |
| Side *b*; angle *C*... | $a=\frac{b}{\cos C}$ | $c=b\times\tan C$ | $B=90°-C$ |
| Side *c*; angle *B*... | $a=\frac{c}{\cos B}$ | $b=c\times\tan B$ | $C=90°-B$ |
| Side *c*; angle *C*... | $a=\frac{c}{\sin C}$ | $b=c\times\cot C$ | $B=90°-C$ |

# XI Mechanics

Machines have certain mechanical features that can modify the effort required to perform a unit of work. Levers, pulleys, etc. are examples of mechanical devices that exhibit these features.

## The Principle of Work

The force applied, multipied by the distance through which it moves, equals the resistance overcome multiplied by the distance through which it is overcome. Thus:

Force × distance = load × distance

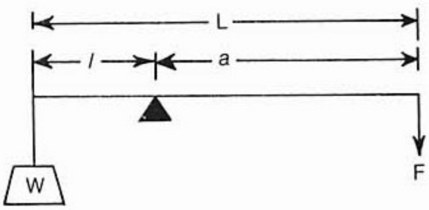
(In the following pages the force F is expressed in kilograms, not in newtons.)

## Levers

The fulcrum or pivot point of the lever is shown in the following diagrams thus ▲ . All values are in millimetres and kilograms.

*Examples:*

### First-order Levers




$F : W = l : a$

$F \times a = W \times l$

$$F = \frac{W \times l}{a}$$

$$W = \frac{F \times a}{l}$$

$$a = \frac{W \times L}{W \times F} = \frac{W \times l}{F}$$

$$l = \frac{F \times L}{W \times F} = \frac{F \times a}{W}$$

*Example:*

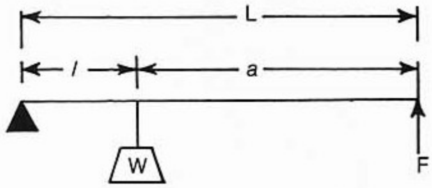
$W$ is a weight of 36 kg. What force, $F$, is required to balance the lever, when $l = 310$, $a = 820$?

$$F = \frac{36 \times 310}{820} = 13.61 \text{ kg}$$

How long must $a$ be to balance the lever when $F = 500$, $W = 4575$, $l = 75$?

$$a = \frac{4575 \times 75}{500} = 686.25 \text{ mm}$$

### Second-order Levers




$F : W = l : L$ $\quad$ $F \times L = W \times l$

$$F = \frac{W \times l}{L} \qquad W = \frac{F \times l}{l}$$

$$L = \frac{W \times a}{W - F} \qquad L = \frac{W \times l}{F}$$

$$l = \frac{F \times a}{W - f} \qquad l = \frac{F \times L}{W}$$

*Example:*

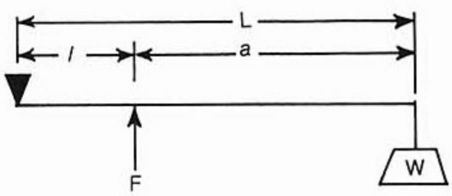
The length, $L$, is 635 mm, $W = 40$, $l = 254$. What force, $F$, is required to hold it horizontal?

$$F = 40 \times \frac{254}{635} = 16 \text{ kg}$$

If $F = 45$, $W = 998$, $a = 1525$, what value must $L$ have to secure equilibrium?

$$L = \frac{998 \times 1525}{998\text{–}45} = 1597 \text{ mm}$$

### Third-order Levers




$F : W = L : l$ $\; F \times l = W \times L$

$$F = \frac{W \times L}{l} \qquad W = \frac{F \times l}{L}$$

*Example:*

$$l = \frac{W \times a}{F\text{–}W} = \frac{W \times L}{F}$$

$$L = \frac{F \times a}{F\text{–}W} = \frac{F \times l}{W}$$

$F = 13$, $l = 250$, $a = 610$ mm

What weight $W$ can be supported?

$L = a + l = 610 + 250 = 860\text{mm}$

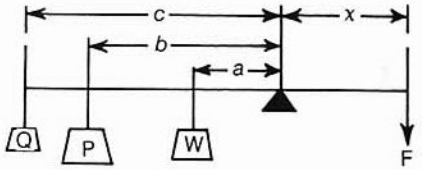
$$W = \frac{13 \times 250}{860} = 3.78 \text{ kg}$$

If $F = 1000$, $W = 450$, $a = 500$, find $l$ and $L$.

$$l = \frac{450 \times 500}{1000 - 450} = \frac{225000}{550} = 409.1 \text{ mm}$$

$$L = 500 + 409.1 = 909.1 \text{ mm}$$

When three or more forces act on a lever:




$$F \times x = W \times a + P \times b + Q \times c$$

$$x = \frac{W \times a + P \times b + Q \times c}{F}$$

$$F = \frac{W \times a + P \times b + Q \times c}{x}$$

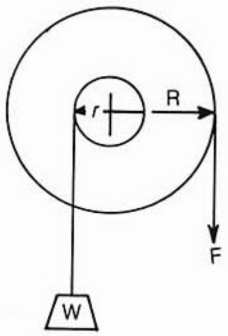
$$W = 20,\ P = 30,\ Q = 15,\ a = 100,\ b = 178,\ c = 254$$

If $x = 150$ find $F$.

$$F = \frac{20 \times 100 + 30 \times 178 + 15 \times 254}{150}$$

$$= \frac{2000 + 5340 + 3810}{150} = 74.3 \text{ kg}$$

## Pulleys and Wheels




$$F : W = r : R$$

$$F \times R = W \times r$$

$$F = \frac{W \times r}{R}$$

$$W = \frac{F \times R}{r}$$

$$R = \frac{W \times r}{F}$$

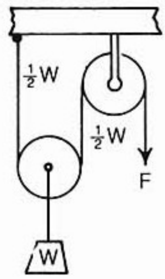
$$r = \frac{F \times R}{W}$$

*Example:*

The lifting rope of a windlass is wound on a drum of radius 50 mm. What force will be exerted at the periphery of a gear of 610 mm radius, mounted on the same shaft as the drum and transmitting power to it, if one tonne (1000 kg) is to be lifted? Here, $W = 1000$; $R = 610$, $r = 50$.

$$F = \frac{1000 \times 50}{610} = 81.96 \text{ kg}$$

*Example:*




$$F = \frac{1}{2} W$$

If $W = 1000$, then

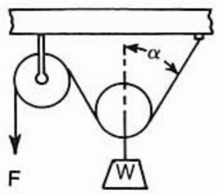
$$F = \frac{1000}{2} = 500 \text{ kg}$$

The velocity with which weight $W$ will be raised equals one-half the velocity of the force applied at $F$.

$$F : W = \sec \alpha : 2$$

$$F = \frac{W \times \sec \alpha}{2}$$

$$W = 2F \times \cos \alpha$$

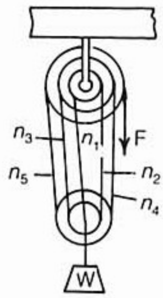



If $\alpha = 30$, then

$$F = \frac{1000 \times 1.1547}{2} = 577.35 \text{ kg}$$

$$W = 2 \times 577.35 \times 0.86603 = 1000 \text{ kg}$$

*Example:*




$n$ = number of strands or parts of rope ($n_1$, $n_2$, etc)

$$F = \frac{1}{n} \times W$$

The velocity with which $W$ will be raised equals $\frac{1}{n}$ of the velocity of the force $F$.

The illustration shows a combination of a double and triple block. The pulleys each turn freely on a pin as axis, and are drawn with different diameters, to show the parts of the rope more clearly. There are five parts of rope.

If 200 kg is to be lifted what force $F$ is required at the end of the rope?

$$F=\frac{1}{5}\times 200=40 \text{ kg}.$$

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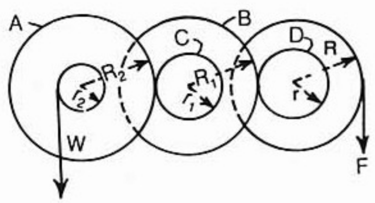
*Example:*

*A, B, C* and *D* are the pitch circles of gears.




$$F=\frac{W\times r\times r_1\times r_2}{R\times R_1\times R_2}$$

$$W=\frac{F\times R\times R_1\times R_2}{r\times r_1\times r_2}$$

If the pitch diameter of gears are $A=760$, $B=712$, $C=306$, $D=256$, then $R_2=380$, $R_1=356$, $r_1=153$, $r=128$, $R=305$, $r_2=100$. What force F is required to lift a weight $W$ 1000 kg (1 tonne) neglecting friction?

$$F=\frac{100\times 128\times 153\times 100}{305\times 356\times 380}=47.46 \text{ kg}$$

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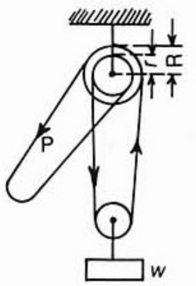
*Example:*




Differential pulley—in the differential pulley a chain must be used, engaging sprockets, so as to prevent the chain from slipping over the pulley faces.

$$P\times R=\frac{1}{2}W(R-r)$$

$$P=\frac{W(R-r)}{2R}$$

$$W=\frac{2PR}{R-r}$$

If $W=1$ tonne (1000 kg), $r=50$, $R=150$, what force is required at $P$ to raise $W$, disregarding friction?

$$P=\frac{1000\times(150–50)}{2\times 150}=\frac{100\ 000}{300}=333.3 \text{ kg}$$

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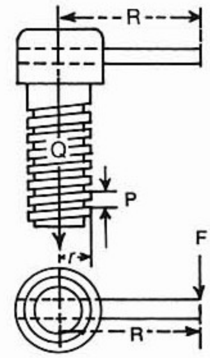
## Screws




$$Q=F\times\frac{6.2832R}{P}$$

$$F=Q\times\frac{P}{6.2832R}$$

where

$F$ = force at end of the handle or wrench

$R$ = radius at which $F$ is applied

$r$ = pitch radius of the screw

$P$ = lead of the thread

$Q$ = resultant force exerted by the screw

Let $F=50$, $R=250$, $r=22.5$ and $P=3$, then, neglecting friction:

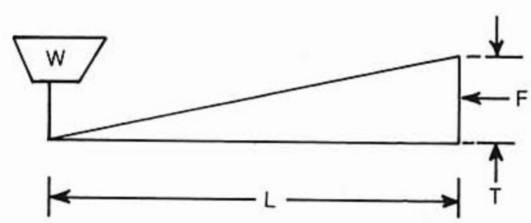
$$Q=F\times\frac{6.2832\times R}{P}=50\times\frac{6.2832\times 250}{3}$$

$$= 26\ 180 \text{ kg}$$

$$F=Q\times\frac{P}{6.2832\times R}=26\ 180\times\frac{3}{6.2832\times 250}$$

$$=50 \text{ kg}$$

## Wedges




$$F:W=T:L$$

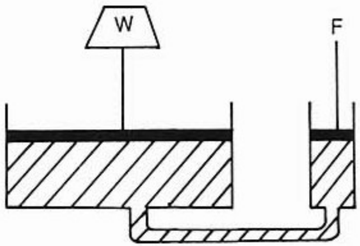
$$F=\frac{T\times W}{L}$$

What force $F$ must be applied to a wedge, where $L=500$, $T=100$, $W=1000$ disregarding friction?

$$F:1000=100:500$$

$$F=\frac{100\times 1000}{500}=200 \text{ kg}$$

## Pascal's Law




The pressure exerted anywhere on an enclosed liquid is transmitted undiminished in all directions to the interior of the container.

$$W{:}F = AL{:}AS$$

$$\frac{W}{F} = \frac{AL}{AS}, \text{ so } W = \frac{AL}{AS} = F$$

where $AF$ = force applied
$AS$ = area of the small piston
$AL$ = area of the large piston
$W$ = resultant force

*Example 1:*

A force $F$ of 100 kg is applied to a 1 $cm^2$ piston. What weight $W$ holds the system in equilibrium if the large piston has an area of 50 $cm^2$?

$$W = \frac{100}{1} \times 50 = 5000 \text{ kg}$$

*Example 2:*

Travel of the pistons is inversely proportional to their areas.

$$AS{:}AL = T{:}t$$

Where $T$ = travel of large piston
$t$ = travel of small piston

In the case shown in Figure A13, $t = 10$ cm

$$T = \frac{AS}{AL} \times t$$

$$= \frac{1}{50} \times 10 = 0.2 \text{ cm}$$

So the large piston travels 0.2 cm.

In all of the above examples no allowance has been made for friction.

# 1

# Workshop hints

## General hints

- Never use a tool too large for the job; over-effort may cause damage — the motto is:
  *Brain first, then brawn.*
- Never stand directly in front of a rotating machine at start-up.
- Use an oilstone or lap for a fine keen tool edge.
- Don't assume it's O.K. as is.
  *Look, think, evaluate, act.*
- Every tool has a purpose—use it for that alone.
- On the lathe, centres can be quickly set up by turning a centre on a piece of material held in the chuck and using a bent tail carrier driving from a chuck jaw. The centre is of course absolutely true.
- Always smear the pilot of a piloted tool with oil before entering the work. The oil can usually be picked up on the finger from some drip or surface of the machine.
- Use a set spanner, the adjustable spanner makes round nuts.
- **Hit** the centre punch before drilling.

## Metal fret

Metal fret is the wearing away of metal through friction. Every precaution should be taken to avoid it, by following the advice below.

- Never assemble two parts together without some lubrication between.

  **Oxygen fittings should not be lubricated; oil and oxygen form an explosive mixture.**
- Screws being assembled into a component should be lubricated. Metal fret can happen rapidly as the load of the tightened screw comes onto the thread flanks. With friction and pressure, the metals can alloy, causing the threads to destroy each other. This is commonly called 'seized thread'.
- A dowel pin driven into a hole of the correct size will seize if not lubricated. Even if cleaned properly the damaged precision hole will become a future fret point.
- Never mount a chuck without first cleaning it and ensuring that there is a light film of oil over the mating surfaces.
- A film of rust can form between two iron surfaces that have been mounted together for some time in dry conditions. This is the result of metal fret. They were probably assembled dry and although appearing not to rub together, in such an assembly they are, in fact, moving minutely, causing friction.
- All mating and moving parts need lubrication, so don't forget this motto:
  *'The oil can is the cheapest machine'*

## Hardening and tempering a small object

It is often necessary to heat treat a small punch, chisel, scriber, scraper, or similar tool using an open flame and it is quite easy and effective using the correct procedure.

Never use the oxygen acetylene torch as this flame is much too severe. If the tool is small it will be burnt, if it is large it will only be skin heated. Use the natural gas/air torch or a propane torch.

### Hardening

Heat the work moving the flame if necessary to spread the heat evenly to a cherry red colour (780° to 800°C, see Table). This colour must be observed in a normal factory light, not in bright sunlight, and with a little experience it is easily discernible. Quench the tool immediately the temperature is reached; usually water is the quenching medium. Agitate the tool vertically in the quench to strip the steam bubbles from its surface.

Hardening temperatures and colours

| °C | Colour |
|---|---|
| 565° | Brown red |
| 600° | Dark red |
| 700° | Blood red |
| 730° | Low cherry red |
| 740° | Low to medium cherry red |
| 750°–760° | Medium cherry red |
| 770°–800° | Cherry red |
| 825° | Bright cherry red |
| 850° | Full red |
| 900°–920° | Bright red |
| 955° | Full bright red |
| 980° | Yellow red |
| 1150° | Yellow |
| 1250° | White |
| 1300°–1330° | Full white |
| 1350°–1360° | Incandescent white |

### Tempering

As soon as the tool is cold, dry and polish it bright with abrasive paper. Do not put your fingers or anything on the bright surface especially in the area that is the working edge of the tool. Using a smaller flame than when hardening, heat the tool slowly and watch for colour change. Keep the tool at the extreme of the flame, not in it. The colour you will see is due to an oxide film, which first appears at 200°C as a very faint straw colour and proceeds through the colour range as the temperature increases. When the desired temper colour is reached (see Table ) the tool is again quenched, although this is not necessary if the heat quickly dissipates and the colours do not go further.

Chisels, punches etc. are usually heated from the end opposite to the cutting edge—in fact, this applies to most tools. The colours will then be able to spread out along the tool and the desired temper obtained at the cutting edge by moving the flame appropriately.

Tempering temperatures and colours

| Temper Colour | °C | Application Guide |
|---|---|---|
| Light straw | 220° | Scrapers, engraving tools |
| Straw | 230° | Paper knives |
| Dark straw | 240° | Scriber, chasers, taps |
| Brown yellow | 255° | Shear blades, punches, dies |
| Red brown | 265° | Wood gouges and chisels, reamers |
| Purple | 275° | Rivet sets |
| Purple blue | 285° | Cold chisels, pin punches |
| Full blue | 295° | Screw drivers |
| Pale blue | 310° | Springs |
| Grey | 330° | |

## Press fit assembly

Where components are press fitted one into the other a lead must be provided to ensure absolute concentricity and alignment. This lead is a *parallel* diameter, a precision location fit with 10 to 15% of the component length usually on the male part, or in the bore, which receives an antifriction bearing. Never use a tapered lead.

## Turning a sleeve bearing

Always finish the outside diameter on a mandrel to ensure roundness and concentricity; the squeeze of the chuck jaws on the cored stock from which it is parted will then not be evident in the finished bearing when assembled.

## Chatter

When all else fails to stop chatter, reduce the speed and increase the feed.

## Setting to marked centre in the lathe

Sharpen a point on a 3 mm brazing rod or similar; place the point in the centre prick and hold the other end in a tailstock chuck. Use the clock indicator on the rod close to the face of the work to set it true.

# 2

# Safety in the workplace

Safety is everyone's responsibility—not just the responsibility of the firm, the people in charge, the teacher or the safety officer. Accidents are prevented by the combined efforts of everyone.

Experience has shown that the best safety measure is a careful worker. It is the duty of every employee to perform work safely as much as it is to do it well. Form the habit of working the safe way, and always be mindful of the safety of your fellow workers.

**Figure 1** Safety items for your protection

## Accidents

There are still far too many accidents in the industrial and materials-handling field. Over recent years the number of accidents involving personal injury and death, or serious damage to machinery, has increased. This may have been partly due to increased mechanization and to the complexity of modern machinery, but to accept these as the only reasons would make it inevitable that the number and the severity of industrial accidents would continue to increase.

While industrial accidents are not publicized as much as road accidents (mainly because of the smaller proportion of fatal accidents), the cost to the community is high when measured in terms of hospital accommodation, personal liability and suffering, damage to equipment and loss of production.

### Causes of Accidents

About 80% of all accidents are directly caused by human error; only a small proportion are attributable to equipment failure. Even the failure of equipment has often been found on further investigation, to be directly attributable to human error. Examples are the lack of maintenance or infrequent inspection of equipment, incorrect and unsafe replacement of parts, and such obvious negligence as faulty work practice.

### Accident Prevention

For many years there have been regulations, standards and codes of practice specifying minimum requirements for the design, manufacture, and use of machines and lifting gear. These regulations appear to have been successful in reducing the number of accidents caused by equipment failure.

## Personal safety

### Eyes

Your eyes are very important to you—protect them. Always wear suitable glasses, goggles or a shield when you are exposed to risk of eye injury. If a foreign body lodges in your eye, seek proper first-aid attention. Do not allow your fellow employee to remove it.

All welding operations should be properly screened, as electric and gas welding can cause damage to your eyes under certain conditions.

If chemicals come into contact with your eyes, immediately apply plenty of clean water and obtain skilled attention as soon as possible.

### Ears

In areas where the noise exceeds a given level, ear muffs must be worn.

### Manual Lifting

During any lifting, your back needs protection. Practising the correct technique during a lift means that when you have to make a heavy lift your back is already trained to be in the correct position.

Bend your knees so that the load can be as near to the body as possible. This guarantees that the centre of gravity of the load is close to the spinal column. Then lift by straightening your knees, and with a straight back, rather than lifting with a straight back only.

If possible, avoid twisting or rotational movements while carrying a heavy load, as this also strains the back. In fact, avoid heavy loads wherever possible.

## First aid

After any type of injury, no matter how small you may think it is, always seek first-aid treatment immediately. Small injuries can become infected, which can lead to serious illness and loss of time. Keeping clean is an important safeguard against infection.

## Orderly workshop habits

### Personal Cleanliness

Personal cleanliness is of the utmost importance and is a fair indication of the attitude of tradespeople to their work. When operators are not clean and tidy in personal appearance and habits, they are unlikely to be any different in their approach to work. A bad approach results in the production of inferior work and is frequently a contributing factor in serious accidents.

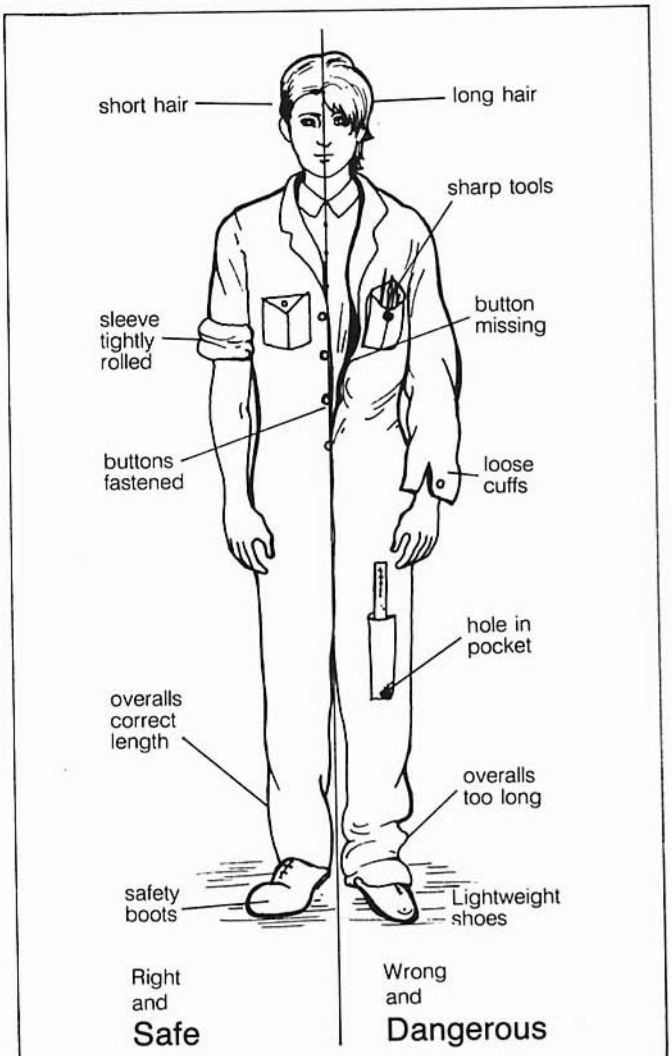



**Figure 2** Right and wrong clothing

Observe these points in regard to clothing, personal cleanliness and appearance (Fig. 2):

- Wear overalls all the time at work. They should be cleaned regularly and must fit comfortably. Loose, ill-fitting and torn clothing can become entangled in machinery and should not be worn. Suitable footwear is essential. Safety boots or shoes fitted with steel toecaps are recommended.
- Long hair is dangerous. Factory regulations demand that a hair net be worn to cover long hair. Preferably, for safety in the workshop, hair should be worn short.
- Where there is any danger of objects falling from above or a risk of bumping your head on sharp metal corners, wear a safety helmet.
- Always try to be as clean and tidy in appearance as your job will allow.

### Horseplay and Skylarking

Games and 'showing off' have no place in industry; they have caused many serious accidents, some fatal. Practical jokes may get some laughs, but can end up giving someone a lifetime of sorrow. That someone could be you!

### Industrial Housekeeping

Where a workshop has been allowed to become dirty and untidy, general inefficiency, poor work practice and frequent accidents often result. (See Figs 3 and 4.)

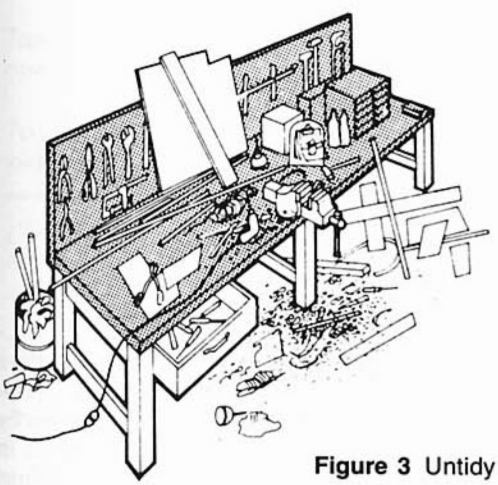


**Figure 3** Untidy workbench

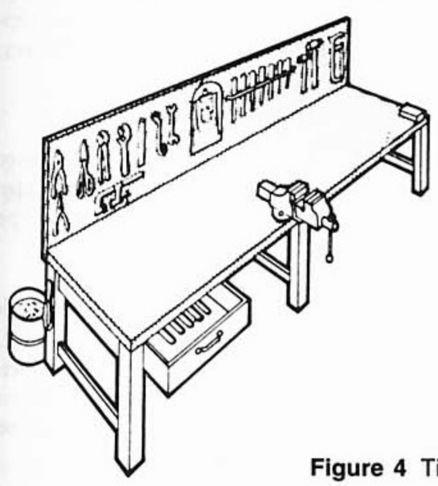


**Figure 4** Tidy workbench

Remember, workshop cleanliness is a function of both management and staff, for the benefit of both. Fundamentally, then, tradespeople make their own working conditions by the attitude they adopt.

## Workshop safety

The efficient operation of any workshop will depend largely on the planning and foresight devoted to its design and construction. Important features to be considered are:

- the most suitable layout for maximum production and efficiency;
- measures that will ensure the safety of both the operator and the machine;
- adequate provision for the maintenance of tools and equipment.

## Equipment safety

### Hand Tools

Never use defective tools, for example those with broken handles, chisels with mushroom heads, spanners with spread jaws, files without handles (especially on the lathe) and tools of the wrong size for the job.

### Machinery

Many accidents are caused by the operation of inadequately guarded machines or where the guards supplied have been removed irresponsibly. Your personal safety is largely dependent on the attitude you adopt towards the use and the maintenance of the safety guards and devices supplied. (See Fig. 5.)

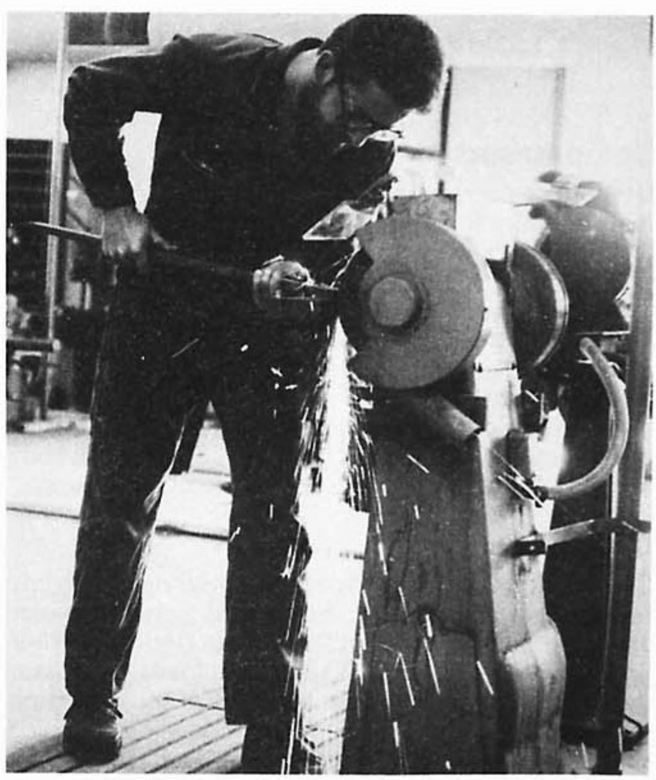


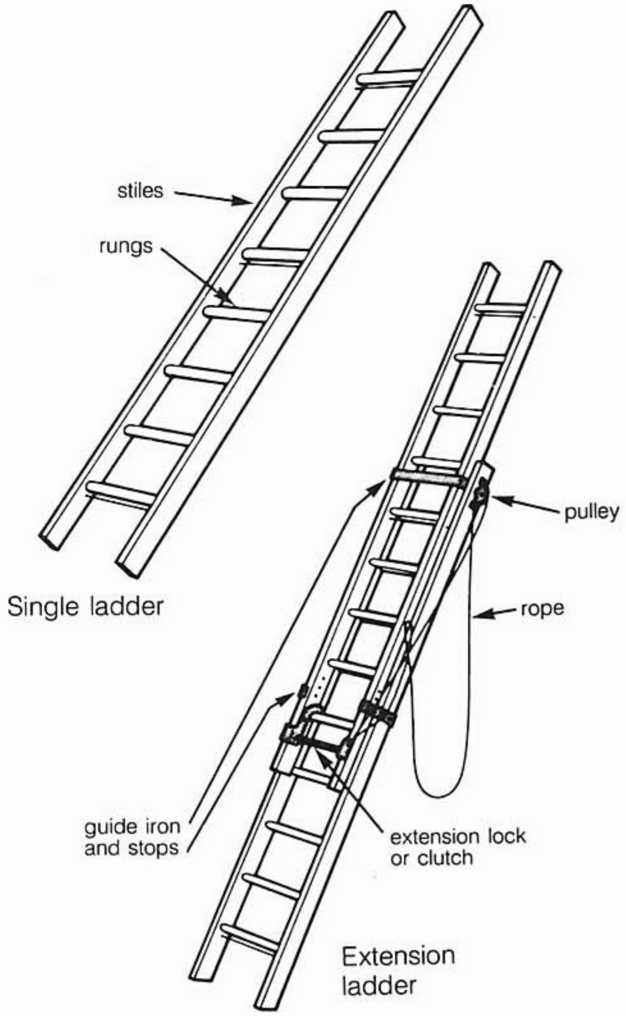
**Figure 5** Safety when grinding (Note the eye protection and the safety shield around the wheel)

## Electrical Equipment

Do not use or tamper with electrical equipment unless you are properly authorized to do so. Electrical equipment must at all times be considered to be 'live', and therefore dangerous. Report and label any apparent defects in wiring or electrical equipment. Do not leave extension cords on the floor when not in use: coil them up and place them in storage, preferably lying flat, not hanging on a hook.

## Ladders

Ladders should be used only for access or when doing simple operations (Fig. 6.) It is best to use mobile platforms or scaffolding for heavy work or when work is likely to take a long time. Make sure the ladder won't slip, either by tying it to a support or by having someone hold it.



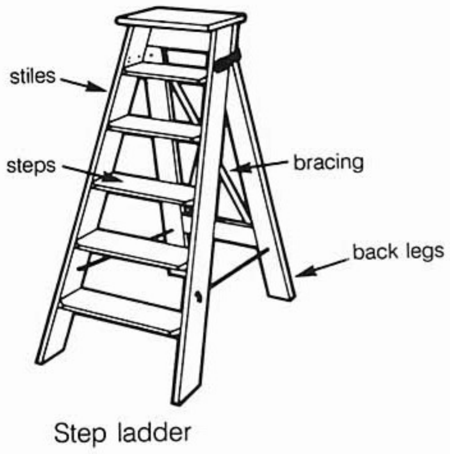




**Figure 6** Ladders

## Compressed Air

Do not use compressed air for any purpose other than that for which it is provided. Never indulge in so-called practical jokes with compressed air.

Do not used compressed air to cool yourself or to blow dust from clothes or hair.

Never direct a stream of compressed air towards your body or the body of another person. A blast of compressed air held within inches of the body can enter the blood stream or the intestines. A pressure of 27 kPa can cause a rupture and possibly an agonizing death. All body openings and skin punctures are particularly vulnerable.

## Cranes

Cranes and other lifting devices must be operated only by properly trained and experienced persons. Never operate a mobile crane under or near electrical power lines. Do not stand beneath suspended loads. Be certain that lifting chains and slings are marked for maximum safe working load (SWL). Worn, faulty or damaged chains and slings must never be used. One person only will give directions to the crane driver (see Fig. 7). (Also see Chapter 53, Lifting and Slinging.)

# Fire fighting

Make sure you know the location of fire escapes, and have a competent person explain how to use the safety equipment and fire extinguishers. Do not block fire escapes by storing materials in exits or doorways. Do not smoke in restricted areas. Never use sawdust to catch oil drippings as this results in a fire hazard. Deposit rubbish, sweepings and oil-soaked swarf in covered metal containers.

## Types of Fire

Class A fire This is a fire where wood, cloth or paper is burning. Water is best for putting out such a fire. Water may be used from a bucket, a hose or a water-type extinguisher (Fig. 8).

Class B fire This fire is one where flammable liquids such as petrol, kerosene, oil, paint or solvents are burning. Such a fire must be blanketed or smothered to keep oxygen away from the flames. Dry powder or foam extinguishers must be used. The extinguisher should be pointed at the base of the fire (Fig. 9).

# KNOW YOUR CRANE SIGNALS

Standard hand signals for controlling cranes

***To move*** One hand only shall be used for signals to move.

***Hoist*** First finger pointing up, rest of hand closed. The whole hand to be moved to indicate upward movement.

***Lower*** Hand fully extended, palm down. Move in downward direction.

***Swing*** First finger pointing in direction wanted, rest of hand closed. Move hand in direction required.

***Jib up*** Thumb pointing upwards, rest of hand closed — whole hand to move upwards.

***Jib down*** Thumb pointing downwards, rest of hand closed — whole hand to move downwards.

***Travel*** Hand fully extended, whole arm to move in direction required.

***To stop*** Hand held head high, palm towards driver.

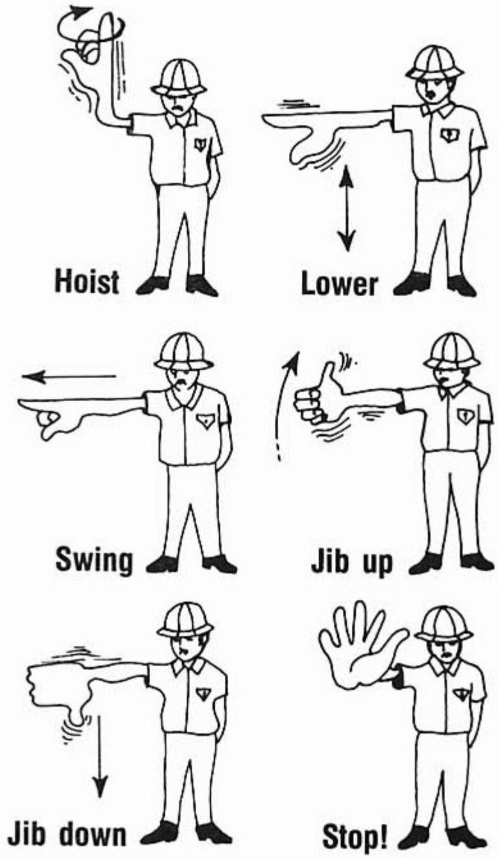
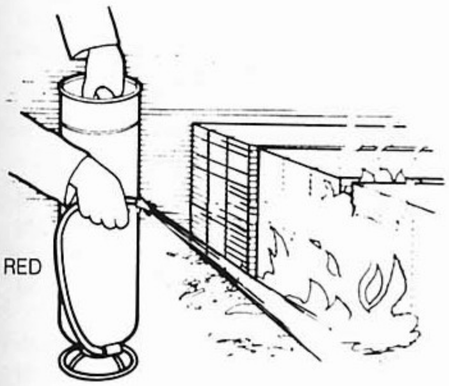



**Figure 7** Crane signals




Use water-type extinguisher

**Figure 8** Class A fires

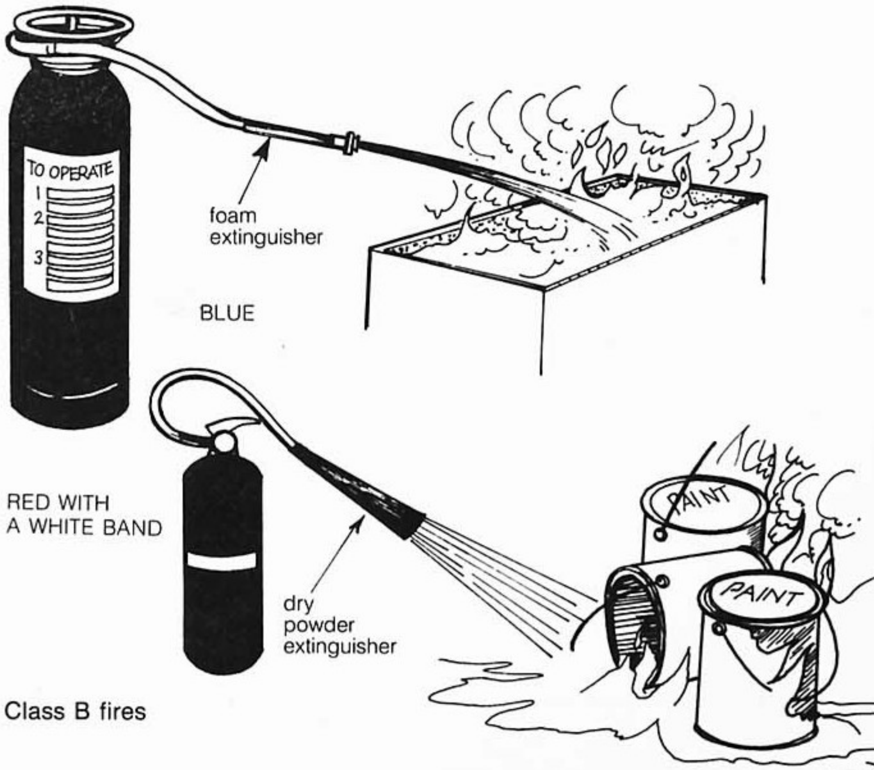



**Figure 9** Class B fires

*Note:* Never use water on a Class B fire as it may splash the burning liquid and spread the fire.

Type E fire   A Type E fire is one where 'live' electrical equipment is burning. If you put water on this type of fire, you could be electrocuted by the electricity being conducted along the stream of water. Such a fire must be blanketed or smothered by using $CO_2$, dry powder or vapourising liquid extinguishers. (See Fig. 11.)

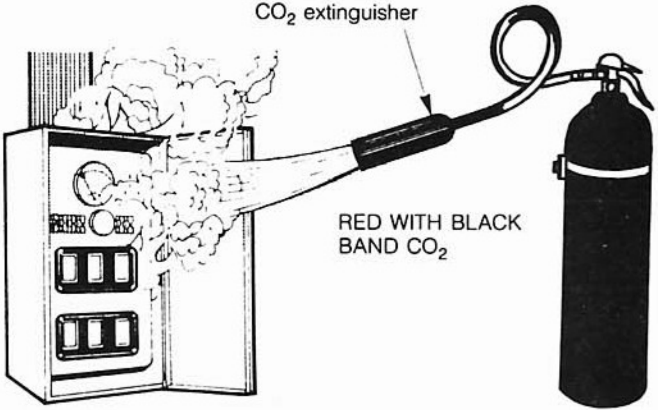



**Figure 10**

# 5

# Materials—Metals

## Uses of common metals

### Iron

Impure iron when smelted from ore in the blast furnace is cast into metal moulds of half-moon sections to form pig iron for sale to foundries, where it will be subsequently melted and cast in sand moulds to produce a wide variety of iron castings for the engineering trade. A large proportion of the iron is held in a liquid state until required in the steelmaking furnaces, where it is refined and treated to produce various grades of steel.

### Copper

High purity copper has many uses in the electrical industry because it is a good conductor of electricity. However, when pure, it lacks strength. To increase its strength and make it useful for other engineering purposes it is alloyed with zinc to produce brass, or with tin to make bronze.

Brass is extruded into many shapes to make parts for electrical equipment and for other work where resistance to corrosion is needed. In sheet form ductile brass is used to make pressings and deep-drawn articles such as cartridge cases.

Bronze is produced in sheet or rod form for use where greater strength is required. It often has a small amount of phosphorus in its composition and is then known as phosphor-bronze. This material is useful in cast form to make bearings and for other castings where strength and corrosion resistance are needed.

### Lead

Lead resists chemical attack from acid solutions, hence it is useful in the chemical industry. Plumbers also make use of it as flashing material and in the form of solder alloys. Lead is used in certain bearing alloys, and when added in very small quantities to free-cutting steels it improves machinability.

### Zinc

Zinc is alloyed with copper to make brass. It is also alloyed with other metals to make die-cast components for automobiles, etc. Zinc is used for dry-cell battery casings, and for galvanizing steel sheet and other steel parts for protection from rust.

### Aluminium

Aluminium alloys are used to make strong light-weight components for aircraft, automobiles, and in general engineering work. Aluminium is also widely used for structural work, kitchen utensils, and as foil for heat insulation purposes and food wrapping.

### Nickel and Chromium

Nickel and chromium are both widely used alloyed with iron to form steels with special properties. They are each used for plating other metals.

### Tin

Tin is alloyed with copper to form bronze. It is also used to plate steel for making cans and is a constituent of solder.

## Ferrous metals

Iron is the principal component of cast irons and steels, and in these forms it is the most widely used of all metals. Iron is soft and ductile. It is easily magnetized but in the purer forms does not retain magnetism. Most steels, however, can be permanently magnetized. The density of iron is 7870 kg/m$^3$, which is between that of zinc and copper.

### Cast Iron

Cast iron is widely used as an engineering material because it can be cast readily into intricate shapes in sand or metal moulds. It has a high damping capacity, that is, a high ability to absorb vibration. Consequently it is useful for manufacturing machine tools, engine blocks, bearing housings, etc.

Many grades are produced for use in the engineering trade. A number of them are special alloys containing nickel or chromium to improve resistance to heat and corrosion and to improve mechanical properties.

The bulk of cast iron used is called grey cast iron. This is made by melting pig iron and selected scrap together, usually in a cupola furnace.

The proportion of carbon and the form in which it is present are important factors influencing the properties of cast iron.

#### Composition, Properties and Uses of Cast Iron

*Grey cast iron*

Grey cast iron is so called because it has a dark-grey fracture. The carbon present is largely in graphitic form, and appears in the microstructure of many cast irons as flakes interspersed in a matrix of ferrite with some pearlite (see Fig. 1). The graphite appears as dark flakes and lines. Ferrite appears as light areas between the darker grains of pearlite. The shape, the size and the distribution of these flakes greatly affect the properties of the metal. They reduce ductility sharply but provide good machinability. Ultimate tensile strength is 124 to 185 MPa. Compressive strength is about 616 MPa. Brinell hardness is about 170.

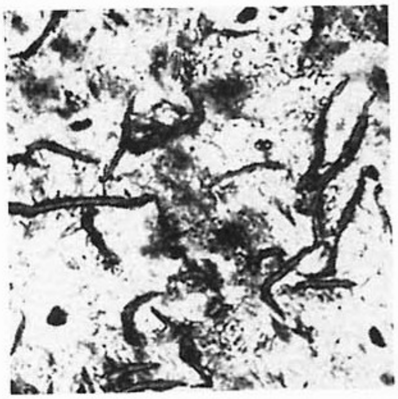


**Figure 1** Microstructure of ferritic pearlite (grey cast iron)

*White cast iron*

White cast iron has a silver-grey fracture. The carbon exists in a combined form as iron carbide, appearing in the microstructure as free cementite in a matrix of pearlite. Pearlite is a mixture of alternate plates of ferrite and cementite. The material is hard,. brittle and difficult to machine. Carbide or ceramic tools must be used. Brinell hardness is 500 to 725.

The usual method of making white cast iron is to transfer liquid iron from the cupola to a Bessemer or Tropenas converter, where free carbon and other elements are removed. Later, sufficient combined carbon and other required elements are added to bring the metal up to specification before pouring.

In some work a metal chill is used in the mould to produce a hard zone about 3 mm thick in the required area. Where this is done the iron is poured directly from the cupola.

White cast iron is used where components require a hard wear-resistant surface, or as the first step in making malleable castings.

*High-duty cast irons*

High-duty cast irons are stronger than grey iron, in which much of the carbon is in coarse flakes. A number of the high-duty irons are special alloys containing nickel, chromium, copper or molybdenum, which improve mechanical properties and resistance to wear, heat and corrosion. Other high-duty irons are produced when certain substances are added to the molten metal.

*Meehanite cast irons*

Calcium silicide is added to the metal before it is poured, producing a fine flake graphite type of cast iron known as meehanite. Ultimate tensile strength (UTS) ranges from 150 to 700 MPa.

*Spheroidal graphitic cast irons*

Cerium and/or magnesium, and perhaps nickel, are added to the liquid metal, producing a fine spheroidized form of graphite.

Spheroidal graphitic cast irons may be used as cast (see Fig. 2). The UTS is 555 to 695 MPa. Brinell hardness is 230 to 310.

The metal may be annealed before use. In this condition the UTS is 400 to 550 MPa, elongation is 5 to 20%.

After annealing, spheroidal graphitic iron is readily forged or welded. Heat treatment can raise the UTS to approximately 850 MPa.

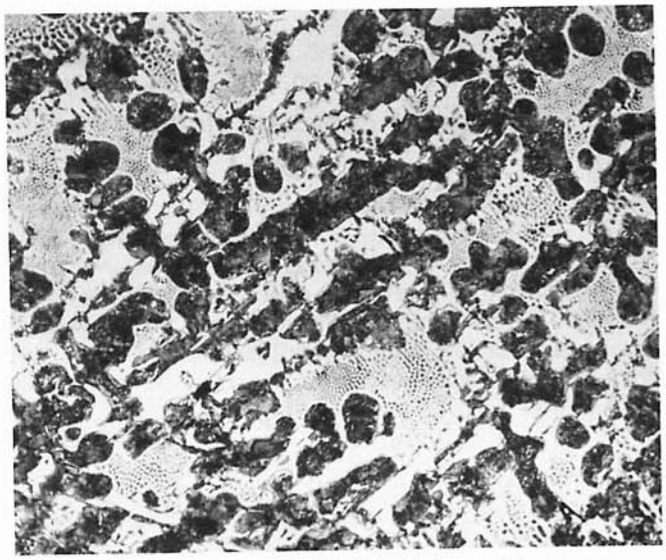


**Figure 2** Microstructure of spheroidal graphite iron as cast

*Malleable cast irons*

Ordinary cast iron is brittle and therefore unsuitable for components that are required to withstand suddenly applied stresses. The cheapest method of producing components that are malleable is to give white cast iron a modifying heat treatment. There are two ways of doing this.

The white-heart process The white iron castings are placed in sealed metal boxes with haematite ore and then heated in a furnace at 900 to 950°C for about 90 hours, followed by slow cooling.

After this time decarburization is complete in castings of less than 10 mm section, the annealed material consisting only of iron (ferrite) and impurities. A modern technique of annealing, which saves handling, is to heat the castings in a controlled decarburizing atmosphere.

The white heart process is now less commonly used.

The black-heart process In this process no attempt is made to decarburize white iron castings. Malleability is attained by the conversion of combined carbon rather than its removal.

Castings for annealing are packed in sand in sealed boxes before being placed in the furnace, or are heated in a neutral atmosphere. The castings are heated for 50 to 60 hours at 800 to 850°C.

Very slow cooling to 650°C will produce ferritic malleable iron (see Fig. 3), in which the graphitized carbon appears as rosettes in a matrix of ferrite. More rapid cooling produces a pearlite matrix.

Pearlitic malleable iron (see Fig. 4) is produced if cast components are to be used instead of low to medium carbon-steel forgings.

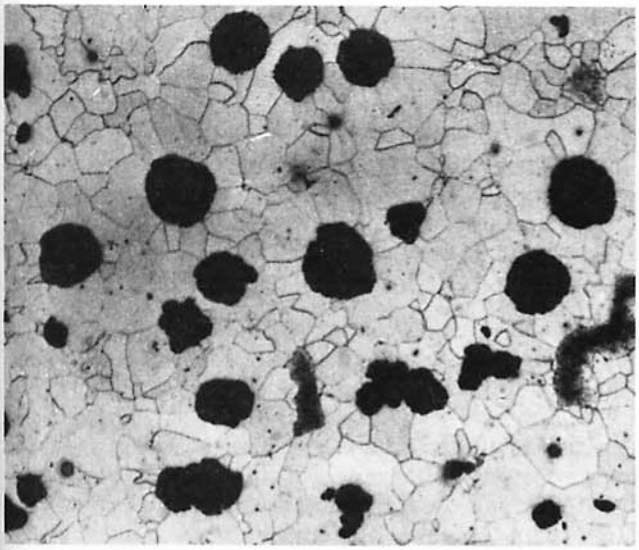


**Figure 3** Ferritic malleable iron

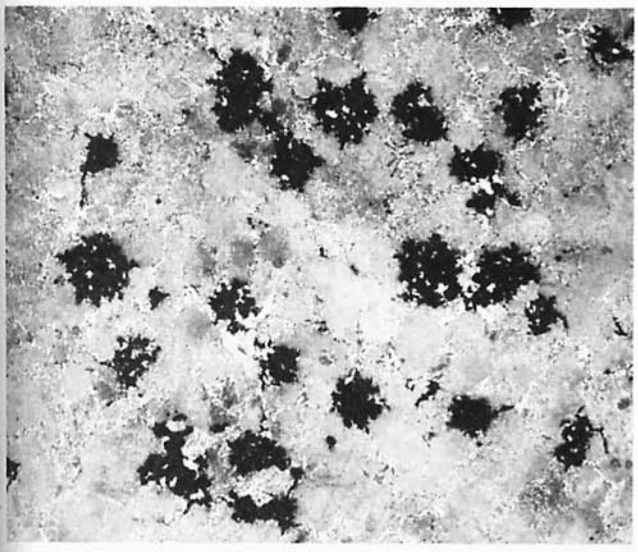


**Figure 4** Pearlitic malleable iron

Ductility of malleable cast iron Ductility of malleable castings measured by elongation on test specimens varies from 4% to 10% (depending on the grade of iron) for castings treated by the white heart process.

Test specimens treated by the black heart process give elongations from 6% to 14% depending on the grade of iron used.,

As a further measure of ductility, test bars are subjected to standard bend tests using mandrels of different diameters.

### Heat Treatment of Cast iron

Grey iron castings may require stress relieving before use so that there will be no later movement in the casting.

When a casting is made, the metal in the mould does not cool uniformly and shrinkage varies in different parts of the same casting. Thick sections cooling slowly contract away from thinner sections that have cooled more quickly. As a result internal stresses are set up, and if the casting were to be machined soon after manufacture, it would warp slightly. This may not be important in many castings, but it could be critical in special pieces of work where an accurately machined surface has to hold its accuracy, as in gauge work, surface plates, etc.

Stress relieving is carried out by heating castings in a furnace from 450° to 550°C followed by slow cooling in the furnace.

In addition to stress relieving, spheroidal iron castings can be hardened and tempered by oil quenching from 780 to 850°C, followed by tempering in the range of 250 to 550°C, depending on the purpose of the product.

## Steel

### Composition of Steel

Iron The element iron, being the principal constituent of steel, is present in very high percentages.

Carbon Plain carbon steels are alloys of iron and carbon, the carbon percentage ranging from about 0.05% in the softest grades to about 1.4% in the hardest. Steel also contains small amounts of manganese, silicon, sulphur and phosphorus. (Cast iron contains the same elements but the carbon content is higher, from about 3% to 4.5%. As much of this is free carbon, the metal is brittle, so that when machined the cuttings break off as small chips.)

Sulphur and phosphorus Percentages of these elements are kept low in steels because they make steel brittle and in the case of sulphur 'hot short'.

Manganese and silicon The addition of these two elements improves the mechanical properties of steel, and if added in relatively large amounts the steels are called alloy steels.

Summary The percentages of elements in plain carbon steels are within the approximate figures given in Table 1.

Table 1 Percentages of elements in steel

| Element | Percentage |
|---|---|
| Carbon (C) | 0.05–1.4 |
| Manganese (Mn) | 0.03–0.7 |
| Silicon (Si) | 0.05–0.3 |
| Sulphur (S) | 0.06 (max.) |
| Phosphurus (P) | 0.06 |
| Iron (Fe) | 96.4–99.65 |

### Effect of Carbon Content on Mechanical Properties of Steel

Both the tensile strength and the hardness of steel are increased by increasing the combined carbon content. The ductility, as measured by percentage elongation in the tensile test, decreases to a very low value at 0.9% carbon. The toughness, which means resistance to sudden shock as measured by the Izod or Charpy impact tests, decreases steadily as the carbon content increases, and reaches a fairly low value at about 0.8% carbon. For example, 0.14% carbon steel, when normalized, may have an Izod value of 134 joules, compared with 1.2% carbon steel, which may have a value of 7.5 joules. (Normalizing is a form of heat treatment.)

Table 2 Percentage of carbon in various steels

| Type of steel | Carbon content (%) |
|---|---|
| Mild | up to 0.3 |
| Structural | 0.23 to 0.35 |
| Medium carbon | 0.35 to 0.5 |
| High carbon | 0.5 to 0.8 |
| Carbon tool | 0.7 to 1.4 |

## Specifications for Steel

Steels used in industry are listed according to standard specifications, which conform to Australian Standards, AS 1442–1973 and AS 1443–1973.

A steel specification is shown by a letter or letters, followed by numbers.

The letters are:

R = rimmed steel (lowest carbon group)
CS = semi-killed steel
S = semi-killed steel (restricted carbon range)
K = fully killed steel.

The numbers follow the letters, the first two indicating the type of steel, the last two, the carbon range.

As an illustration, CS 1030 specifies semi-killed steel, type 10, which is plain carbon steel, and 30, which indicates 0.3% carbon. When the first two figures are 11, 12 or higher, this indicates that alloy elements have been added. The particular figure indicates the type of steel.

## Properties and Uses of Plain Carbon Steels

### *Mild steels, carbon content up to 0.25%*

**Dead soft mild steels** Carbon content 0.06–0.14%. These steels have relatively low strength and hardness. They are very ductile and may be readily deep drawn, pressed, cold forged, hot forged and welded.

A typical composition is S 1006:

| | |
|---|---|
| Carbon (C) | 0.08% max. |
| Manganese (Mn) | 0.4% max. |
| Sulphur (S) | 0.05% max. |
| Phosphorus (P) | 0.05% max. |

This steel is suitable for forging and welding.

**Free-cutting steels** These steels are manufactured for use on automatic lathes for the production of small components where high mechanical strength is not required. Examples are small screws, pins and collars.

Three types of free-cutting steel listed are: XS 1115, XS 11L12, and S 1214:

- The XS 1115 grade has a higher sulphur content than other grades of steel and the manganese and sulphur combine to form manganese sulphide, which exists in the steel as microscopic inclusions; these inclusions help to lower resistance to cutting during machining operations.

  Specification of XS 1115 is:

| | |
|---|---|
| Carbon (C) | 0.1–0.17% |
| Manganese (Mn) | 1.1–1.4% |
| Silicon (Si) | 0.1% max. |
| Sulphur (S) | 0.2–0.3% |
| Phosphorus (P) | 0.05% max. |

- The XS 11L12 grade contains 0.15 to 0.35% lead as well as more manganese and sulphur. The lead exists in the steel as particles or globules which improve machinability.
- The S 1214 grade is one of the re-phosphorized types of free-cutting steel. Its composition is:

| | |
|---|---|
| Carbon (C) | 0.15% max. |
| Manganese (Mn) | 0.8–1.2% |
| Sulphur (S) | 0.25–0.35% |
| Phosphorus (P) | 0.04–0.09% |

**Mild steels** Carbon content 0.14 to 0.25%. Mild steels are stronger but less ductile than dead soft steels. They can be readily welded, forged and machined but will not fully harden in heat treatment. Mild steel is used in the form of bars (flats, round, etc.), sheet, castings and forgings for a very wide range of applications wherever a fairly cheap, strong and ductile metal is required.

There are a number of compositions for mild steel and selection depends on the application for which the mild steel is required.

A typical composition is CS 1020:

| | |
|---|---|
| Carbon (C) | 0.15–0.25% |
| Manganese (Mn) | 0.4–0.8% |
| Silicon (Si) | 0.15% max. |
| Phosphorus (P) | 0.6% max. |
| Sulphur (S) | 0.06% max. |

Mechanical properties are of the order:

- ultimate tensile strength 400 to 500 MPa;
- elongation 25%, minimum;
- reduction in area 35%;
- Izod impact value 45 joules, minimum.

### *Structural steels*

The carbon content of structural steel is slightly higher than that of average mild steel and, as a result, the steel is stronger but less ductile. This steel is made into girders, beams and plates for use in buildings, bridges and ships.

A typical composition is:

| | |
|---|---|
| Carbon (C) | 0.3% |
| Manganese (Mn) | 0.7% |
| Silicon (Si) | 0.2% |
| Sulphur (S) | 0.05% |
| Phosphorus (P | 0.05% |

Mechanical properties (approximate) of 'as rolled' steel are:

- ultimate tensile strength 50 MPa;
- elongation 30%;
- Izod impact value 55 joules.

### *Medium-carbon steels*

Carbon content is 0.35 to 0.5%. Steels in this group machine and forge without difficulty but are not as easy to weld as mild and structural steels. Increasing the carbon content increases the tensile strength but lowers the ductility of the steel.

Steels in this group are widely used where a combination of strength and ductility is required. Their uses include shafts and spindles of machines, crankshafts, axles, gears and locomotive forgings.

A typical composition is K 1045:

| | |
|---|---|
| Carbon (C) | 0.43–0.5% |
| Manganese (Mn) | 0.6–0.9% |
| Silicon (Si) | 0.15–0.3% |
| Phosphorus (P) | 0.05% max. |
| Sulphur (S) | 0.05% max. |

After normalizing at 850°C, the properties of medium carbon steels are approximately as follows:

- ultimate tensile strength 590 MPa, minimum;
- yield point 370 MPa;
- elongation 25%;
- Izod impact value 40 joules.

*High-carbon steels (not including tool steels)*

Carbon content is 0.5 to 0.8%. These steels have higher tensile strength, hardness and wear resistance, but lower ductility, weldability and machinability than the preceding groups. They are generally used quenched and tempered.

Uses for steels in this group include leaf and large coil springs (carbon content in steels used for coil springs ranges up to 1.0%). railway rails, wheel tyres for railways and wire rope. The wire used in steel cables is cold drawn to an extent where the tensile strength ranges from 1100 to 2000 MPa.

A typical composition is:

| | |
|---|---|
| Carbon (C) | 0.6% |
| Manganese (Mn) | 0.7% |
| Silicon (Si) | 0.2% |
| Phosphorus (P) | 0.05% |
| Sulphur (S) | 0.05% |

Two locally produced steels in this range area:

- S 1058 Carbon (C) 0.56–0.63%;
- S 1067 Carbon (C) 0.63–0.73%.

*Tool steels of plain carbon steel*

Carbon content is 0.7 to 1.4%. Tool steels are manufactured under carefully controlled conditions to produce the required quality. The manganese content is kept low to minimize the possibility of cracking during water quenching.

A typical composition of plain carbon tool steel is:

| | |
|---|---|
| Carbon (C) | 1.0% |
| Manganese (Mn) | 0.3% |
| Silicon (Si) | 0.25% |
| Phosphorus (P) | 0.04% |
| Sulphur (S) | 0.04% |

Tool steels are made to a number of grades for different applications. The choice of grade depends on whether a keen cutting edge is necessary, as in a stamping die, or whether the tool has to withstand impact loading and service conditions encountered with such hand tools as axes, picks and quarrying implements. The higher carbon grades are used for such applications as stamping dies, metal cutting tools, etc.

The heat treatment for carbon tool steels consists of water quenching from 760 to 820°C followed by tempering in the range 150 to 300°C depending on the hardness and the toughness required. Typical working hardness after tempering ranges from 58 to 64 Rc.

## Alloy Steels

The addition of alloying elements improves the metal's ability to harden; its ductility; its stability in hardened work and its resistance to wear, corrosion and heat. Alloying elements retard transformation through the critical range during heat treatment, therefore alloy steels can be quenched more slowly than plain carbon steels, They can be quenched in oil or in an air stream. Improvement in ductility in constructional steel is most important. Although plain carbon steels of a similar strength can be made as strong as alloy steels, they do not exhibit the same ductility and will not give the same service as alloy steels of similar strength.

### Important Properties of Alloy Steels

*Ability to harden*

The presence of one or more alloy elements allows steel to harden more readily and to greater depth.

*Stability on hardening*

For some purposes, such as blanking dies, it is essential that distortion and dimensional change be minimal. Certain alloy die steels, called non-shrink steels, have this property to a high degree.

*Wear resistance*

Hardness increases wear resistance. Chromium or tungsten added to steels greatly improves their resistance to wear.

*Toughness*

Toughness is generally associated with constructional steels. However, for certain applications in tool work, such as coining dies, the steels should be shock resistant. Furthermore, all cutting tools need to be tough enough for their purpose. The required degree of toughness is imparted by tempering. Alloy tool and die steels, suitably hardened and tempered, are generally tougher than plain carbon tool steels.

*Hardness*

This is the most important property in heat-treated tool steels. It should be noted that alloy tool and die steels cannot be made any harder than plain carbon steels. The highest hardness values are found in files, which are made of plain carbon steel.

*Grain size*

Grain size is an inherent property of steel. The ideal tool steel is fine grained. Overheating will coarsen the structure of steel and grain size will increase. This lowers toughness, so overheating should always be guarded against. Vanadium is used to retard grain growth.

*Resistance to softening at elevated temperatures*

This important property is required in high-speed tool steels and hot working die steels. Tungsten and molybdenum give this property to such steels.

*Corrosion resistance*

Steels containing more than 11.5% of chromium are rust resistant because of the tenacious film of chromium oxide ever-present on the steel's surface. If the film is broken, for example by polishing, it quickly re-forms. When chromium is combined with nickel, a steel is produced that is strongly resistant to corrosion and the effects of heat.

### Common Alloying Elements and Their Effects on Steel

#### *Manganese (Mn)*
Manganese is present in all steels. When its proportion ranges from 1 to 1.6%, it improves the steel's ability to harden as well as its mechanical properties. Present in large amounts, it produces a work-hardening steel on which a zone of hardened structure appears.

#### *Chromium (Cr)*
Chromium improves steel's ability to harden and its mechanical properties. It is often combined with nickel and sometimes with molybdenum in constructional steels. When the chromium content is approximately 11.5% or higher the steel becomes resistant to corrosion because a tenacious film of chromium oxide builds up on the surface.

#### *Nickel (Ni)*
Nickel improves steel's ability to harden and its mechanical properties when added in amounts up to 5%. Combined with chromium in great percentages it produces a steel strongly resistant to corrosion and heat.

#### *Tungsten (W)*
Tungsten improves steel's ability to harden. It is added to tool and some hot working die steels to improve wear resistance and resistance to softening at elevated temperatures.

#### *Vanadium (V)*
Vanadium improves steel's ability to harden and its mechanical properties. It refines grain size and is an important element in some tool and construction steels.

#### *Molybdenum (Mo)*
Molybdenum improves steel's ability to harden and its mechanical properties. It is now used in some types of high-speed steel, in particular in steels used to make saws and twist drills. When combined with nickel and chromium a high-strength steel alloy is produced with ultimate tensile strength in excess of 1200 MPa.

#### *Cobalt (Co) and Silicon (Si)*
Other important elements found in alloy steels are cobalt and silicon. Cobalt is used in special grades of high-speed steel to increase its 'red hardness', that is, its ability to resist wear at high operational temperatures. Silicon is used in the manufacture of high fatigue resisting steels for springs and shock resisting tool and die steels.

*Note*: Both tungsten and tungsten–molybdenum types of high-speed steel have their hardness increased slightly on tempering within a certain range. In the 18%-tungsten type this occurs between 560 and 600°C. This increase in hardness is referred to as secondary hardening.

### Die Steels
Some die steels have excellent wear-resistant qualities, while others provide good shock resistance. Certain types are also noted for their stability in hardening. Movement during hardening is restricted to a minimum, therefore these steels are suitable for stamping dies of intricate shapes.

# Non-ferrous metals

Metals other than iron and its alloys, that is, the non-ferrous group of metals, are widely used in industry, sometimes singly but usually in alloy form.

Some non-ferrous metals are:

| | |
|---|---|
| Aluminium | Nickel |
| Chromium | Tin |
| Copper | Titanium |
| Lead | Zinc |
| Magnesium | |

The properties and uses of common non-ferrous metals and their alloys are dealt with in this section.

## Copper and Copper Alloys

Copper has a well-known attractive reddish colour. The metal is soft and very ductile. Of all the less costly metals copper is the best electrical conductor. Its thermal conductivity is also very good. Copper is the principal element in widely used brasses and bronzes. Its density is 8940 kg/m³, between that of iron and silver.

In the final stages of the manufacture of copper, small amounts of phosphorus, arsenic and other elements may be added, or special treatment given to produce various grades for use in electrical installations, plumbing work or chemical plants.

Copper combines readily with a number of elements to produce a variety of industrial alloys. Common alloying elements are zinc, aluminium, nickel, manganese, tin and iron. Lead is added to some alloys to improve certain properties, although it is not an alloying element. The alloys produced are known as brass or bronze. A brass is an alloy of copper and zinc, and a bronze an alloy of copper and tin.

### Brasses

#### *Alpha brasses*
Copper under ideal conditions will dissolve up to 38% zinc to form a single solid solution. In commercially produced brasses, the limit of solubility of zinc in copper to form a single solid solution is approximately 33%. Brasses containing less than this amount of zinc have a microstructure consisting of one constituent that is referred to as the alpha structure, and such brasses are known as alpha brasses.

Throughout the alpha range the brasses are like copper in that they can be cold worked. As the zinc content is increased the material becomes stronger but gradually less ductile. It will require annealing between cold working operations. At the same time the material becomes paler in colour.

### Alpha–beta brasses

In this group the zinc content is greater than in the alpha group. A second constituent, the beta structure, appears in the microstructure. Alpha–beta brasses are harder and less ductile. They are generally not suitable for cold working although one grade produced, containing a small amount of lead (0.5 to 0.8%), is suitable for bending and punching operations.

Some brasses in this group are now described.

Muntz metal This is the traditional 60:40 brass. It is manufactured as hot-rolled plate or extruded in a large variety of shapes such as rounds, flats, or non-standard sections, all for general use. The material is also used for the production of hot forgings from standard bars, UTS 350 MPa, elongation 40%.

Free machining brass This brass contains 3% lead in place of some copper and zinc in a 60:40 type brass. It is very suitable for machining in automatic lathes producing small components. The lead, being insoluble in copper, exists as tiny nodules throughout the alloy. These nodules cause small cuttings and assist penetration of the cutting tool.

Naval brass Naval brass contains 1.25% tin instead of some zinc. It has good corrosion-resistant properties in salt water.

Alloy (high tensile) brasses These are usually called bronzes but do not contain much tin, if any. They are of the 60:40 type of brass but contain small amounts of nickel, manganese, iron or tin to make the alloys stronger and more resistant to wear than standard brasses. A common type that combines good corrosion resistance with strength and good forging properties is manganese bronze UTS 550 MPa, elongation 30%.

## Bronzes

True bronzes are alloys of copper and tin. They may also contain some nickel, zinc, phosphorus or lead. Most bronze alloys are used in the production of castings.

Copper will dissolve up to 14% tin to form a single solid solution. However in practice wrought alloys do not contain more than 8% tin, because above this figure the alloy is apt to be brittle, because of the presence of the beta constituent.

### Gunmetals

Copper–tin alloys containing zinc are known as gunmetals.

### Phosphor bronze

Phosphorus is added to molten bronze as a de-oxidizing agent. A small amount remains in the metal and further improves its properties. The alloy is known as phosphor bronze.

Produced in strip or wire form, phosphor bronze has a spring-hard temper. It is used to make wire screens, small coil and flat springs, clips, contacts and welding rods. A hard-drawn alloy containing 5% tin would have the following properties, depending on the amount of cold working:

Ultimate tensile strength (UTS) 200 to 700 MPa and 60 to 220 Brinell hardness.

The composition of a typical wrought phosphor bronze is:

| | |
|---|---|
| Copper | 95% (approx.) |
| Tin | 5% |
| Phosphorus | 0.2% |

### Aluminium bronzes

These are alloys of copper and aluminium, and they may also contain nickel, iron and manganese. They are characterized by their high tensile strength and resistance to fatigue, corrosion and wear.

Copper will dissolve up to 9.4% aluminium to form a single solid solution. However, wrought alloys required for cold working operations, such as deep drawing, have an aluminium content of 4 to 7% Wrought aluminium bronze is used in making imitation jewellery, cosmetic containers, etc.

Extruded sections in bar form are used for pump rods, shafts and spindles where resistance to corrosion and oxidation at high temperatures is required. The material is also used in the production of hot forgings.

A typical composition is:

| | |
|---|---|
| Copper | 90.5% |
| Aluminium | 9.5% |

## Copper–nickel Alloys

There are two main types of copper-based alloy containing nickel. They are cupronickels and nickel-silvers.

### Cupronickels

Alloys of this type consist mainly of copper and nickel with small amounts of iron and manganese. Such alloys resist corrosion by sea water and are therefore used in marine applications. They are extruded in standard sections.

### Nickel–silvers

These are alloys of copper, zinc and nickel; they have a silver appearance, hence the name. The addition of nickel in place of some copper in brass of 60:40 type lightens the colour of the metal in addition to making it more ductile. A number of grades of this alloy are produced for the manufacture of nickel-silver tableware, spring contacts, wire for electrical resistors and for telephone equipment. Nickel-silver alloys are also extruded in standard sections.

## Copper Casting Alloys

The structure of cast bronzes depends largely on the cooling rate of the castings. If the tin content is less than 7%, bronze castings that are slowly cooled will contain only the alpha constituent. In alloys having a higher percentage of tin a further constituent, a eutectoid, is present. This increases the hardness and tensile strength of the alloy.

Cast aluminium bronzes containing about 10% aluminium, in addition to small amounts of iron and manganese, are similar to tin bronzes in that both the alpha and eutectoid constituents are present.

## Monel Metal

The main applications of the Monel alloys are as components for use in the chemical industry, testing equipment in chemical laboratories and small fittings on marine craft.

This is a nickel-based alloy containing copper and other elements. Monel metal is characterized by its good tensile strength and ductility in conjunction with resistance to corrosion in sea water and many chemical solutions. A typical composition of Monel metal is as follows:

| | |
|---|---|
| Nickel | 66% |
| Copper | 31.5% |
| Iron | 1.35% |
| Manganese | 0.9% |
| Carbon | 0.12% |

## Nickel and Chromium Alloys

### Nickel

Nickel is a hard, silvery-white, lustrous metal much used in alloys and for plating other metals. Its density is 8902 kg/m³.

### Chromium

Chromium has similar properties to nickel but is more brittle. It is used in alloys and for plating other metals. Its density is 7190 kg/m³.

## Nickel–chromium Alloys

Nickel–chromium alloys are nickel-rich alloys containing chromium and other elements. Nickel and chromium readily dissolve (chromium up to 35%) to form a solid solution. Such alloys are very useful where resistance to corrosion, hot acids, alkalis, oxidation and heat is required.

Several grades also possess high electrical resistance ('nichrome' alloys) and they are excellent materials for electrical heating elements. The nimonic group (nickel–chromium alloys) have resistance to metallic creep at high temperatures. Nimonic alloys were originally developed for use as turbine blades for jet engines in aircraft.

Heating elements used in electric furnaces, toasters, stoves and certain other electrical appliances are made from nickel–chromium alloys capable of withstanding intermittent heating and cooling over long periods.

## Aluminium and Aluminium Alloys

### Aluminium

Aluminium, a silver-grey metal, is widely used, and the demand for it continues to increase.

Reasons for its popularity as an industrial metal are:

- light weight, its density being 2698 kg/m³;
- resistance to corrosion;
- high thermal and electrical conductivity;
- high reflectivity;
- ease of fabrication;
- moderate cost;
- colour.

### Protective Film of Aluminium Oxide

Commercially pure (99%) aluminium resists corrosion in normal atmospheric conditions because of the thin film of oxide present on the surface of the metal. This film protects it against further corrosion.

### Uses of Aluminium

Because of its light weight, the metal is extensively used in aircraft, superstructures of modern ships, transport vehicles and the building industry. Its high thermal condictivity and light weight make it a popular metal for cooking utensils.

High electrical conductivity and moderate cost, as against the high cost of copper, have brought aluminium cables, strengthened with a steel core, into wide use in electrical power transmission lines.

Commercially pure aluminium and some alloy grades have excellent cold-working properties, enabling them to be spun or deep drawn with ease, and often without interstage annealing being required.

Form-rolled sheet aluminium is replacing galvanized iron for roofing and cladding on industrial and rural buildings. Extruded sections are used for window and door frames and other fittings in modern buildings.

The transport-vehicle industry makes use of aluminium and its alloys rather than steel in truck and van bodies, thus reducing weight and increasing carrying capacity.

Aluminium castings are produced where light weight and moderate strength are required.

### Alloys of Aluminium

Aluminium alloys containing manganese, magnesium or chromium are also strongly resistant to atmospheric corrosion.

Alloys containing silicon are slightly less resistant. Least resistant are alloys containing copper, nickel, iron and zinc.

**Alclad surfaces** The corrosion resistance of alloy sheet containing small amounts of manganese, or manganese and magnesium, is further improved by giving the material a surface coating of pure aluminium. The product is called 'alclad'.

**Anodizing** Aluminium products are often anodized. This is an electrical process for treating the surface of the article to leave a hard permeable oxide film, which readily absorbs coloured dyes.

**Duralumin** Alloys containing copper, silicon, magnesium and manganese can be given solution heat treatment followed by accelerated age-hardening treatment. Such alloys are known as duralumin alloys.

**Identification of wrought aluminium alloys** In Australia aluminium alloys are identified by the four-digit series. The first digit indicates the alloy group, that is, the figure 2 stands for the alloys containing copper; the second digit indicates modifications to the alloy; and the last two identify the aluminium alloy.

The alloy numbers may also carry suffix letters and numbers that convey the particular condition, treatment and properties.

*Examples*: T6 is solution heat treated and then artificially aged. H36 is cold worked and stabilized to develop a 75% hard condition.

**Identification of cast aluminium alloys** A system of two letters plus three digits is used to identify these alloys. The first letter indicates any alloy modifications, the letter A, indicating the original alloy is replaced by B, C, or

D for any subsequent modifications. The second letter P or S indicates the alloy as primary or secondary.

The first digit indicates the alloy group 1 to 8. In group 1 the last two digits indicate the minimum percentage of aluminium greater than 99.0%. In groups 2 to 8 the last two digits identify different alloys.

## Magnesium and Magnesium Alloys

### Magnesium

Magnesium, a light-grey metal, is lighter than aluminium. Its density is 1738 kg/m³, but unlike aluminium it is unsuitable for industrial use except when alloyed with other metals, notably aluminium, zinc and manganese. Production techniques have now improved, as has the development of suitable alloys. Rigid control of impurities has resulted in the production of stronger alloys.

The addition of a small amount of manganese improves the corrosion resistance of magnesium alloys (which generally are not strongly resistant to corrosion), particularly for parts used in salt-laden or humid atmospheres. Specially prepared protective coating materials and paints are often used on the surface or on components.

### Methods of Working Magnesium Alloys

#### *Heated pressure dies*

Cold-worked magnesium alloys work-harden rapidly, requiring frequent interstage annealing. Few components are produced by this process. A more successful technique, when making hollow parts, is to use magnesium in powder form in sealed and heated pressure dies.

#### *Press forging*

One important method of making components is by press forging. Working at temperatures in a range of 375° to 450°C, important parts for aircraft and other work are produced, particularly where pressure-tight and fatigue-resisting components are required.

#### *Sand or die-casting*

The most common method of making magnesium alloy components is by sand- or die-casting. Sand-casting requires special techniques. Magnesium alloys react with moisture when liquid, therefore the moulding sands used are carefully prepared and contain an agent to reduce formation of magnesium oxide.

### Identification of Magnesium Alloys

Magnesium alloy products, including sheet, bar and plate, are supplied in a pre-treated condition, as for aluminium alloys. Symbols are generally used to indicate condition, treatment and properties. A set of letters and numbers is employed to designate the hardness of the alloy or the amount of annealing in cold worked parts.

*Example:* H23 is strain hardened and partially annealed.

## Titanium and its Alloys

### Properties of Titanium

Titanium, a dark-grey metal, has better physical properties than other light-weight metals traditionally used in the aircraft and other industries. Its density is 4507 kg/m³.

Titanium has greater tensile strength, and resists heat and corrosion better than aluminium or magnesium.

The ultimate tensile strength of 99.2% titanium ranges from 450 MPa (25°C) to 170 MPa (425°C) (aluminium 1.25 MPa²). In alloys its tensile strength may be increased to 815 MPa at 425°C.

Generally the tensile strength of titanium decreases with temperature rises, but it maintains useful properties at temperatures much higher than those at which other light-weight metals can be employed. Some titanium alloys in use at present are capable of withstanding operational temperatures up to 500°C.

Titanium has excellent corrosion resistance when in contact with sea water, some acid solutions, metallic chlorides and sulphides.

### Methods of Working Titanium Alloys

#### *Cold working*

Although titanium does not work harden to any great extent when cold worked, components that have been made by stamping or bending are usually annealed before use.

#### *Machining*

Titanium and its alloys are readily machinable when suitable lubricants are used.

#### *Forging*

Some grades of the alloy may be hot forged. However, care must be taken to keep forging time to a minimum because of the danger of surface contamination.

#### *Welding*

Fusion arc welding can also be carried out provided a shield of argon gas is used.

### Uses of Titanium Alloys

Titanium is a comparatively expensive metal to extract and refine, and this at present is the limiting factor in its use. As production of the metal increases, the price will fall. At present its uses are generally restricted to the aircraft industry, chemical plants and plating trades. It is also in demand for surgical implants.

## Zinc and its Alloys

### Properties and Uses

Zinc is a grey metal, which exhibits good resistance to corrosion under normal weather conditions. Its density is 7133 kg/m³. Zinc or zinc alloy sheeting is useful for the manufacture of such articles as dry battery cell casings, meter cases, eyelets, flash-light reflectors and other formed components.

One of the major uses of zinc is as an alloy for die-casting metal.

Dimensionally accurate and thin-walled pressure die-castings can be made at low cost, eliminating machining. If necessary the alloy is easily machineable. The automotive industry uses many zinc die-castings both as mechanical components and as interior fittings.

# Bearing materials

## Friction and Wear

Bearings of all types need an adequate form of lubrication to reduce friction and lessen wear between the bearing surface and its journal. If the lubricant film between the mating surfaces breaks down, scoring will take place and the general rate of wear and temperature will rise rapidly. Certain bearing metals, notably alloys containing lead, provide some protection against scoring of the shaft.

## Properties of Bearing Materials

Ideally, bearing materials should possess the following properties:

Compatibility Bearing materials that possess anti-scoring properties when operated with mating shafts are said to be compatible.

Wear resistance Hard bearing materials having good wear resistance are sometimes desirable. Phosphor bronze is a good example.

For good service and to reduce scoring of the mating journal, the journal itself should be hardened to approximately 400 BHN.

Phosphor bronze performs well where bearing pressure is high and journal speed fairly low, for example less than 300 m/min.

Compressive strength Compressive strength of bearing or bearing lining material is needed to prevent extrusion of the bearing material under heavy load.

The compressive strength of white metals (Babbitts) decreases as the bearing temperature rises, therefore the softer alloys should be used only for bearings under comparatively light loading pressures and operating at temperatures less than 150°C.

Conformability The softer bearing metals can compensate for slight misalignment of bearings with shafts and other geometric errors. Because of this they are said to have good conformability.

Fatigue resistance This is particularly important in bearings that are used in linkages for reciprocating motion. In such cases the load changes direction and subjects the bearing material to fluctuating stresses that may cause fatigue of the metal. Bearing lining materials that fail through fatigue fragment into flakes.

Corrosion resistance Resistance to corrosion is largely controlled by the use of correct lubricants, particularly with some bearing materials made of leaded alloys. Bearing materials containing tin or aluminium are corrosion resistant.

## Selection of Bearing Material

No bearing material excels in all the properties listed above. Selection of a suitable alloy or material is therefore based on:

- operational speed of the journal;
- type of load;
- amount of load and bearing area;
- operating temperature;
- method of lubrication.

Since the load capacity of a plain bearing is closely related to the speed of the journal, the selection of a suitable material should be based on load and speed.

## Some Common Bearing Materials

### White Metals (Babbitts)

These are rated highest in compatibility and conformability. There are two types:

- Tin-based alloys with some copper present. These have higher hardness and tensile strength than lead-based types and have good corrosion resistance. They are less liable than the lead-based types to pick up on journals having poor lubrication.
- Lead-based alloys. These are less costly than tin-based types. A lead-based alloy containing arsenic has properties that make it compare well with tin-based alloys.

### Copper–lead Alloys

These alloys possess both good fatigue resistance and high temperature performance.

### Lead Bronzes

Lead–bronze alloys offer good compatibility, are easy to cast, have good machinability.

### Phosphor Bronzes

This group provides strong and hard bearing materials having excellent load-carrying capacity at temperatures up to 260°C. They require adequate and reliable lubrication.

### Aluminium–tin Alloys

Alloys of this type have high load-carrying capacity, good fatigue resistance, and good thermal conductivity. Aluminium–tin alloys are now used in connecting rods and main bearings by some automobile manufacturers. For automotive use improvement in compatibility is obtained by coating the bearing surface with a thin overlay, 0.04 mm thick, of lead-based white metal or electro-deposited lead–tin alloy.

### Porous Bronzes

These are sintered metal products containing copper and tin; a small amount of graphite is included in one type. Bushings of the material are made by mixing the metal powders together then compressing them under high pressure in moulds. This is followed later by heating the mouldings to just below melting point so that the material sinters into a solid mass.

Porous bronze bearings are soaked in oil before use. The bearings are popular for light equipment not readily accessible for regular lubrication.

### Plastics

Characteristics of plastic bearing materials include freedom from corrosion, good wear resistance, and excellent compatibility, reducing the need, if any, for lubrication.

One of the most commonly used plastic materials for bearings is nylon, either as plain nylon or heat-stabilised nylon containing graphite or molybdenum di-sulphide. Heat-stabilised nylon resists distortion at temperatures up to 150°C.

Nylon bushings are popular for equipment exposed to weather conditions and where lubrication is not practical.

Problems associated with the use of plastic bearings are the following:

- Their low thermal conductivity limits application to low speed uses only.
- Dimensional stability is greatly affected by any rise in temperature.
- They have low mechanical strength.

These are partly overcome by the use of composite metal plastic bearings or by glass reinforcing of the plastics.

*Note*: Refer to the 'Australian Institute of Metals Handbook' for complete specifications of all metals and alloys of metals and their suppliers.

# 6

# Materials — Plastics

Plastics material is a substance that can be moulded through heat and pressure. Some plastics occur naturally but those in common use, and far more numerous, are artificially made.

The first artificial plastic was made by a Belgian, Leo Baekeland, in 1907. It was patented under the name of Bakelite, which is still used today.

Like all other substances plastics are made up of atoms and molecules. However, in plastics the molecules are joined together to form long chains. Substances containing many small molecules linked together like this are called polymers—'poly' meaning many and 'mer' (see Fig. 1) means units. The joining process, in which small molecules link up to form chains, is called polymerization. For example, polythene is a polymer consisting of approximately 1200 carbon atoms each with two hydrogen atoms attached to each individual carbon atom (see Fig. 2). This molecular arrangement explains the strength and toughness of this type of plastic. Many of the properties of plastics can be explained in terms of long polymer chains.

**Figure 1**

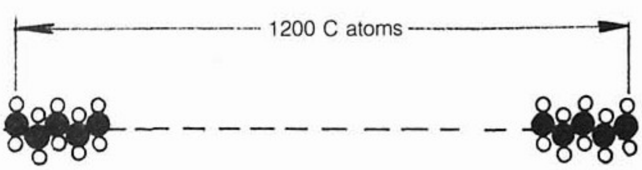



**Figure 2**

Plastics can be divided into two broad groups, thermoplastics and thermosetting plastics. The main difference between these two groups can be explained in terms of the polymer chains. What happens to the polymer chains of a thermoplastic when it is heated can be shown diagrammatically (see Fig. 3).

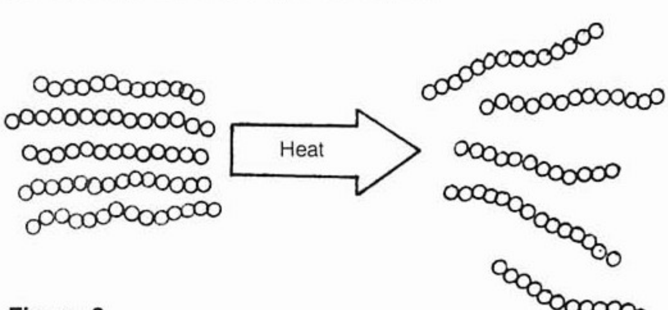



**Figure 3**

Heating causes the polymer chains to become less closely packed, and the plastic softens. If enough heat is applied the plastic will melt and flow.

Thus, thermoplastics are those that soften on heating and can be melted down and re-moulded to a different shape. Examples of thermoplastics are: polythene, polystyrene, poly vinyl chloride (PVC), nylon, perspex, polypropylene, and many others.

Thermosetting plastics, unlike thermoplastics, undergo a chemical change when heated. The molecular chains form cross-linkages, making them three dimensional, (Fig. 4).

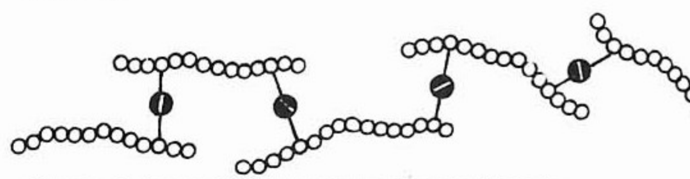


**Figure 4** Atoms forming strong chemical bonds

When they cool, thermosetting plastics become hard and rigid. They cannot be softened again. The cross-linkages between the polymer chains make thermosetting plastics strong and chemically stable. They are used to make articles such as saucepan handles, ashtrays, light fittings, etc.

Examples of thermosetting plastics include Bakelite, melamine, epoxy resins, polyester.

Cold-setting plastics are those that become permanently hard as a result of a chemical reaction that takes place at room temperature. Examples of these plastics are the epoxy resins used as glues (such as Araldite) and as a laminate in fibre glass.

When a number of different monomers are linked in chain form, the term co-polymers is used, for example vinyl choride plus vinyl acetate produces the substance poly(vinyl chloride acetate) (used in record manufacture). (See Fig. 5.)

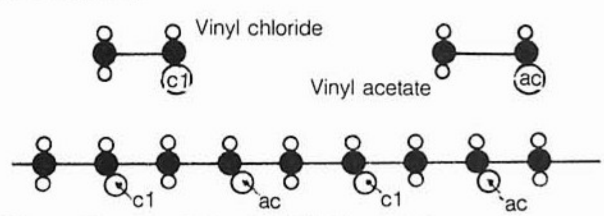



**Figure 5** Poly vinyl chloride acetate

The forces of attraction between chain molecules may be modified by inserting spacer molecules to separate them, increasing the fluidity of the material. The spacers are termed plasticizers because of their effect on the properties of the polymers.

For example, the plasticizer camphor added to cellulose nitrate produces the substance known commercially as celluloid, a mouldable plastic when heated.

The physical properties of many plastics can be greatly improved by reinforcing with a filler material. Fibrous materials such as wood flour, sawdust, waste paper, cotton etc. are used to increase strength, while asbestos fibres improve high-temperature resistance, and electrical resistance is enhanced with a mica filler.

Laminated materials using sheets of plastics-impregnated paper or cotton cloth are a sandwich-type construction for use where a strong panel is required. Wood veneers may be bonded to the surface to improve appearance.

Fibre-reinforced plastics are produced to attempt to increase the strength of otherwise brittle or weak materials. Glass fibre has for many years been used in conjunction with epoxy resins for construction of boats, car body panels and many similar products. A more recent development is the use of carbon filaments as a base for some very high-strength, low-weight composites.

## Synthetic rubbers

Natural rubber is produced by removing the water content of latex, the sap of the rubber tree. It is a polymer consisting of long, tangled molecular chains. Natural rubber is both elastic and thermoplastic. It becomes permanently deformed when stretched and softens with increasing temperature.

In 1839, Charles Goodyear found that by heating a mixture of sulphur and latex the properties of the resulting product were much improved. Vulcanizing, as the process has become known, forms cross-links between the rubber chain molecules, making the rubber tougher and more elastic. It also softens at a much higher temperature than natural rubber.

The American-developed synthetic rubber, GR-S, is a polymer of butadiene and styrene. It is very similar to natural rubber but cheaper to produce and is used in the manufacture of tyres, footwear, hosepipe, conveyor belts and cable insulation.

Neoprene is another synthetic rubber closely related to natural rubber. It has a superior resistance to vegetable and mineral oils and also to high temperatures. Neoprene is an expensive material, generally used for hoses, conveyor belts, gaskets and cable sheathing.

Butyl rubber is a co-polymer of isobutylene and isoprene. It is very stable chemically and has good resistance to heat and many chemicals. Butyl rubber is cheaper than natural rubber and is less likely to perish. It is impermeable to air and other gases and is used for inner tubes, tubeless tyres, air bags, sporting equipment and moulded diaphragms. It is also used for hoses, tank linings and conveyor belts.

## Applications of some common plastics

### Poly vinyl chloride (PVC)

In the unplasticized form PVC is tough and hard. When plasticized it becomes soft, flexible and rubbery. It has good dimensional stability and is resistant to water, acids, alkalis and most common solvents. Plasticized material stiffens with age.

*Uses:* The rigid form is used in mouldings of all kinds, the flexible form in imitation leather cloth, table cloths, raincoats, etc. PVC is also used for piping, guttering and electrical cable covering, safety helmets and chemical tank linings.

### Polytetrafluoroethylene (PTFE or 'Teflon')

Teflon is tough and flexible, has excellent heat resistance and in fact does not burn. It is not attacked by any known reagent and no known solvent. It is an excellent electrical insulator. It has a waxy surface and low coefficient of friction, and is relatively expensive.

*Uses:* Bearings, fuel hoses, gaskets and tapes, and non-stick coatings for cookware. It is also used in the chemical industry because of its resistance to attack.

### Polyamides (nylons)

Polyamides are strong, tough and flexible. They resist abrasion well, and are dimensionally stable. Nylons absorb water but resist most common solvents. They deteriorate with long exposure outdoors. They provide good electrical insulation.

*Uses:* A number of different varieties are in use. Nylons are used in gears, valves, electrical equipment, handles, knobs, bearings, cams, shock absorbers, combs. Other uses are in surgical and pharmaceutical packaging, raincoats, filaments for bristles, climbing ropes, fishing lines and textiles.

### Phenol Formaldehyde (Bakelite)

In the 'raw' state, phenolics are brittle, so they are filled with fibrous materials to increase strength. They have diverse properties depending on the filler used. In thin sections they are likely to be brittle. Bakelite absorbs water but resists alcohol, oils and most common solvents. It does not soften but it decomposes above 200°C.

*Uses:* Electrical equipment, handles, buttons, radio cabinets, furniture, vacuum cleaner parts, cameras, ash trays, and engine ignition equipment are some of the uses. Other uses are for cheap jewellery, ornaments, laminated materials—electrical equipment, gears, bearings, aircraft parts. Bakelite is also used for chemical equipment, and clutch and brake linings.

### Polyethylene (polythene)

Polythene is one of the most versatile thermoplastics. It is tough and flexible across a wide temperature range, and has good dimensional stability. It is easily moulded, and resists most common solvents well. Its properties ensure it weathers well but there is some deterioration on long exposure to light.

*Uses:* Polyethylene is used largely in packaging as bags and squeeze-bottles. It is also used in a wide range of household goods such as buckets, bowls and other containers. Piping, chemical equipment, coating for cables and wires and other applications.

# Properties and uses of thermoplastic materials

Table 1 lists some physical properties and uses of the common thermoplastics.

**Table 1** Properties of some thermoplastics

| Group | Compound | Relative density | Tensile strength (N/mm²) | Typical uses |
|---|---|---|---|---|
| Cellulosics | Cellulose nitrate | 1.37 | 40 | Brush and cutlery handles, drawing instruments, fountain pens, instrument dials, labels, spectacle frames, piano keys, toilet seats, tool handles. Flammability limits use. |
| | Cellulose acetate | 1.30 | 33 | Artificial leather, brush-backs, combs, spectacle frames, photographic film, mixing bowls, lamp-shades, toys, laminated luggage, knobs, wire- and cable-covering. |
| Vinyls | Poly vinyl chloride (PVC) | 1.35 | 55 | Artificial leather cloth, gloves, belts, toys, dolls, curtains, raincoats, safety-helmets, protective clothing, packaging, industrial piping, beading, radio components, cable covering, factory-ducting, plating vats. |
| | Poly vinyl chloride acetate | 1.3 | 25 | Gramophone records, containers, chemical equipment, screens, protective clothing. |
| | Poly vinylidene chloride ('Saran') | 1.68 | 28 | Food wrapping, packaging, filaments used in weaving upholstery fabrics, rugs and carpets, outdoor furniture, seats for buses, filters, chemical equipment, screens, coating of wire. |
| | Polythene | 0.92 | 13 | Acid-resisting linings, babies' baths, bottle-caps, dust-bins, electrical insulation, kitchen equipment, packaging film, wrapping material, chemical equipment, cold-water plumbing, squeeze-bottles, surgical items, etc. |
| | Polypropylene | 0.90 | 33 | Packaging, pipes and fittings, cable insulation, battery boxes, refrigerator parts, sterilizable bottles and other uses where boiling water is involved, cars. |
| | Polystyrene | 1.06 | 45 | Radio and TV parts, food containers, kitchen equipment, refrigerator parts, toys, toilet articles. The foam form is used for ceiling tiles and packaging. |
| | ABS | 1.01 | 35 | Pipes, radio cabinets, tool handles, valves, protective helmets, textile bobbins, pumps, battery cases, luggage. Now used in large amounts for automobile bodywork. |
| Fluorocarbons | Poly tetrafluoroethylene (PTFE, Teflon) | 2.15 | 25 −350 | Gaskets, valve-packings, inert laboratory equipment, chemical plant, piston rings, bearings, non-stick coatings (frying pans), electrical insulation, filters. |
| Polyamides | Nylon 66 | 1.12 | Moulded-66 filaments | Raincoats, yarn (clothing), containers, cable-covering, gears, bearings, cams, spectacle frames, combs, bristles for brushes, climbing-ropes, fishing lines, shock absorbers. |
| Polyesters (thermo-plastic) | Terylene, Dacron | 1.38 | 175 | Synthetic fibres — a wide range of clothing. |
| Acetal resins | | 1.42 | 70 | Bearings and cams, gears, flexible shafts, office machinery, carburettor parts, pump-impellers and bowls, car instrument-panels, knobs and handles. |
| Acrylics | Poly methyl methacrylate (PMM, Perspex, Plexiglass) | 1.18 | 55 | Aircraft glazing, building panels, roof lighting, baths, sinks, protective shields, advertising displays, windows and windscreens, automobile tail-lights, lenses, toilet articles, dentures, knobs, telephones, aquariums, double-glazing, garden cloches. |

Table 2 lists some of the physical properties and uses of thermosetting materials.

**Table 2** Properties of some thermosetting plastics

| Group | Compound | Relative density | Tensile strength ($N/mm^2$) | Typical uses |
|---|---|---|---|---|
| Phenolics | Phenol formaldehyde ('Bakelite') | 1.45 | 50 | Electrical equipment, radio cabinets, vacuum cleaners, ashtrays, buttons, cheap cameras, automobile ignition systems, ornaments, handles, instrument panels, advertising displays, novelties and games, dies, gears, bearings (laminates), washing-machine agitators. |
| | Urea formaldehyde | 1.48 | 45 | Adhesives, plugs and switches, buckles, buttons, bottle tops, cups, saucers, plates, radio cabinets, knobs, clock cases, kitchen equipment, electric light fittings, surface coatings, bond for foundry sand. |
| | Melamine formaldehyde | 1.49 | 50 | Electrical equipment, handles, knobs, cups, saucers, plates, refrigerator coatings, trays, washing-machine agitators, radio cabinets, light fixtures, lamp pedestals, switches, buttons, building panels, automotive ignition blocks, manufacture of laminates. |
| Polyesters (setting types) | | 1.3 | 40 | Adhesives, surface coatings, corrugated and flat translucent lighting-panels, lampshades, radio grills, refrigerator parts. Polyester laminates are used for hulls of boats, car bodies, wheelbarrows, helmets, swimming pools, fishing rods and archery-bows. |
| Alkyd resins | | 2.2 | 25 | Enamels and lacquers for cars, refrigerators, and stoves. Electrical equipment for cars, light-switches, electric-motor insulation, television-set parts. |
| Polyurethanes | | 1.2 | Mainly foams | Adhesives (glass to metal), paint base, wire-coating, gears, bearings, electronic equipment, handles, knobs. Foams are used for insulation, upholstery, sponges, etc. Rigid foams are used for reinforcement of some aircraft wings. |
| Epoxy resins | Heat-resistant type<br>General purpose | 1.15<br>1.15 | 70<br>63 | Adhesives (metal glueing), surface coatings, casting and 'potting' of specimens. Laminates are used for boat hulls (with fibre glass), table surfaces and laboratory furniture, drop-hammer dies. Epoxy putty is used in foundries, to repair defective castings. |

# 9

# Lubricants

The main function of all lubricants is to separate moving contacting surfaces with a film that prevents metal to metal contact.

## Types of lubricant

Machines are lubricated by two types of lubricant: oils and greases.

### Lubricating Oils

#### Functions

Oils have many important functions and are used:

- as a lubricant wherever surfaces are in contact;
- as a circulating fluid for hydraulic mechanisms in machine tools;
- as a coolant when machining metals;
- as a quenching fluid for heat-treatment of steels;
- as a protection against rust.

Oil technologists have developed fluids to meet the special requirements of each application. These oils should not be mixed either by mislabelling of stocks or by contamination. Bearing seals and wiper felts on slides prevent contamination and, as well, retain lubricants within a specified area. They should be kept clean, and be replaced from time to time.

#### Properties

*Viscosity*

The molecules of lubricating oils flow easily becaue they have very little adhesion to each other. The resistance they offer to any movement is called viscosity. The units of viscosity are indicated by numbers, for example SAE 10 (Society of Engineers 10) is a thin oil and flows easily, SAE 50 is a thicker oil with good adhesive qualities. Viscosity is affected by temperature and bearing pressure. Increase in temperature causes a decrease in viscosity. Increase in pressure of oils in confined spaces increases viscosity. When choosing lubricating oils the following general rules apply:

- For bearings supporting light loads at high speeds, use low viscosity (thin) oils, for example grinding machine spindles.
- For bearings supporting heavy loads at low speed, use medium viscosity oils, for example for plain shaft bearings carrying pulleys, chains, etc.
- If there is considerable pressure between the contacting surfaces, such as there is with some helical and worm gearing applications, it is necessary to choose an oil of suitable viscosity and adhesion to the frictional surfaces to resist the pressure.

#### Oil Changing

Mineral oils have a tendancy to become oxidized and to form resinous gummy insolubles after a period of time, particularly if the oil is being constantly mixed with the surrounding air. These insolubles may affect the surface to be lubricated, and because other pollutants (condensation, dirt, other oils) also affect lubricated surfaces, it is essential that the oil be constantly cleaned or changed at regular intervals.

Drip feed oilers and regular application from an oil can are also means of overcoming the above problems.

*Quality*

In most instances modern lubricants contain substitution compounds or additives to improve and intensify certain characteristics of the base oil for specific applications or to widen their field of usefulness (see Table 1). It is important that the base oil be of high quality and the finished lubricant be manufactured with great care.

### Greases

Lubricating grease is a more or less firm paste. It has the advantage of firm adhesion to frictional surfaces. Greases comprise oil mixed with soapy materials.

Grease = oil + soap

The properties of the two components determine the properties and structure of the grease.

- Thin oils and low soap content produce soft greases.
- Thick oils (usually green) give compact, firm greases.
- The type of soap materials (see Table 2) selected for the mixture will determine properties such as water resistance, resistance to changes in temperature, and extreme pressure resistance.
- Additives provide rust resistance, extreme pressure (EP) qualities, and antioxidant properties (See Table 2).

#### Types of Grease

Table 2 gives a guide to the selection of greases. Oil company consultants are generally most helpful when full information is required.

#### Consistency

Consistency of a grease is mainly a guide to the means of application. It is not a guide to lubricating ability. Table 3 shows the method of application of various consistencies.

**Table 1** Types of additives used in industrial lubricants

| Lubricant | Type of additive used | Purpose |
|---|---|---|
| Turbine oils, hydraulic oils, circulating oils, electric motor oils, spindle oils | Oxidation inhibitor | Provide long life |
| | Rust inhibitor | Prevent rusting in system |
| | Antifoam compound | Minimize foaming |
| | Extreme pressure agent | Withstand extreme pressures |
| | Pour depressant | Outdoor use in cold weather |
| Air compressor oils | Oxidation inhibitor | Prevent varnish, sludge and corrosion of alloy bearings |
| Air-line lubricator oil | Rust inhibitor | Inhibit rusting |
| | Polar compound | Improve lubrication in presence of water |
| | Antifoam compound | Minimize foaming |
| Gear oils: EP-hyphoid type | Chlorine, sulphur, lead, zinc, and phosphorous compounds | Withstand extreme pressures and shock load, antiwelding |
| | Rust inhibitor | Prevent rust in presence of moisture |
| Heavy duty and worm type | Polar-fatty materials | Improve film strength and lubrication |
| | Antifoam compound | Minimise foaming |
| Cutback agent | Petroleum thinner, chlorinated, or coal-tar solvent | For ease of application |
| Steam cylinder oils — compounded | Fatty material such as tallow, degras, and lard | Provide ample lubrication of cylinders and valves using wet steam |
| | Pour depressant | For fluidity and handling at low temperatures |
| Heavy-duty motor and diesel crankcase oils, portable compressor crank-case oils | Viscosity-index improver | Permit easy starting in cold weather and multi-viscosity |
| | Pour-point depressant | SAE grade |
| | Detergent-dispersant | Maintain engine cleanliness |
| | Oxidation-corrosion and anti-wear inhibitors | Resist oil oxidation and prevent bearing corrosion. Reduce cylinder, rings and cam wear |
| | Antifoam compound | Minimize foaming |
| | Antirust agent | Gives rust resistance |
| Way or slide oils | Oiliness agents, EP compounds | Reduce friction, seizure-wear and furnish lubricity and EP |
| | Tackiness agent | Non-drip, ability to withstand squeezing out |
| Rustproof or slushing oils | Polar materials, emulsifiers and petrolatum mixtures | Protect steel from rusting |
| Roll oils | Palm oil, tallow or other polar additives | Prevent scratching and provide good surface finish |
| | Soluble oil or other emulsifiers | Provide ease of emulsion formation |
| Thread compounds | Powdered lead, zinc, copper, graphite or molybdenum disulphide | Prevent galling of threads |
| | | Provide good seal under pressure |
| Soluble oils | Water-soluble sulphonates, soaps, and other emulsifiers | Provide stable oil in water emulsions |
| | Bactericides | Eliminate bacterial action |
| EP | Extreme-pressure agents | Withstand extreme pressures |
| | Rust inhibitors | Prevent rusting of processed parts |
| | Antifoam compound | Minimize foaming |
| Cutting oils | Polar or fatty materials | Give adhesion to metals and reduce friction |
| | Sulphur, chlorine, phosphorous compounds and sulphurized fats | Withstand extreme pressures |
| | Antifoam compounds | Minimize foaming |
| Quenching oils | Polar materials and other wetting agents | Provide quick wetting of hot metal |
| Fire-resistant hydraulic fluids | Rust inhibitors | Rust and corrosion resistance |
| | Oxidation inhibitor | For long life |
| | Antifoam compound | Minimize foaming |
| | Antiwear inhibitor | To reduce wear in gear pumps |
| Ball and roller bearing greases | Mixed calcium and sodium | Thickening agent to provide consistency and high dropping point |
| | Lithium or sodium soaps | |
| | Oxidation inhibitor | Oxidation resistance and change of structure |
| | Rust inhibitor | Prevent rusting in wet conditions |
| | Metal deactivators | Prevent catalytic effect of metals |
| EP greases | Calcium, lithium or sodium soaps | Thickening agents |
| | Chlorine, sulphur, phosphorous, lead, zinc or molybdenum disulphide | To withstand extreme pressures and shock loading |
| | Polar compounds | Used in presence of water and to improve lubrication |
| | Oxidation inhibitor | Oxidation resistance |
| Cup greases | Calcium soap | Thickening agent |

Table 2 Types of grease

| Base | Texture | Principal uses | Remarks |
|---|---|---|---|
| Lime | Smooth to buttery | General purpose industrial, grease cups, pressure guns, heavy duty | Good mechanical stability up to 71°C (do not use above 71°C). Good water resistance |
| Soda | Fibrous to buttery | Moderately high temperature lubrication<br>Anti-friction plain bearings<br>Flat surfaces | Good resistance to mechanical breakdown and oxidation at high speeds and temperatures (110°C plus) |
| Mixed | Various | Special applications<br>Life-lubricated bearings | Mixed base greases vary widely and are made for special applications |
| Aluminium | Smooth to stringy | Where extreme tackiness is needed<br>Chassis fittings<br>Oscillating bearings etc. | Maintain consistency and texture up to melting point<br>Never tacky or fibrous |
| Barium | Smooth to fibrous | General automotive lubrication<br>Multi-purpose bearings | Bring together best qualities of other greases<br>Have high soap content, which may cause trouble in very-high-speed bearings, in low-temperature conditions, and in grease-dispensing systems |
| Lithium | Smooth to buttery | Best for both high and low-temperature uses<br>Aircraft lubrication<br>Multi-purpose | Have the best all-round temperature and mechanical stability |
| Clay | Smooth | Used for higher temperature applications | Do not melt at higher temperatures |

### Types of grease

Table 2 gives a guide to the selection of greases. Oil company consultants are generally most helpful when full information is required.

Table 3 Method of application of greases

| Consistency number | Description | Method of application |
|---|---|---|
| 0 | Semi-fluid | Brush |
| 1 | Very soft | Pin-type grease cup |
| 2 | Soft | Pressure gun or centralised pressure system |
| 3 | Light cup grease | Pressure gun or centralised pressure system |
| 4 | Medium cup grease | Pressure gun or centralised pressure system |
| 5 | Heavy cup grease | Pressure gun or by hand |
| 6 | Block grease | Hand lubricated, cut to fit lubricator or bearing pocket |

## Applying lubricants

### Methods

Methods of applying lubricants have progressed together with the development of modern machinery, but many of the oldest systems are still in use because of their simplicity and cheapness. However, expensive machinery is protected by sometimes elaborate splash and force feed systems.

The method of application depends on factors such as the following:

- Type of service – plain bearing, ball or roller bearing, slides, gears, chains, etc.
- Type of lubricant required – oil or grease.
- The complexity of the equipment – a cheap plain bearing may require daily application with an oil can. Ball and roller bearings in a steel rolling plant will require a centralized pressure grease system.

Some simple methods of applying lubricants are shown in Table 4 and are illustrated in Figures 1 to 8. Students should enlarge the list by observation and study of the many other methods.

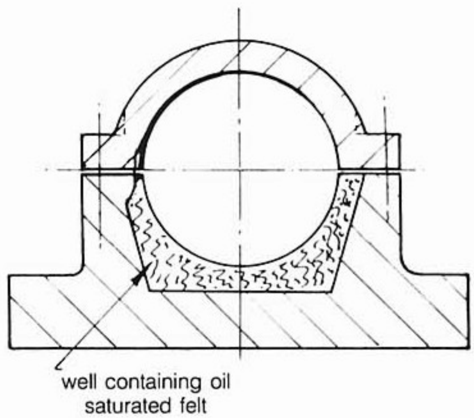



**Figure 1** Waste pad lubrication

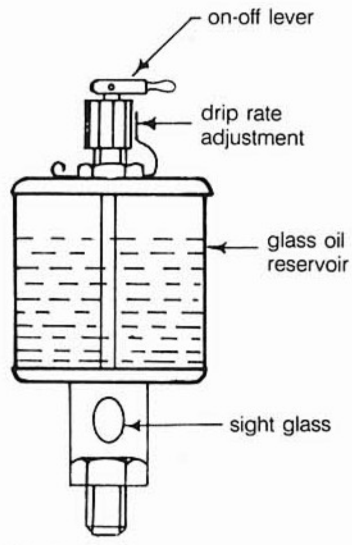



**Figure 2** Sight feed oiler

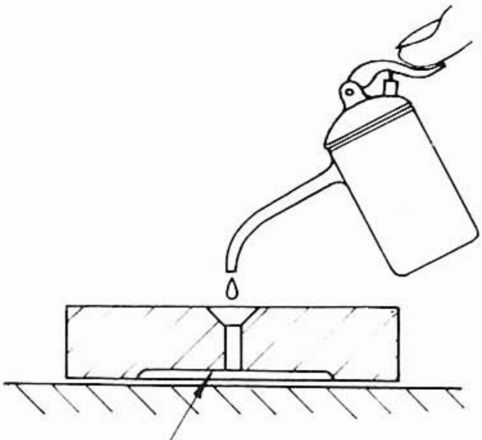



**Figure 3** Oil can lubrication

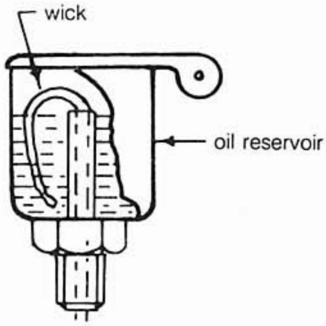



**Figure 4** Wick feed oiler

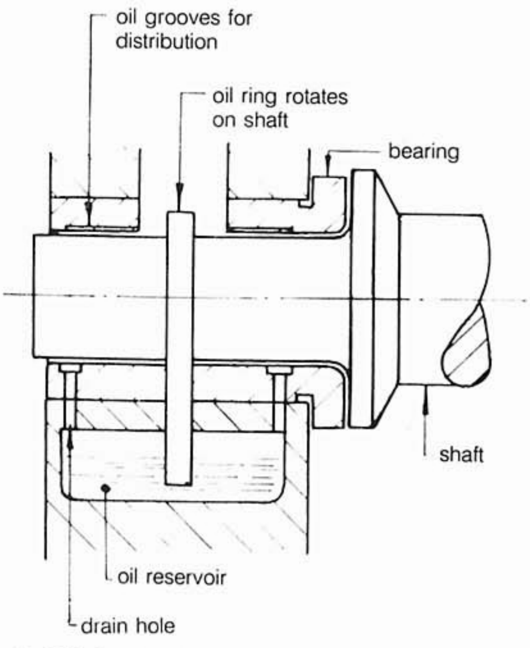



**Figure 5** Oil ring lubrication

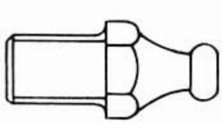


**Figure 6** Grease or oil nipple

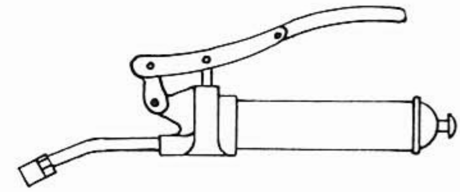


**Figure 7** Grease gun

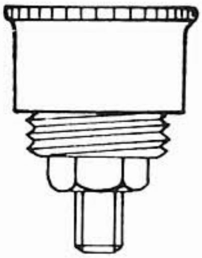


**Figure 8** Grease or oil cup

## Frequency of Application

The frequency of lubrication of a bearing is determined by many factors. The type of bearing, the speed and load under which it operates, temperature, dirt and dust conditions must all be considered.

There is one certain factor—a film of oil must be maintained at all times.

### Lubrication Charts

Machinery manufacturers usually supply a lubrication chart indicating the lubrication points, the type of lubricant, and the frequency of application. It is the duty of machinists to seek out the lubrication details of machines in their charge and to attend to these requirements. (See Fig. 9.)

Most machine tools have a number of points requiring daily lubrication with an oil can. This should never be overlooked and it must be appreciated that as cleanliness is vital to effective lubrication, machine slides must be kept clean.

### Over-lubrication

Over-lubrication, particularly with force-feed systems, can be damaging to seals and is often the cause of drag, which leads to overheating, inefficiency and damage to the bearing surface. The recommended quantity is all that should be applied. Over-lubrication of food-processing machinery may lead to food contamination, and in other industries contribute materially to poor working conditions.

Table 4 Methods of applying lubricants

| Method | Description | Uses |
|---|---|---|
| Pad | A felt or similar pad saturated in oil rests on the revolving shaft. Requires daily filling from an oil can. | Slow speed applications in dusty conditions. |
| Sight feed oilers | Sight feed oilers are screwed to the bearing or to a copper pipe attached to the bearing. The oil supply is visible and the flow adjustable. The rate of flow may be seen through a sight glass. | Good quality plain bearings requiring a constant supply of clean oil. |
| Oil cans | The simplest method and very effective when used regularly. Oil is applied through an oil hole, which leads into oil grooves cut in the bearing surface. The oil grooves distribute the oil over the clearance areas. | Plain bearings and slides on most types of machinery. |
| Wick feed oilers | The oil flows through a wick by capillary and siphon action from the oil reservoir. | Machine slides, plain bearings. |
| Oil rings | A large diameter ring or chain rests on the shaft and dips into an oil reservoir. As the shaft revolves the oil is lifted from the reservoir by the turning of the ring. Oil grooves distribute the oil along the bearing and a groove at each end collects the oil for draining back into the reservoir. | Medium size and medium speed bearings when only a small amount of attention can be given. Reservoirs must be cleaned periodically to remove dust and grit. |
| Grease nipples and grease guns | Grease or oil nipples are screwed to the bearing. They are used in conjunction with a grease or oil gun, which is used to force the lubricant into the bearing at regular intervals. A spring-loaded ball prevents the grease from flowing back through the nipple. | Plain, ball and roller bearings, machine slides, applications with high dust content, e.g. automobiles, tractors, agricultural machinery, machine tools, etc. |
| Grease cups | A very simple means of forcing grease into a bearing. The cap is filled with grease and screwed onto the cup, which is attached to the bearing. Oil cups act in the same way. The cap is given one or two turns at regular intervals, until clean grease is visible at the sides of the bearings. | Slow-speed bearings or slides on earth-moving and agricultural machinery, industrial applications with high dust element. |

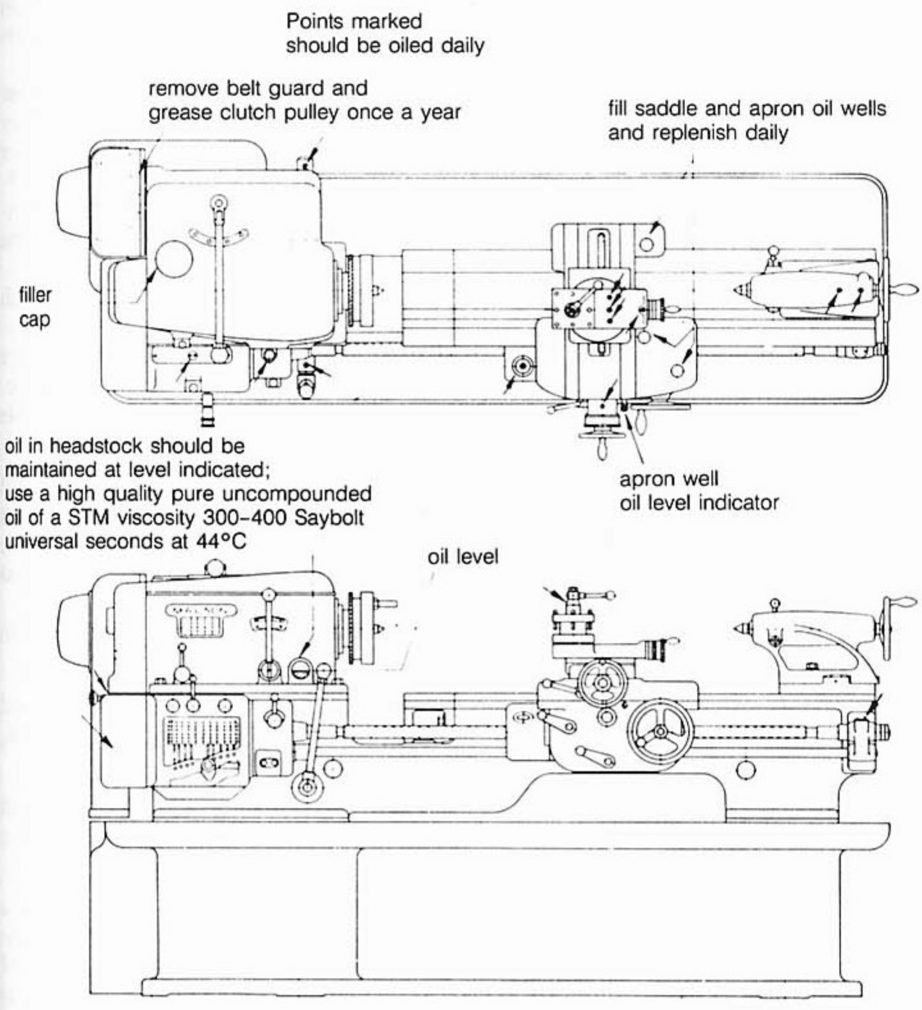



**Figure 9** Typical lubrication chart for a lathe

# 12

# Benches and bench vices

## Benches

Part of the basic equipment of an engineering workshop is a fitter's bench. Fitters benches are designed to suit the type of work for which they are used.

### Types of Bench

Wall bench   A wall bench is fixed very rigidly to the wall and floor.

Island bench   An island bench rests on, or is fixed to, the floor. Vices can be attached to both sides of this type of bench, and then a protective screen should be erected along the centre to prevent injury from flying particles of metal.

Portable bench   A portable bench is mounted on castors or wheels so that it may be moved from place to place as required. It is particularly useful when carrying out maintenance work away from the main workshop.

### Construction of Benches

- The frame of the bench may be made of timber, or of structural steel sections welded together. It should be braced and rigid.
- The top is usually made of sheet metal or burnie board with angle-iron edging because of the high cost of a solid timber top. A flat bench is most suitable.
- The average height of the benchtop is 850 mm from the floor. This height enables work to be held in a vice in a position suitable for chipping, filing and other fitting operations. The most convenient height is with the top of the vice jaw at elbow height.
- When constructing a bench provision for tool storage should be made. This may take the form of a shelf, backboard or locker on the bench, or drawers under the bench. Each tool should have its own place.

### Position of the Bench

The ideal position is one where the light comes from above and behind the fitter when facing the bench. Both poor light and glare should be avoided.

### Tidiness

Tools in use may be set out on the bench, but it should be clean at all times and free from tools and materials not being used.

## Engineers' vices

Vices for bench work vary in construction and size depending on the purpose for which they are to be used. The size of a vice is determined by the width of the jaws. Vices may be made of cast iron or fabricated steel.

### Types of Vices

Plain screw vice   This is the most common type of vice and consists of a fixed jaw, which is bolted to the bench, and a sliding jaw (Fig. 1). Detachable, knurled and hardened steel jaw strips are screwed to each jaw. The sliding jaw is usually operated by a square-form screw and nut (see Fig. 2).

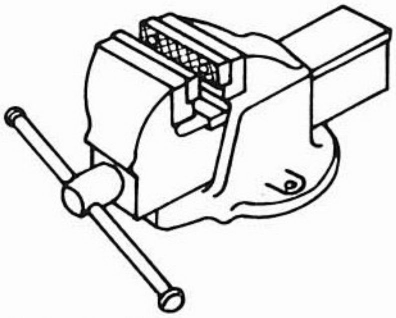


**Figure 1** Plain screw vice

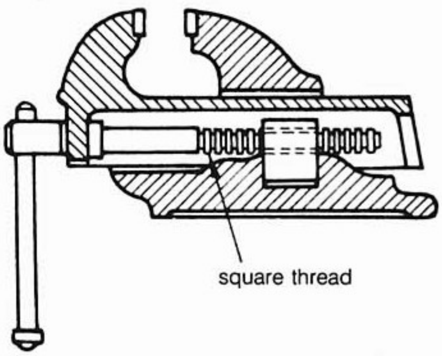



**Figure 2** Sectional view of a screw vice

Quick action vice   This is similar to the plain screw vice, but is operated by a buttress-form screw and a half nut. The half nut may be withdrawn to allow rapid adjustments to the sliding jaw. This type of vice is more commonly used in carpentry and pattern-making shops.

Offset vice   This vice enables long work to be held vertically (see Fig. 3).

Swivel base vice   The work may be swivelled to a suitable position, then locked in place by two clamping screws, making the vice more adaptable. (See Fig. 4.)

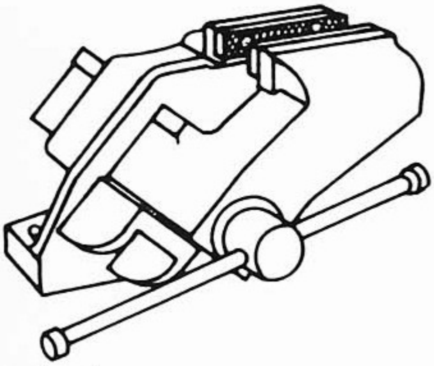


**Figure 3** Offset vice

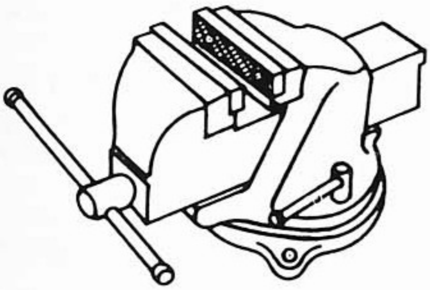


**Figure 4** Swivel base vice

Pipe vice   Pipe vices (Figs 5 and 6) are used principally for holding a length of pipe for screwing.

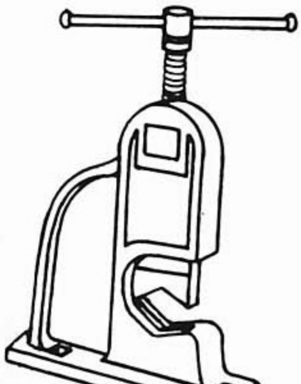


**Figure 5** Pipe vice

**Figure 6** Chain type pipe vice

## Location of the Bench Vice

To ensure rigidity and quietness the vice should be bolted directly above the leg of the bench. The fixed jaw should extend approximately 1.5 mm beyond the edge of the bench top to enable long work to be held vertically.

## Special Jaws

Soft jaws   These may be made of aluminium, copper, lead or other soft metal (Fig. 7). They are used to protect soft or finished work from the knurling on the jaws in the vice. They may also be used to protect the jaws from work that has been hardened.

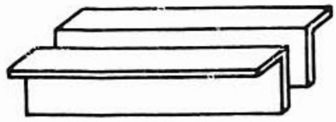


**Figure 7** Soft jaws

Various false jaws or vice clamps   These are often used for holding round, threaded, tapered or irregular work in a vice (see Figs 8 and 9).

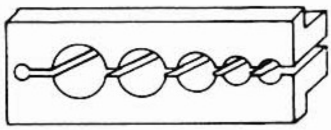


**Figure 8** False jaws

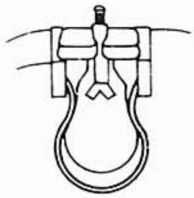


**Figure 9** False jaws with spring

## Care and Use of the Vice

Observe these points:

- Clean the vice and lubricate the slide, the screw and the nut regularly.
- Do not strain the vice by excessive tightening. The handle has been designed to provide the maximum safe leverage when used in a normal manner. If it is difficult to grip a piece of work firmly enough that it will not move, place a supporting block beneath it (Fig. 10). If movement is due to an overhanging portion of the work, support it from the floor with a wooden prop.

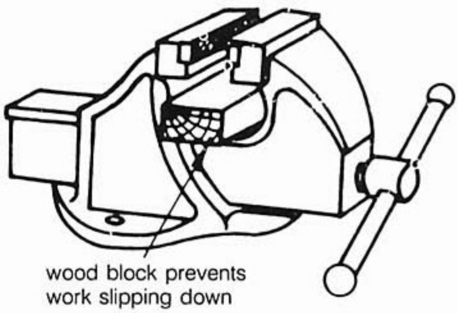



**Figure 10** Use of wooden block to support work

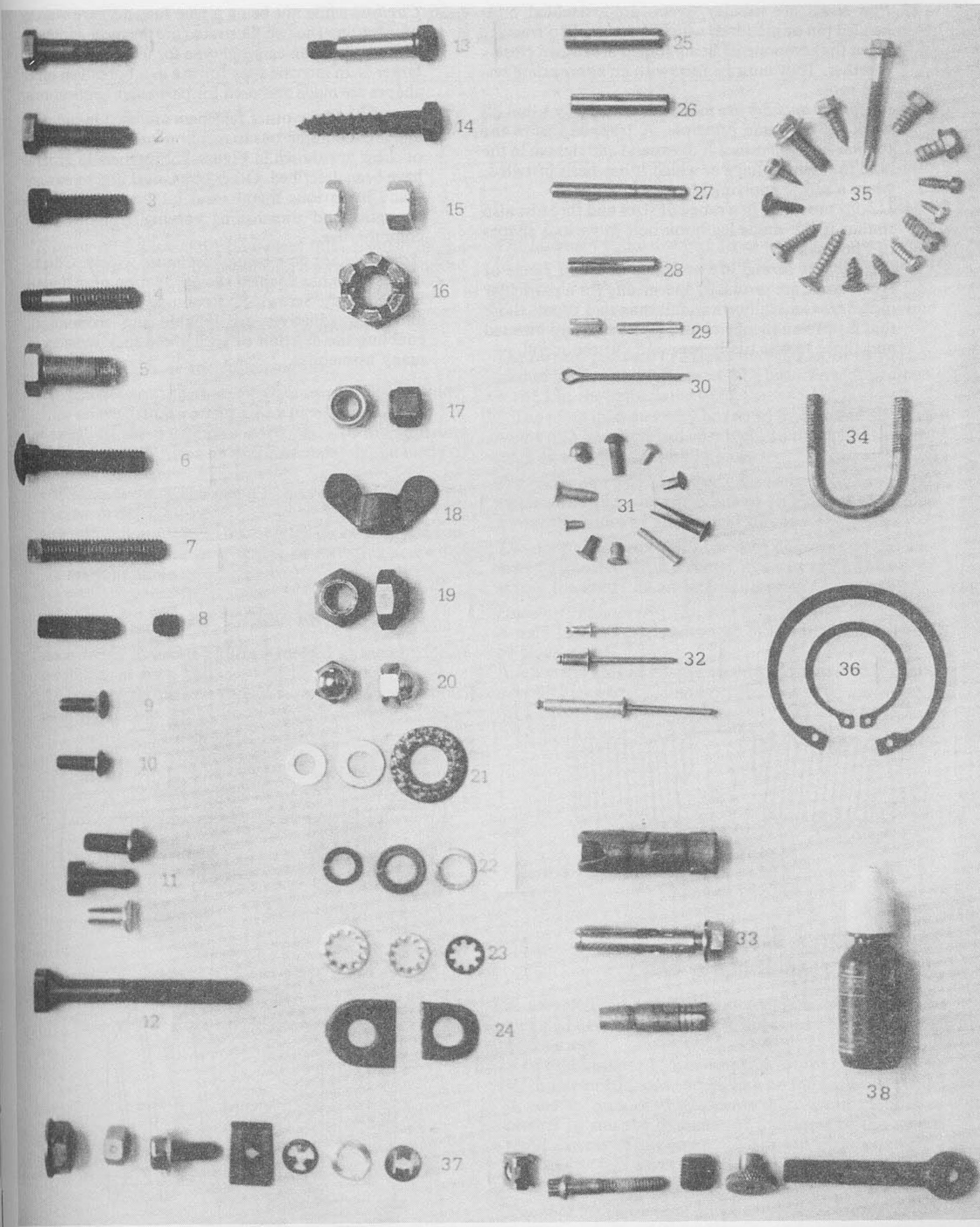
- Grip the work in the centre of the jaws, or pack the opposite end of the jaws to equalize the strain. Failure to do this may result in a broken sliding jaw.
- Use soft or false jaws where required.
- Never use the vice as a hammering plate or as an anvil.
- When using tools such as hammers, chisels, files, hacksaws, etc., take care that these do not damage the vice.

# 13

# Fasteners

The many devices and materials we use to hold two or more components together are called fasteners.

1 *Hexagon head bolt*, made in BSW, metric, UNC and UNF thread; it is the most common bolt used in general engineering.
2 *Hexagon head set screw* has the thread cut the full length, and in all other respects is the same as the bolt.
3 *Socket head cap screw* has a hexagon in the head to accept a hexagon key. Cap screws are made of high-tensile steel. They are available in BSW, UNC, BSF, UNF, BA and metric thread.
4 *Engineers stud*, usually in BSW or metric thread. The thread length on the short end is $1\frac{1}{2}$ times the diameter, and bolt length on the other end.
5 *Unified hexagon head set screw*, made in UNC and UNF thread; it is also made in bolt-length thread. Note the washer face under the head.
6 *Cup head square neck bolt*, made in BSW and metric thread. It is commonly called a carriage bolt as it was used mainly for bolting wood to wood and wood to metal by coach builders.
7 *Square head set screw*, made in BSW, UNC, and metric thread; it is a high-tensile or case-hardened screw, with either a cup or a half-dog point.
8 *Socket set screw*, made in BSW, UNC, UNF, metric and BA thread. The point can be either flat, cone, cup, knurled cup, half dog, full dog, or oval. The short screw is commonly called a grub screw.
9 *Socket countersunk screw*, made in BSW, UNC, UNF, metric and BA thread.
10 *Socket button head screw* made in BSW, UNC, UNF, and metric thread.
11 *Metal thread screw*, made to $\frac{3}{8}$ in. or 10 mm diameter in BSW or metric thread, with cheese, round, or countersunk heads.
12 *T-bolt*, made in BSW or metric thread; it is used on machine tables to fit into the standard T-slot for clamping purposes.
13 *Shoulder screw*, made in BSW, UNC, and metric thread. It has a socket head and the shank is cylindrically ground. It is identified by the shank diameter and length, not the thread, i.e. a 10 mm screw has an 8 mm thread.
14 *Coach screw* is a large wood screw with a square or hexagon head.
15 *Hexagon nut* and *lock nut* are made in all common thread sizes.
16 *Slotted or castellated nut*. To make the nut secure, a cotter pin is inserted in the slots through a hole in the screw.
17 *Nyloc nut* has a nylon ring securely trapped in the outer end, which conforms to the thread when used; then, being under compression, it exerts a gripping action on the screw.
18 *Conelock nut* has the top conelike section cold forged and slightly triangular. This produces a force fit thread section as it is tightened.
19 *Wing nut* is hand tightened by the thumb and fingers; it is used for light and convenient fastening.
20 *Acorn or dome nut* is a hexagon with a dome, which increases its length, enabling the tapped hole to be blind; therefore, when fitted, it protects the bolt or stud from dirt and corrosion.
21 *Plain washers* of various gauges and diameter are usually black, bright or galvanized finish.
22 *Spring washers* are most commonly made of square-section spring wire. Flat section is also used to add tension to a tightened fastener, but it is less common.
23 *Serrated or shakeproof washers* are made of spring steel with teeth formed either on the inside or outside which, owing to their form, bite into the nut or bolt head resisting it from vibrating loose. They are also made for countersunk screws.
24 *Taper or girder washers* are used on the taper surface of rolled joists and channel sections to effectively produce a surface square to the fastener.
25 *Dowel pin* is a hardened and ground pin used as a drive fit to hold various engineering components in the correct place.
26 *Tapped dowel pin* is used in blind holes. The tapped hole is used for extraction. Note, the flat is designed to allow the air and/or oil to escape.
27 *Taper pins* have a taper of 1 in 48 imperial and 1 in 50 metric, and are made in a range of 15 diameters, from 2.5 mm to 18 mm diameter and up to 150 mm long. They are used to secure collars, gears, wheels to shafts—in fact a myriad of applications where accuracy and ease of removal are needed.
28 *Grooved pin* is a plain pin with V-grooves pressed into its diameter, deeper at one end. This gives it a slight taper on diameter, enabling it to be driven into a drilled hole.
29 *Roll pin or spring pin* is a dowel pin made by forming spring steel into an open joint tube section, which can be driven into a drilled hole; it makes an excellent economical dowelled assembly.
30 *Cotter pin or split pin*, as it is sometimes called, is used with the castle nut and in other similar securing applications.
31 *Rivets* are made in a range of heads and various metals for particular applications.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32 *Pop rivets* are tubular rivets, pre-assembled on a headed pin or mandrel, which is designed to fracture when the components being joined are drawn closely together. They must be used with an appropriate setting tool.

33 *Masonary anchors* are made in many designs, but all work on the same principle. A trapped nut in the tubular housing causes it to expand and tighten in the hole in the masonary in which it has been installed, when a screw applying a load is tightened.

34 *U bolts* are made in a range of sizes and threads; also similar is the single leg hook bolt in various shapes of hooked end.

35 *Self-tapping screws* are available in a vast range of types; some are produced specifically for a particular industry. Generally, they fall into two types, those that flow form the metal into which they are inserted and those that actually tap, and cut the metal.

36 *Circlips*, while not being a true fastener, are worthy of mention. The two illustrated are the most common. The smaller is an external type for use on a shaft, the larger is an internal type for use in a bore. Ten other shapes are made and used for particular applications.

37 *Fasteners* Many other fasteners are used in industry and are too numerous to mention individually. A few of these are shown in Figure 1. Fasteners in general have been described. Other bolts, nuts and screws are made in various metals and qualities with tensile strengths and dimensions varying from those in common use.

38 *Adhesives* are now being used more widely. Chemical research has enabled the production of materials like 'Nutloc', 'Screwloc', 'Retaining Compound' etc. and such adhesives are reliable and economical, enabling the deletion of spring and lock washers in many assemblies.

# 14

# Screw threads

A screw thread is a uniform helical ridge formed on the surface of a cylinder by producing helical grooves of the required shape and depth.

## Uses for screw threads

Screw threads have the following uses:

- to fasten parts together, as when using bolts and nuts, set screws, studs, or threaded pipe joints;
- to adjust the position of parts, as with the adjusting screws for gib strips on machine slides or the blade of a lawn mower;
- to exert force, when using a vice, a screw jack, or a screw press;
- to transmit motion, as by the lathe cross-slide and top-slide screws, lathe lead screw, or elevating screw for a machine table.

## Screw thread terms

*An external thread* is a thread formed at the outside of a cylinder as on a bolt.
*An internal thread* is a thread formed in a round hole, as in a nut (Fig. 1).

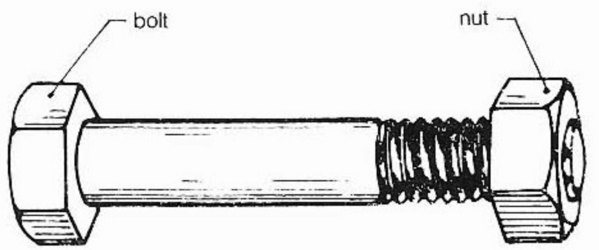



**Figure 1** Nut and bolt

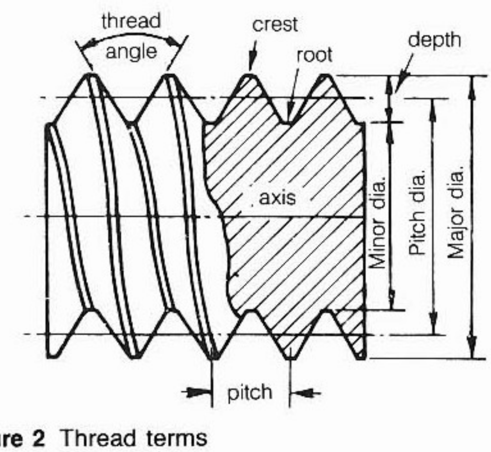



**Figure 2** Thread terms

*The pitch (P)* is the distance from a point on one thread to the corresponding point on the next thread, measured parallel to the axis. (Fig. 2.)

*The lead (L)* is the distance a nut will travel along in one revolution (measured parallel to the axis).

*The threads per inch (TPI)* are the number of threads or pitches in a length of one inch. The term 'threads per inch' is used in the imperial system.

The pitch in inches may be found by dividing one inch by the number of threads per inch. In the metric system, pitch is expressed in millimetres.

*The major diameter (MD)*, or outside diameter, is the diameter measured over the crests of an external thread or across the roots of an internal thread.

*The minor diameter (md)*, or root diameter, is the diameter measured at the roots of an external thread or across the crests of an internal thread.

*Hand of threads (Fig. 3)*
A right-hand thread is advanced by turning it to the right, or clockwise.
A left-hand thread is advanced by turning it to the left, or anticlockwise.

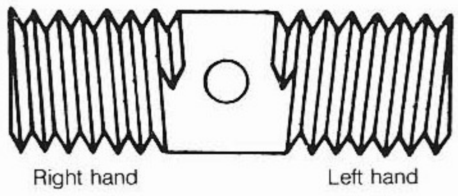



**Figure 3** Hand of threads

## Common V-thread forms and proportions

A complete study of thread forms is too vast to be included here, but the main features may be summarized as follows:

In each standard form the shape of the thread may be V, square or rounded, depending on the reason for using it, and in each of these forms there are a number of pitches to suit the diameter of the screw or the special requirements of the job.

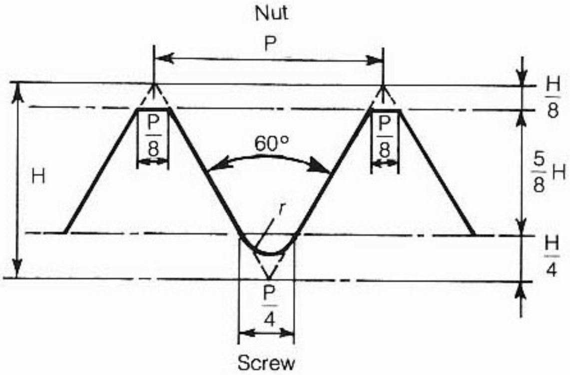
### ISO Metric Thread

The ISO metric general purpose screw thread series is in common use throughout Europe and has been adopted in Australia.

A

### ISO metric thread

Basic form of screw thread AS 1275–1985




$P$ = Pitch mm

$H$ = Theoretical depth = $0.86603 \times P$

$\frac{5}{8}H$ = Actual depth = $0.54127 \times P$

$\frac{H}{8}$ = Truncation = $0.10825 \times P$

$\frac{H}{4}$ = Truncation = $0.21651 \times P$

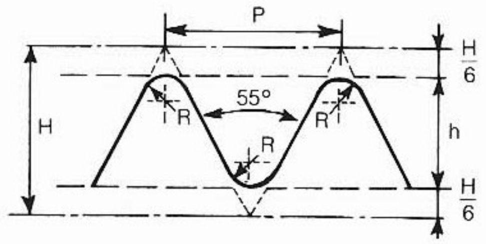
$r$ = Radius = $0.125 \times P$

**Figure 4**

B

### British standard Whitworth thread (B.S.W.)

Basic form of screw thread BS 84–1956




$P$ = Pitch = $\frac{1}{\text{No. of threads per inch}}$

$H$ = Theoretical depth = $0.960491 \times P$

$h$ = Actual depth = $0.640327 \times P$

$\frac{H}{6}$ = Rounding at crest and root = $0.160082 \times P$

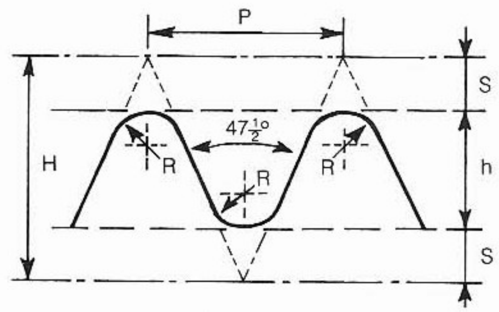
$R$ = Radius at crest and root = $0.137329 \times P$

**Figure 5**

C

### British Association thread (B.A.)

Basic form of screw thread AS 2829–1986




$P$ = Pitch = $\frac{1}{\text{No. of threads per inch.}}$

$H$ = Theoretical depth = $1.13634 \times P$

$h$ = Actual depth = $0.60000 \times P$

$S$ = Rounding at crest and root = $0.26817 \times P$

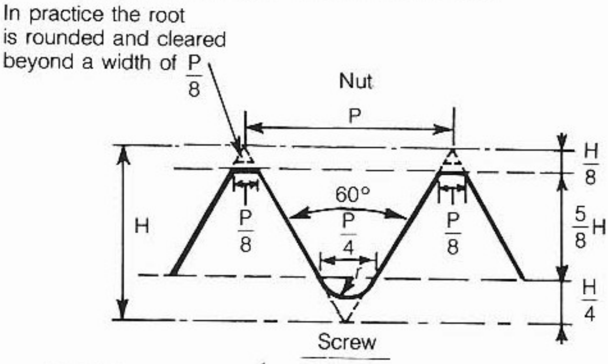
$R$ = Radius at crest and root = $0.18083 \times P$

**Figure 6**

D

### Unified and American threads (U.N.C. & N.C.) (U.N.F. & N.F.)

Basic form of screw thread BS 1580–1962




$P$ = Pitch = $\frac{1}{\text{No. of threads per inch.}}$

$H$ = Theoretical depth = $0.86603 \times P$

$\frac{5}{8}H$ = Actual depth = $0.54127 \times P$

$\frac{H}{8}$ = Truncation = $0.10825 \times P$

$\frac{H}{4}$ = Truncation = $0.21651 \times P$

$r$ = Radius = $0.14434 \times P$

**Figure 7**

The metric form has a thread angle of 60°. The depth is proportional to the pitch.

In practice the root of the male thread is a radius beyond the theoretical $P/4$ width. (See Fig. 4.)

*Note*: The metric thread is very similar to the unified thread.

## Whitworth Thread

The Whitworth form has a 55° thread angle. The depth is proportional to the pitch and is calculated by multiplying the pitch by 0.6403. Depth = $0.64P$ is sufficiently accurate for most workshop applications. (See Fig. 5.)

The crest and the root of the thread are rounded.

The relationship between the major diameter and the number of threads per inch is the difference between the various standards using this form. The common standards using the Whitworth form are the following:

- *British Standard Whitworth, BSW*—a coarse series used for bolts, nuts, and screws for general purposes.
- *British Standard Fine, BSF*—a fine series used on equip-

ment where finer pitch will be more satisfactory because of the larger minor diameter of the thread, or because a finer pitch thread has less tendancy to slacken under vibration.

- *Other standards* using the Whitworth form are the British Standard Brass BSB-26 TPI for all diameters and the British Standard Pipe, BSP, used on water, steam, and gas pipes.

## British Association Thread, BA

The British Association thread is a series of small-diameter threads devised to fill the need for small work below $\frac{1}{4}$ in. diameter not catered for by the Whitworth standard. It is mainly used in the manufacture of electrical and instrument components. (See Fig. 6.)

## Unified Threads

Unified threads have been adopted to replace and interchange with the older American 60° threads known as National Coarse (formerly Sellers) and National Fine (formerly SAE). (See Figs 7 and 8.) Standards using the unified form are the following:

- *Unified coarse, UNC* for general purpose bolts and nuts.
- *Unified fine, UNF* used where minor diameter strength is important and/or where vibration may cause the nut to slacken.

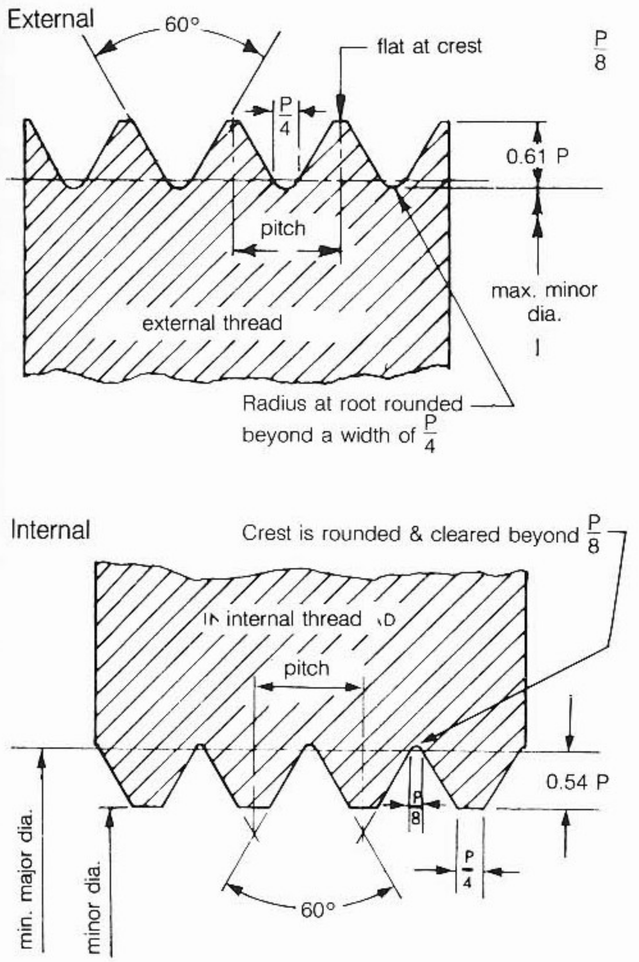



**Figure 8** Unified form

- *National pipe NPSF, NPTF* for American water, steam, gas and conduit (pipe and electrical conduit are identical).
- American Petroleum Institute, API.

## V-thread calculations

### The Minor Diameter

In order to calculate the minor diameter of a thread, it is necessary to know:

- the form of the thread;
- the major diameter;
- the pitch, or the number of threads per inch.

*Example 1, Metric:*

Calculate the minor diameter of a 10–1.5 pitch ISO metric bolt and nut.

*Bolt*
(See Fig. 4 for depth proportion.)

$$\text{Depth} = 0.61P = 0.61 \times 1.5 = 0.92 \text{ mm}$$

*Nut*
(See Fig. 4 for height proportion.)

$$\text{Height} = 0.54P = 0.54 \times 1.5 = 0.81 \text{ mm}$$

Minor diameter (*md*) = major diameter (*MD*) − twice depth of thread (*d*)

$$md = MD - 2d = 10.00 - 2(0.91) = 10.00 - 1.82 = 8.18 \text{ mm}$$

$$md = MD - 2d = 10.00 - 2(0.81) = 10.00 - 1.62 = 8.38 \text{ mm}$$

*Example 2, Imperial:*

Calculate the minor diameter of a $\frac{3}{4}$ in BSW thread. This thread has 10 TPI. For these calculations the depth of a Whitworth-form thread may be taken as $0.64P$.

$$\text{Pitch} = \frac{1}{TPI} = \frac{1}{10}$$

$$\text{Depth} = 0.64 \times P = 0.64 \times \frac{1}{10} = 0.064 \text{ in.}$$

Minor diameter = major diameter − twice depth of thread

$$md = MD - 2d = 0.750 - 2(0.064) = 0.750 - 0.128 = 0.622 \text{ in.}$$

*Example 3:*

Calculate the minor diameter of a 1 in. UNC thread to be cut on a bolt.

From the above table 1 in. UNC has 8 threads per inch. The maximum depth for a UNC bolt thread may be calculated from the formula.

$$\text{Depth} = 0.61P = 0.61 \times \frac{1}{8} = 0.076 \text{ in. (approximately)}$$

$$md = MX - 2d = 1.000 - 2(0.076) = 1.000 - 0.152 = 0.848 \text{ in.}$$

*Example 4:*
Calculate the minor diameter of a 1 in. UNC nut. The depth of thread is calculated from the basic formula.

$$\begin{aligned} \text{Depth} &= 0.54P \\ &= 0.54 \times \frac{1}{8} \\ &= 0.067 \text{ in. (approximately)} \\ md &= MD - 2\,d \\ &= 1.000 - 2(0.067) \\ &= 1.000 - 0.134 \\ &= 0.866 \text{ in.} \end{aligned}$$

### Practical 'Tapping Sizes'

The size to drill the hole before tapping depends on:

- whether a full depth thread is necessary—on work where the nut will be left fastened, a thread 75–80% of the full depth has proved satisfactory, and is much more economical to produce;
- the nature of the metal to be tapped—full threads may be produced in ductile metals, although the hole has been drilled larger than the minor diameter of the thread.

The size may be obtained by one of the following methods:

- by reference to a table showing the tapping drill sizes and the difference between the drill size and the minor diameter;
- by calculating the minor diameter and then selecting a drill after taking into consideration the percentage depth of thread required and the type of metal to be tapped;
- by subtracting the pitch from the major diameter, which will result in the production of metric threads approximately 93% of full depth, and Whitworth threads approximately 78%.

*Example 1* using the last method:
Calculate the tapping size drill for a 10 to 1.5 metric thread.

$$\begin{aligned} \text{Tapping size drill} &= MD - \text{pitch} \\ &= 10.00 - 1.5 \\ &= 8.5 \text{ mm} \end{aligned}$$

## Screw Thread Table

Table 1 shows the relationship between diameter, pitch, and tapping drill size for V-thread forms.

Table 1 Diameter pitch and tapping drill size for V-thread forms

| | | | ISO metric coarse | ISO metric fine | metric conduit | BSW | BSF | BA | B.S. conduit | Brass | UNC | UNF | BSP | BSPT | NPSF | NPTF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thread form* | | | A | A | A | B | B | C | B | B | D | D | B | B | D | D |
| Number or size | Maj.diam. (in.) | (mm) | Pitch (mm) / Tap drill | | | Threads per inch / Tap drill size (mm) | | | | | | | | | | |
| 0 | .06 | 1.52 | | | | | | | | | | 80/1.20 | | | | |
| 1/16 | .062 | 1.57 | | | | 60/1.2 | | | | | | | | | | |
| 10 | .067 | 1.70 | | | | | | 72.6/1.4 | | | | | | | | |
| 1 | .073 | 1.85 | | | | | | | | | 64/1.5 | 72/1.5 | | | | |
| | .0787 | 2.00 | 0.4/1.6 | | | | | | | | | | | | | |
| 9 | .075 | 1.91 | | | | | | 65.1/1.55 | | | | | | | | |
| 2 | .086 | 2.18 | | | | | | | | | 56/1.7 | 64/1.8 | | | | |
| 8 | .0866 | 2.20 | | | | | | 59.1/1.8 | | | | | | | | |
| 3/32 | .0937 | 2.38 | | | | 48/1.9 | | | | | | | | | | |
| 7 | .0984 | 2.50 | 0.45/2.1 | | | | | 52.9/2.1 | | | | | | | | |
| 3 | .099 | 2.51 | | | | | | | | | 48/2.0 | 56/2.1 | | | | |
| 6 | .1102 | 2.80 | | | | | | 47.9/2.3 | | | | | | | | |
| 4 | .112 | 2.84 | | | | | | | | | 40/2.3 | 48/2.4 | | | | |

**Table 1** Diameter pitch and tapping drill size for V-thread forms (cont.)

| | | | ISO metric coarse | ISO metric fine | metric conduit | BSW | BSF | BA | B.S. conduit | Brass | UNC | UNF | BSP | BSPT | NPSF | NPTF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thread form* | | | A | A | A | B | B | C | B | B | D | D | B | B | D | D |
| Number or size | Maj.diam. (in.) | (mm) | Pitch (mm) / Tap drill | | | Threads per inch / Tap drill size (mm) | | | | | | | | | | |
| | .118 | 3.00 | 0.5/2.5 | | | | | | | | | | | | | |
| 1/8 | .125 | 3.18 | | | | 40/2.5 | | | | | | | | | | |
| 5 | .126 | 3.20 | | | | | | 43/2.7 | | | | | | | | |
| 6 | .138 | 3.50 | 0.6/2.9 | | | | | | | | 32/2.85 | 40/2.95 | | | | |
| 4 | .142 | 3.61 | | | | | | 38.5/3.0 | | | | | | | | |
| 5/32 | .156 | 3.96 | | | | 32/3.2 | | | | | | | | | | |
| | .157 | 4.00 | 0.7/3.3 | | | | | | | | | | | | | |
| 3 | .161 | 4.09 | | | | | | 34.8/3.4 | | | | | | | | |
| 8 | .164 | 4.17 | | | | | | | | | 32/3.5 | 36/3.5 | | | | |
| | .177 | 4.50 | 0.75/3.8 | | | | | | | | | | | | | |
| 2 | .185 | 4.70 | | | | | | 31.3/4.0 | | | 56/1.8 | 64/1.8 | | | | |
| 3/16 | .1875 | 4.76 | | | | 24/3.7 | 32/4.0 | | | | 24/3.8 | 32/4.1 | | | | |
| 10 | .190 | 4.83 | | | | | | | | | 24/3.9 | 32/4.1 | | | | |
| | .1968 | 5.00 | 0.8/4.2 | | | | | | | | | | | | | |
| 1 | .2087 | 5.30 | | | | | | 28.2/4.5 | | | | | | | | |
| 12 | .216 | 5.49 | | | | | | | | | 24/4.5 | 28/4.7 | | | | |
| 7/32 | .2187 | 5.55 | | | | 24/4.5 | | | | | 24/4.6 | 32/4.9 | | | | |
| 0 | .236 | 6.00 | 1.0/5.0 | | | | | 25.4/5.1 | | | | | | | | |
| 1/4 | .250 | 6.35 | | | | 20/5.1 | 26/5.3 | | | 26/5.3 | 20/5.1 | 28/5.5 | | | | |
| | .2756 | 7.00 | 1.0/6.0 | | | | | | | | | | | | | |
| 5/16 | .3125 | 7.94 | | | | 18/6.5 | 22/6.8 | | | 26/6.9 | 18/6.6 | 24/6.9 | | | | |
| | .315 | 8.00 | 1.25/6.8 | 1.0/7.0 | | | | | | | | | | | | |

*A = ISO metric thread
B = British Standard Whitworth thread
C = British Association thread
D = Unified thread

† Nominal size of pipe

Table 1 Diameter pitch and tapping drill size for V-thread forms (cont.)

| | | | ISO metric coarse | ISO metric fine | metric conduit | BSW | BSF | BA | B.S. conduit | Brass | UNC | UNF | BSP | BSPT | NPSF | NPTF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thread form* | | | A | A | A | B | B | C | B | B | D | D | B | B | D | D |
| Number or size | Maj.diam. (in.) | (mm) | Pitch (mm) / Tap drill | | | Threads per inch / Tap drill size (mm) | | | | | | | | | | |
| | .3543 | 9.00 | 1.25/7.8 | | | | | | | | | | | | | |
| 3/8 | .375 | 9.53 | | | | 16/7.9 | 20/8.3 | | | 26/8.5 | 16/8.0 | 24/8.5 | | | | |
| 1/8 pipe | †13/32 | 10.32 | | | | | | | | | | | 28/8.8 | 28/8.2 | 27/8.7 | 27/8.4 |
| | .3937 | 10.00 | 1.5/8.5 | 1.25/8,8 | | | | | | | | | | | | |
| | | 10.00 | 1.0/9 | | | | | | | | | | | | | |
| 7/16 | .4375 | 11.11 | | | | 14/9.3 | 18/9.8 | | | 26/10.2 | 14/9.4 | 20/10 0 | | | | |
| | .4724 | 12.00 | 1.75/10.3 | 1.25/10.8 | | | | | | | | | | | | |
| 1/2 | .500 | 12.70 | | | | 12/10.5 | 16/11.0 | | 18/11.0 | 26/11.8 | 13/10.8 | 20/11.5 | | | | |
| 1/4 pipe | †17/32″ | 13.49 | | | | | | | | | | | 19/11.8 | 19/11.0 | 18/11.2 | 18/11.0 |
| | .551 | 14.00 | 2.0/12.0 | 1.5/12.5 | | | | | | | | | | | | |
| Spark plug | | 14.00 | | 1.25/12.75 | | | | | | | | | | | | |
| 9/16 | .5625 | 14.29 | | | | 12/12.0 | 16/12.7 | | | 26/13.2 | 12/12.2 | 18/12.8 | | | | |
| 5/8 | .625 | 15.88 | | | | 11/13.5 | 14/14.0 | | 18/14.25 | 26/14.75 | 11/13.5 | 18/14.5 | | | | |
| | .630 | 16.00 | 2.0/14 | 1.5/14.5 | 1.5/14.5 | | | | | | | | | | | |
| 3/8 pipe | †11/16″ | 17.46 | | | | | | | | | | | 19/15.25 | 19/14.5 | 18/14.75 | 18/14.5 |
| 11/16 | .6875 | 17.46 | | | | 11/15.25 | 14/15.5 | | | | 11/15.0 | 16/16.0 | | | | |
| | .709 | 18.00 | 2.5/15.5 | 1.5/16.5 | | | | | | | | | | | | |
| 3/4 | .750 | 19.05 | | | | 10/16.5 | 12/17.0 | | 16/17.0 | 26/18.0 | 10/16.5 | 16/17.5 | | | | |
| | .787 | 20.00 | 2.5/17.5 | 1.5/18.5 | 1.5/18.5 | | | | | | | | | | | |
| 13/16 | .812 | 20.64 | | | | | | | | | 10/18.0 | 16/19 | | | | |
| 1/2 pipe | †27/32″ | 21.43 | | | | | | | | | | | 14/19.0 | 14/18.0 | 14/18.0 | 14/17.5 |
| | .866 | 22.00 | 2.5/19.5 | 1.5/20.5 | | | | | | | | | | | | |
| 7/8 | .875 | 22.23 | | | | 9/19.5 | 11/20.0 | | | 26/21.0 | 9/19.5 | 14/20.5 | | | | |
| | .945 | 24.00 | 3.0/21.0 | 2.0/22.0 | | | | | | | | | | | | |
| | .984 | 25.00 | | | 1.5/23.5 | | | | | | | | | | | |
| 1″ | 1.000 | 25.40 | | | | 8/22.0 | 10/22.5 | | 16/23.5 | 26/24.25 | 8/22.0 | 12/23.5 | | | | |

**Table 1** Diameter pitch and tapping drill size for V-thread forms (cont.)

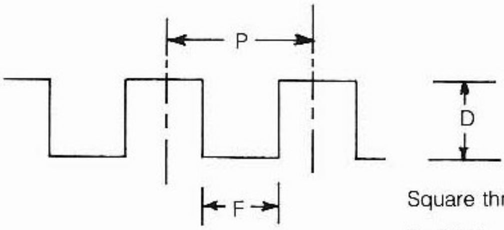
| | | | ISO metric coarse | ISO metric fine | metric conduit | BSW | BSF | BA | B.S. conduit | Brass | UNC | UNF | BSP | BSPT | NPSF | NPTF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thread form* | | | A | A | A | B | B | C | B | B | D | D | B | B | D | D |
| Number or size | Maj.diam. (in.) | (mm) | Pitch (mm) / Tap drill | | | Threads per inch / Tap drill size (mm) | | | | | | | | | | |
| ¾ pipe | †1 1/16″ | 26.99 | | | | | | | | | | | 14/24.5 | 14/23.0 | 14/23.0 | 14/23.0 |
| | 1.063 | 27.00 | 3.0/24 | | | | | | | | | | | | | |
| 1⅛″ | 1.125 | 28.58 | | | | 7/25.0 | 9/25.5 | | | | 7/25.0 | 12/26.5 | | | | |
| | 1.181 | 30.00 | 3.5/26.5 | | | | | | | | | | | | | |
| 1¼″ | 1.250 | 31.75 | | | | 7/28.0 | 9/28.5 | | 16/30 | | 7/28.0 | 12/29.5 | | | | |
| | 1.260 | 32.00 | | | 1.5/30.5 | | | | | | | | | | | |
| | 1.299 | 33.00 | 3.5/29.5 | | | | | | | | | | | | | |
| 1″ pipe | †1 11/32″ | 34.13 | | | | | | | | | | | 11/31.0 | 11/29.5 | 11.5/29.5 | 11.5/29.0 |
| 1⅜″ | 1.375 | 34.93 | | | | 6/30.0 | | | | | 6/31.0 | 12/33.0 | | | | |
| | 1.417 | 36.00 | 4.0/32.0 | | | | | | | | | | | | | |
| 1½″ | 1.500 | 38.10 | | | | 6/33.5 | 8/34.5 | | 14/36.0 | | 6/34.0 | 12/36.0 | | | | |
| | 1.535 | 39.00 | 4.0/35.0 | | | | | | | | | | | | | |
| | 1.575 | 40.00 | | | 1.5/38.5 | | | | | | | | | | | |
| 1¼″ pipe | †1 11/16″ | 42.86 | | | | | | | | | | | 11/40.0 | 11/38.0 | | 11.5/37.5 |
| 1¾″ | 1.750 | 44.45 | | | | 5/39.0 | 7/40.5 | | | | | | | | | |
| 1½″ pipe | †1 29/32 | 48.42 | | | | | | | | | | | 11/45.5 | 11/43.5 | | 11.5/43.5 |
| | 1.968 | 50.00 | | | 1.5/48.5 | | | | | | | | | | | |
| 2″ | 2.000 | 50.8 | | | | 4.5/44.5 | | | 14/48.5 | | | | | | | |
| 2″ pipe | †2⅜″ | 60.33 | | | | | | | | | | | 11/57.0 | 11/55.0 | | 11.5/56.0 |

*A = ISO metric thread
B = British Standard Whitworth thread
C = British Association thread
D = Unified thread

† Nominal size of pipe

## Square-thread forms

The square thread is mainly used as a motion-transmitting screw or for screw jacks and similar components. The screw is cut to the standard shown in Figure 9 and the nut is cut 0.025 to 0.1 mm wider and deeper to achieve running clearance.

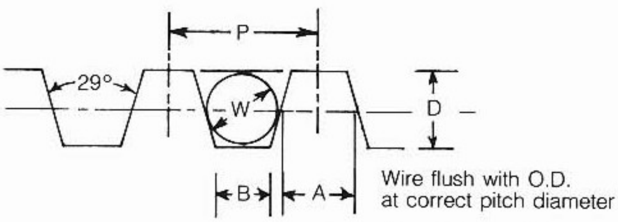



Square thread
P = Pitch
D = P × 0.5
F = P × 0.5

**Figure 9**

## Acme-thread forms

Acme thread is used as a motion transmitter more so than the square thread. It is used on feedscrews, leadscrews etc. in machine tools. The screw is cut to the standard shown in Figure 10, and the nut cut wider and deeper to achieve running clearance. It is advisable on long screws working horizontally to have a minimum of clearance on the outside diameter in the nut so that it acts as a bearing. This stops the wedging action that can take place on the thread flanks as the screw droops.




Acme thread—Imperial
P = Pitch
D = P × 0.5
A = P × 0.5
B = P × 0.37
Tool width = (P × 0.37) − 0.005″
W = P × 0.4872

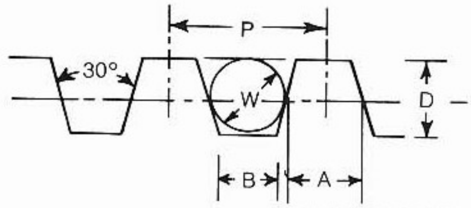
**Figure 10**

## Trapezoidal-thread forms

The trapezoidal thread is the metric equivalent of the Acme thread, (Fig. 11).

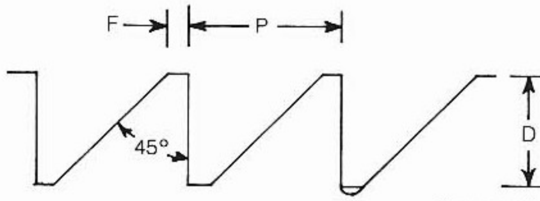
## Buttress-thread forms

Screw threads of this type are designed to resist heavy axial loads in one direction. Figure 12 shows the simplest form, which may have a flat or radius in the bottom of the thread. Other forms have the angle on the load side at up to 5°, with the other side varying from 33° to 50° depending on the application.




Trapezoidal thread—Metric
P = Pitch
D = P × 0.5
A = P × 0.5
B = P × 0.366
W = P × 0.4865
Tool width (P × 0.366) − 0.125

**Figure 11**

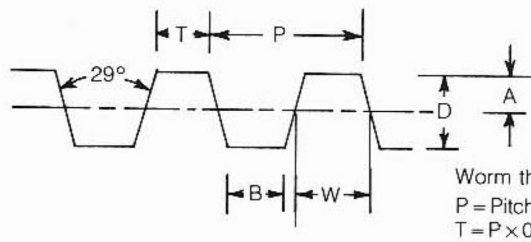



Buttress thread
P = Pitch
D = P × 0.75
F = P × 0.125

**Figure 12**

## Worm-thread forms

As its name implies the worm thread is the thread used on a worm gear. It is a true basic rack wrapped around a diameter and is similar to the Acme thread; the proportions are shown in Figure 13. Many worm drives used in industry are far removed from this basic 14½° p.a. form and are too numerous to mention here.




Worm thread
P = Pitch
T = P × 0.335
B = P × 0.31
D = P × 0.6866
W = P × 0.5
A = P × 0.318

**Figure 13**

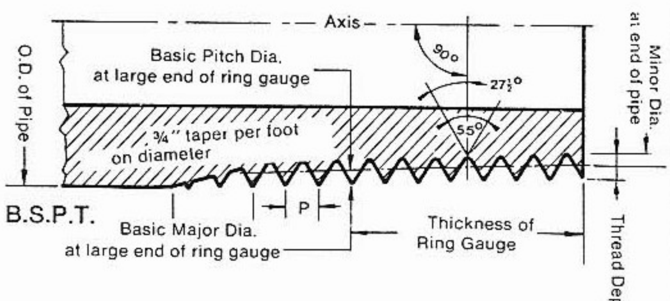



**Figure 14** British standard pipe taper form thread

There are many other thread forms used to a small extent in all fields of engineering.

# 15

# Hand tools

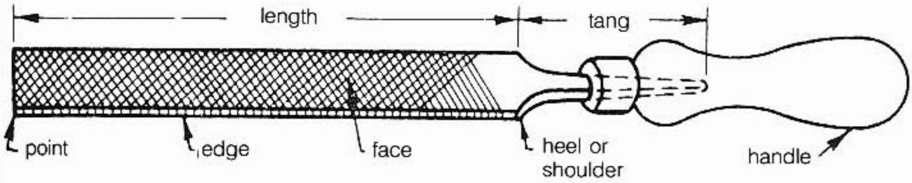



**Figure 1** Parts of a file

Hand tools have been designed, made and used for centuries. This chapter will deal with those tools commonly found in an engineering workshop.

## Files

Files are one of the most important and most frequently used type of hand tool, even today. The varieties available have been developed over many years and are among the oldest tools in use: files made of bronze are reputed to have been used as long ago as three thousand years.

Modern files are made of high-grade 1.2% carbon tool steel. When files are manufactured they are forged to shape, the surfaces are ground, the teeth are cut, and the files are then hardened and tempered. The teeth were originally cut by hand with a chisel-like tool, but today are mostly made by machine.

Files are used for roughing and finishing surfaces in many different ways. They may be used to shape small parts; reduce the size of one part so that it will fit another; remove tool marks left by chipping or machining; prepare surfaces for scraping or for polishing; and for many other purposes.

### Parts of a File

Figure 1 shows the principal parts of a file. Some files hve two flat faces; others, like the half-round file, have only one flat face, the curved side being referred to as the back.

### Classification of Files

Files are classified by the features discussed below.

#### Length of a File

The length of the file is measured from the point to the heel or shoulder and does not include the tang (see Fig. 1). The common types of files are made in various lengths.

#### Kinds of Cut

Single-cut files (Fig. 2) give a smoother finish, but do not remove the metal as quickly as double-cut files. They are used for draw filing, lathe filing, for filing brass and similar metals, for saw sharpening and on tough steels generally. Double-cut files (Fig. 3) have two rows of intersecting inclined cuts. They are used for general purpose filing on soft steel and cast iron.

Dreadnought-cut files (Fig. 4) have coarse, curved teeth and are used for cutting soft metals such as aluminium, lead and alloys such as white metal.

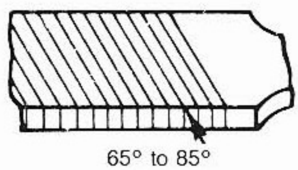



**Figure 2** Single cut

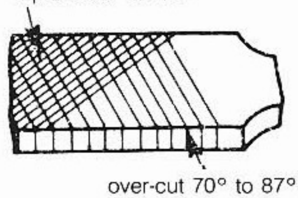



**Figure 3** Double cut

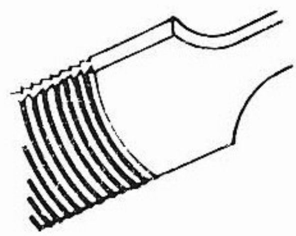


**Figure 4** Dreadnought file

#### Grades of Cut

The grade of cut is indicated by the pitch or size of the file teeth. The grades found on common types of files are known as rough, coarse, bastard cut, second cut, smooth, and dead smooth.

Small files used by toolmakers, instrument makers and jewellers are designated by numbers from 1 to 5, 5 being the finest.

They can be compared only with files of the same kind and length; the teeth on files are made coarser as the length increases. Figure 5 illustrates the differences between the pitches of the teeth on small and large files.

*Uses for the various grades of cut*

The rough-cut file These are always single cut, and are sometimes referred to as floats. They are for filing soft metals and materials.

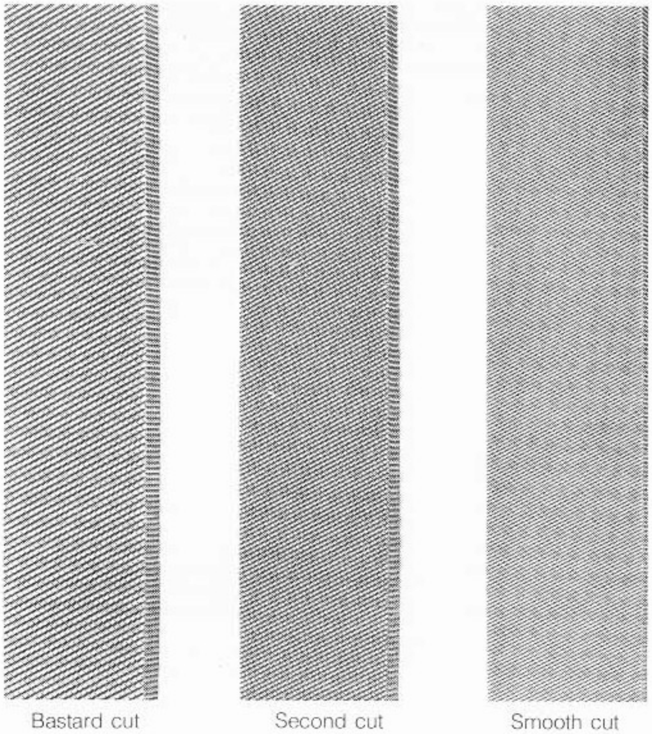



**Figure 5** Full size photographs showing the pitch or spacing of the teeth

A dreadnought file cuts more freely and keeps cleaner than a float because it has a tendency to clear itself.

**The coarse-cut file** This cut is effective for removing large amounts of metal.

**The bastard-cut** This is the grade used most commonly for roughing down.

**The second-cut file** This cut is used to produce a smoother finish following roughing down by a bastard-cut file. The second-cut file is also suitable for roughing down hard metals and for filing across narrow surfaces. This grade of file cuts more freely on hard metal than one of coarser grade and, because of the larger number of teeth in contact with the work, the points of the teeth are less inclined to break.

**The smooth-cut file** This cut is used to produce a smoother surface than can a second-cut file.

**The dead-smooth-cut file** Although not in general use, this file may be used when a very smooth finish is required.

## Longitudinal Shapes

Files are tapered at the point end for about one-third of their length. If the longitudinal shape of the file is not specified, it is assumed that a taper file is required.

Blunt files have the same sized section throughout their length.

## Cross-sectional Shapes

Files usually derive their names from their cross-sectional shape, for example round, square, and half-round files; or from the type of work on which they are often employed, for example flat, warding and mill saw files.

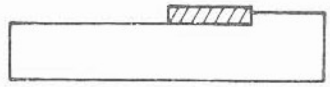


**Figure 6** Flat file

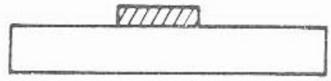


**Figure 7** Hand file

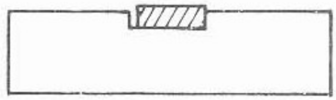


**Figure 8** Pillar file

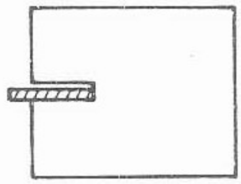


**Figure 9** Warding file

**Figure 10** Millsaw files

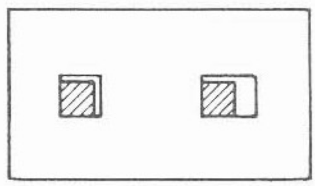


**Figure 11** Square file

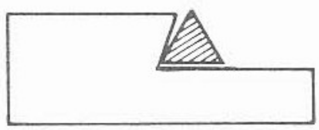


**Figure 12** Three square file

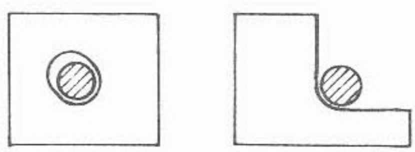


**Figure 13** Round file

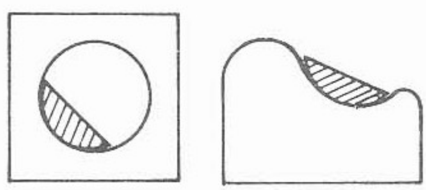


**Figure 14** Half–round file

The names, description, and uses of the more common files are as follows:

- The *flat file* (Figs 6 and 15) is rectangular in cross-section and has the width and thickness tapered.
- The *hand file* (Figs 7 and 15) is rectangular in cross-section. The width is parallel and greater than in the flat file; the thickness is tapered and it has one safe, uncut edge.

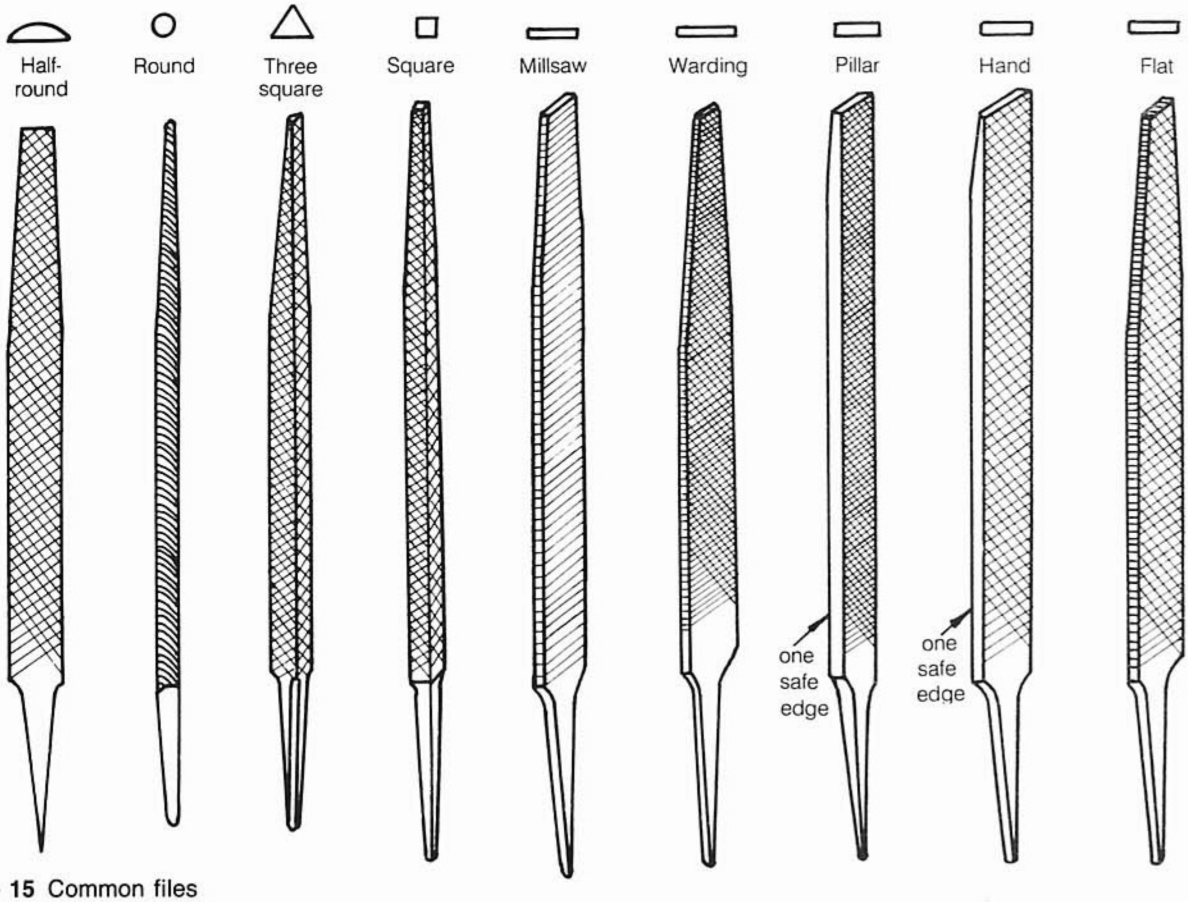



**Figure 15** Common files

It is used for filing flat surfaces, the safe edge being useful when filing up to shoulders.

- The *pillar file* (Figs 8 and 15) is similar to the hand file, but is smoother, narrower and thicker. It is used for filing in places inaccessible to other files, such as in slots of keyways.
- The *warding file* (Figs 9 and 15) is rectangular, thin and parallel in thickness, with much tapering on the width.

  It is used to file keys, locks and narrow slots.
- The *millsaw file* (Figs 10 and 15) is similar in general appearance to the flat file, but is single cut and not so thick.

  Common uses are in draw filing, filing in the lathe, and sharpening of mill saws. Files used for saw sharpening have one or both edges rounded.
- The *square file* (Figs 11 and 15) is square in section and is usually tapered. It is used for filing square or rectangular holes and wherever its shape and dimensions make it suitable.
- The *three-square file* (Figs 12 and 15) is in the form of an equilateral triangle with fairly sharp corners, and the usual type is tapered. It has double-cut teeth and should not be confused with the triangular saw file, which has single-cut teeth and rounded corners.

  Uses for this file include filing out sharp corners and acute internal angles of 60° or more.
- The *round file* (Figs 13 and 15) is round in section, has spiral-cut teeth, and is usually tapered.

  It is used to enlarge round holes, to file fillets, etc.
- The *half-round file* (Figs 14 and 15) has one flat face and a curved back. It is used to file round holes and concave curves.

Always select a round or half-round file as near as possible to the size of the curve being filed to avoid producing corrugations in the work.

- The *lathe file* (not illustrated) has teeth cut at a long angle, which promotes quick cutting and allows the file to clear itself, producing a smooth finish when lathe filing. It has safe edges and is only available in 12 inch and 14 inch.

## 'Belly' on Files

Most files are made with their surfaces bellied or slightly curved along their length (see Fig. 16). This is necessary to:

- allow for the distortion that may occur during hardening;

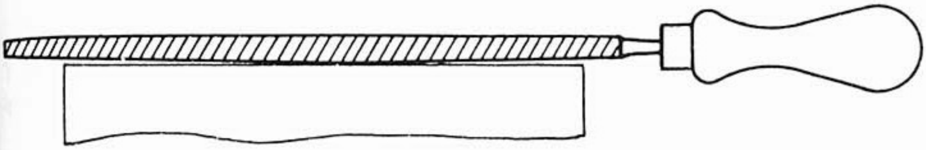


**Figure 16** Illustrating the 'belly' on a file

- enable the file to cut more freely;
- allow for some 'rock' as the file is pushed across the work piece when producing a flat surface;
- make it easier to remove high spots from the work piece.

## Using a File

If the correct file has been selected the results obtained will depend on the correct use of the file, namely the relative position of the work, the stance, and the holding and controlling of the file. (See Fig. 17.)

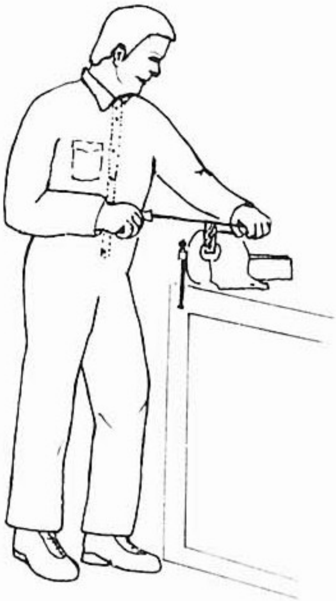


**Figure 17** Correct stance and height of work

### Height of Workpiece

For general filing the surface to be filed should be at elbow height (the height of the elbow when the person who is to do the filing is standing, the upper arm being vertical and the forearm horizontal. This height enables the forearm to be kept in line with the file, giving better control and causing less fatigue.

For heavy filing, the workpiece should be lower to enable more pressure to be applied onto the surface.

### Methods of Filing

The two methods of using a file to obtain a flat surface are known as cross filing and draw filing.

#### *Cross-filing*

The file is moved both across and along the work (see Fig. 18). When possible, the entire surface to be filed should be covered. The direction of filing should be changed at short intervals as this helps to obtain a flat, smoother surface. Because the file marks cross, the file cuts more freely too.

Correct stance is essential when filing. The left foot should be placed forward and in line with the direction of filing, the right foot to the rear. The position should be comfortable and the weight should be evenly balanced on both feet (see Fig. 17).

The grip on the file must be correct. The file handle should be held in the right hand with the thumb on top and the fingers around the handle.

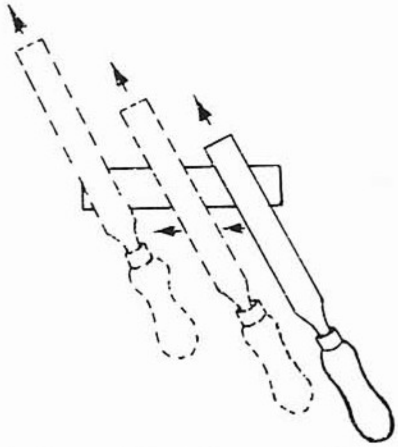


**Figure 18** Positions of file during cross filing

For heavy filing, the fleshy part of the left hand is placed near the point of the file with the fingers crooked around the end but not gripping it (see Fig. 19).

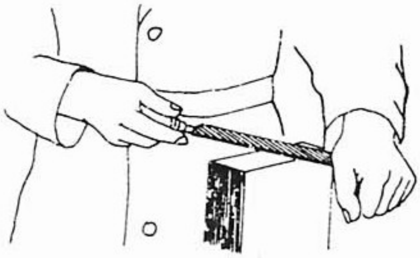


**Figure 19** Grip for heavy filing

For light filing, the left hand may be placed as shown in Figure 20a or 20b.

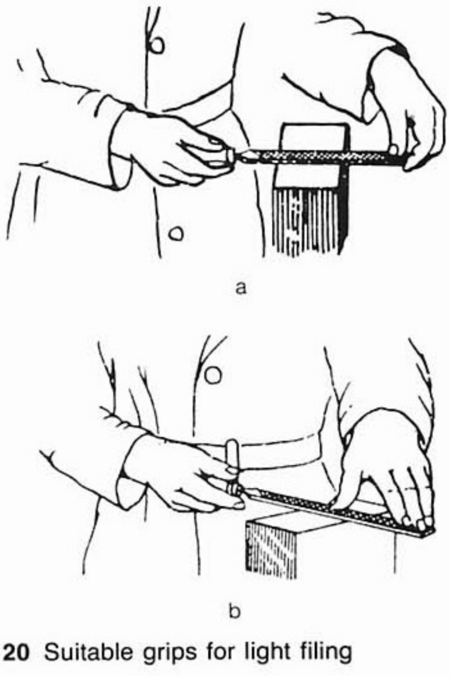


**Figure 20** Suitable grips for light filing

For filing across broad surfaces, or for filing along an edge, sometimes referred to as long-filing, the method of gripping the file shown in Figure 21 has proved very satisfactory.

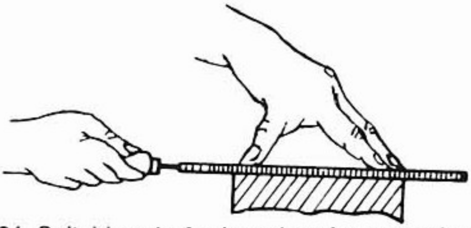


**Figure 21** Suitable grip for broad surfaces or along narrow edges

Having the correct stroke and balance of the file is important. It is advisable that the right arm be kept close to the body, and that the file be balanced at all times in order to prepare a flat surface. If the same pressure were to be kept both on the point of the file and on the handle throughout the stroke, the point would drop as the file crossed the work. Consequently a flat surface could not be produced.

To overcome this and to keep the file in balance throughout the stroke, the pressure on the point of the file must be gradually decreased and that on the handle gradually increased.

This eventually becomes a reflex action. Although the stroke is made using the arms, the body should not remain stationary. For average work it should follow the file at the beginning of the stroke, but, as the stroke progresses, the hands should move farther forward than the body. In conjunction with these movements pressure should be gradually transferred from the point of the file to the handle. The body movements described help with this gradual transfer of pressure.

### *Speed of filing*

Filing should be performed easily, with steady strokes: about 50 strokes per minute is a satisfactory average. More metal can be removed by filing at the correct speed than by filing too quickly, for in the latter case the file will not penetrate, but will slip over the surface, damaging the file teeth and glazing the surface of the workpiece.

If the metal is hard or the surface very broad, it will be necessary to file at a slower rate and to exert more pressure in order to force the file to penetrate. If the metal is soft or the surface very narrow, the tendency should be to file slightly more quickly and with less pressure, to avoid damage to the edges of the file teeth.

### *Draw-filing*

Draw-filing should be considered more as a method of finishing work using a file than as a method of efficient filing. The file should be held between the thumb and the fingers of both hands (Fig. 22). The index fingers are over the centre of the file and the work in order to maintain balance and to direct pressure as required. The thumbs push the file and the fingers draw the file back.

The file should be placed on the work at right angles to the direction of stroke so that it will cut when being pushed forward. Care should be taken to apply uniform pressure and to avoid rocking the file. Draw-filing should not be carried out for long periods as it removes less metal at the centre. The convexity of the file face may also affect the flatness of the surface being produced.

Considerable practice is needed if the skill of filing is to be mastered.

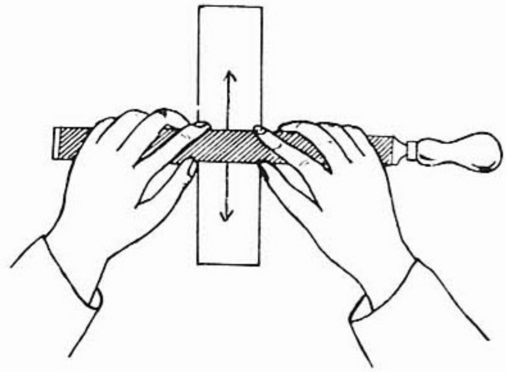


**Figure 22** Draw filing

### How to Reduce Pinning

During filing particles of metal often become wedged between the teeth of the file. This is known as pinning and causes deep scratches to appear in the surface of the work.

The file grooves should be kept clean and a little chalk or cutting compound applied. This will cause the file to cut less freely, but reduces the tendency to pin. However nothing should be applied to the file when working on cast iron or the file teeth will not penetrate.

### Cleaning a File

It is essential to keep the file grooves clean as a dirty file acts like a dull file. The removal of dirt and pins is usually done with a file brush (see Fig. 23), used in line with the grooves on the file. If the particles of metal are firmly wedged they may be removed with a piece of soft metal. This should be pushed across the file and along the grooves (Fig. 24).

**Figure 23** File brush

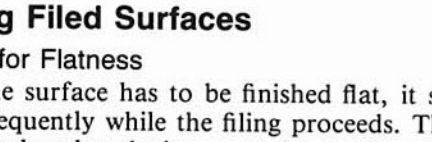


**Figure 24** Removing pins with a piece of soft metal

## Testing Filed Surfaces

### Testing for Flatness

When the surface has to be finished flat, it should be tested frequently while the filing proceeds. The testing should be done lengthwise, crosswise and diagonally (Fig. 25), using either a straight edge or the blade of a square.

Defects will show up more clearly if the work and the straight edge are held up to the light. When a higher degree of accuracy is required than can be obtained by testing with a straight edge, a surface plate is used. (This method will be described later.)

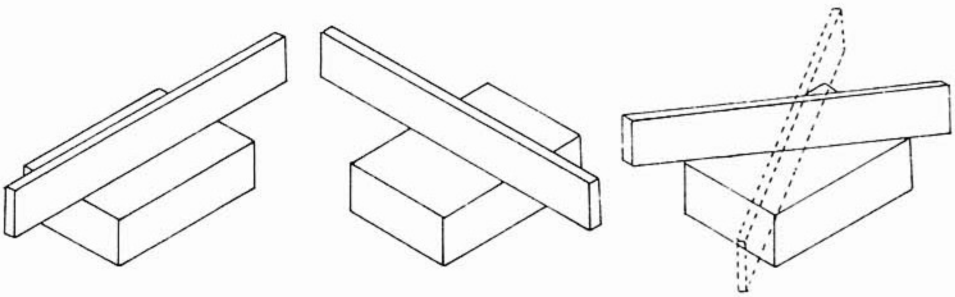


**Figure 25** Testing for flatness

### Testing for Squareness

If the surface being filed has to be at 90° to a previously finished surface, it should be frequently tested with a square (Fig. 26). The work should be kept fairly square even when roughing down.

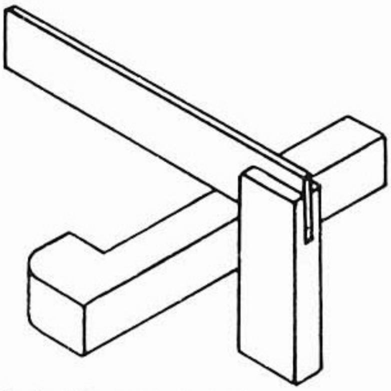


**Figure 26** Testing for squareness

### Testing for Size, Parallelism, and Location

When surfaces have to be tested for size, parallelism, or location, calipers may be used. (See Figs 27 and 28.)

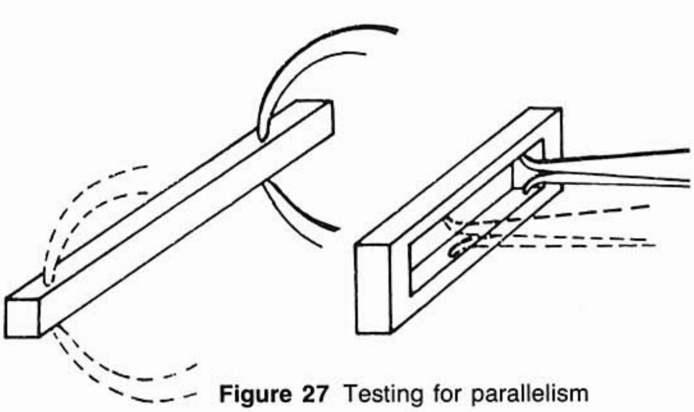


**Figure 27** Testing for parallelism

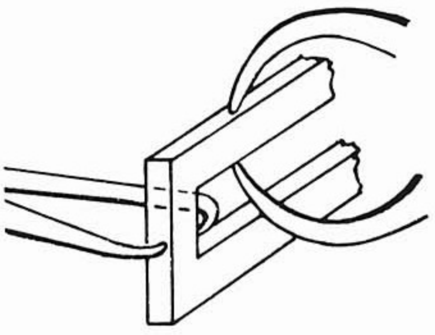


**Figure 28** Testing for location

## Filing a Square Hole

The necessary steps for filing a hole with square parallel sides are as follows:

1 Mark out the square hole (Fig. 29) and on the same centre mark a circle 1 to 2 mm less in diameter than the size of the finished hole.
2 Drill the hole to this diameter.
3 Roughly file the drilled hole to an undersized square hole (Fig. 30).
4 File side A (Fig. 31) to size and, if necessary, parallel to an edge of the workpiece. Test for parallelism and location using calipers.
5 File side B square to side A and to the work edge (Fig. 32). Use a file with a safe edge.
6 File side C to size, and parallel to side B. Test using calipers.
7 File side D to size and parallel to side A.
8 Finally fit the work to a gauge or to the mating part, carefully removing high spots until the required fit is obtained.

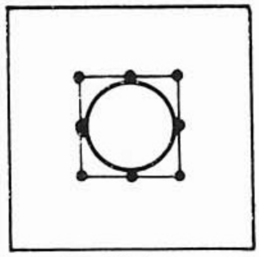


**Figure 29** Mark out and drill

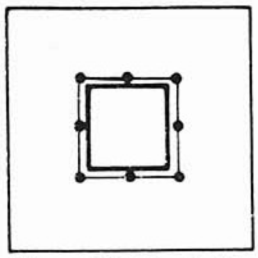


**Figure 30** Rough file square hole

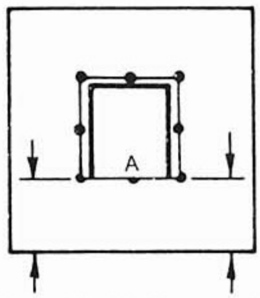



**Figure 31** Finish one side

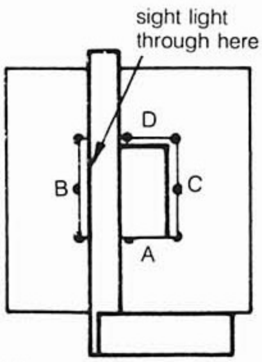



**Figure 32** Finish adjacent side

## Filing a Square on a Shaft

Squares to fit handles or other machine parts are sometimes filed on shafts. As it is usually necessary for the square to be centred on the shaft axis, the following procedure should be used.

1 Mark out the square on the end of the shaft (Fig. 33).
2 File side No. 1, checking for location and parallelism using calipers, or a micrometer.
3 File side No. 2 square to No. 1 and check for location and parallelism in the same manner as for side No. 1.
4 File side No. 3 square to No. 1, also to size and parallel to No. 2.
5 File side No. 4 to size and parallel to side No. 1. Check for squareness to sides 2 and 3 while filing.

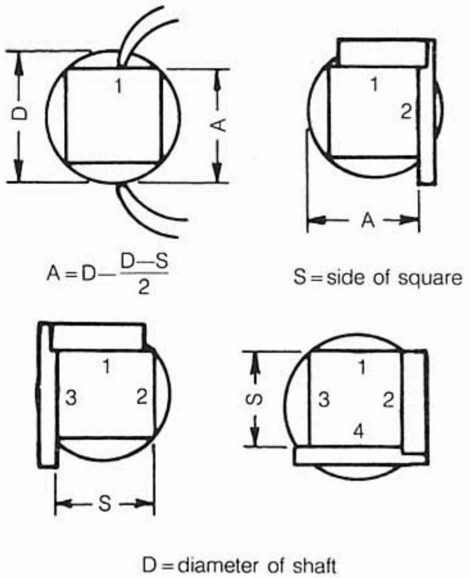



**Figure 33** Steps in filing a square on a shaft

## Care of Files

The life of files can be lengthened by choosing the correct file and storing and using it in the proper manner. Observance of the following details will help considerably.

- Remove roughness from the surface of castings and forgings by chipping it with either a flat chisel, the edge of an old file, or piece of grinding wheel.
- If possible, reserve new files for use on broad surfaces of brass, bronze, and cast iron, where keen cutting teeth are essential, but avoid using them across narrow surfaces. A file that has become too dull to cut brass satisfactorily will cut steel nearly as well as a new file.
- The coarser grades of cut should never be used across narrow surfaces.
- A file should not be allowed to slip, as slipping wears the teeth. Rubbing the hands on the work when filing cast iron increases this problem. Enough pressure should be applied to keep the file cutting.
- Pressure should be released on the return stroke.
- Files, both when in use and when stored, should not be allowed contact with other files or tools.

### Safety Precautions

- Never use a file without a handle.
- Check that the handle is not split and that it fits securely.
- Handle a file carefully, and in such a manner that there is no possibility of it coming out of its handle.
- A finger extended beyond the file handle can be injured on a corner of the workpiece or the vice.

## Files for Use Under Special Conditions

### Riffler Files

Riffler files (Fig. 34) are used by toolmakers who produce finely finished cavity tools for plastic, rubber and diecast products. These files are made in 31 different shapes and two lengths. Much of the finishing that is undertaken after cavities have been machined is done with riffler files. The files are long and thin with teeth at either end in cuts No. 1 to 6. The middle is kept free of teeth so that the file can be gripped and easily used. These files are not designed to remove large quantities of material, but they provide a good finish under restricted conditions.

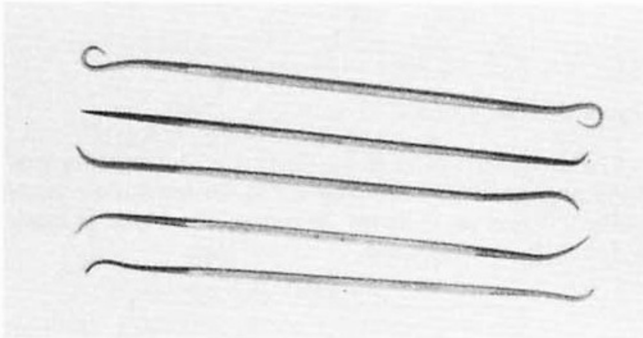


**Figure 34** Riffler files (5 of the 31 shapes)

### Needle Files

Needle files (Fig. 35) are used to clean up material in confined spaces. They are used by toolmakers on cavity work and on very small work, such as extrusion and drawing dies. They are usually double-cut files and have a handle at one end, which has a light knurl to provide a grip. It is usual, however, to use a plastic handle with these files. Needle files, which are made in 12 different cross-sections and usually in cut No. 2, can be found in most tool rooms and are invaluable when working on small tools.

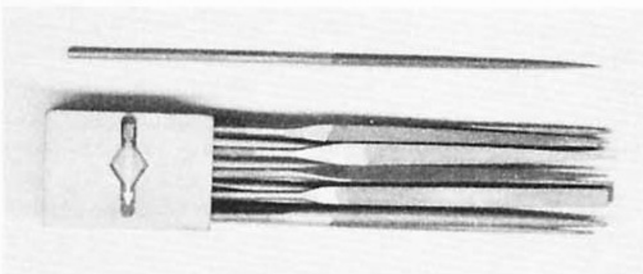


**Figure 35** A set of needle files

# Chisels and chipping

Chisels for cutting metal are made of 0.9% carbon tool steel or of alloy tool steel. They are forged to the shape and size required, then hardened and tempered. They should be tough enough to withstand the impact of a blow, yet sufficiently hard to maintain their cutting edges.

## Common Types of Chisel

Chisels are usually classified by the length of the stock, the width of the cutting edge, and the type.

Examples are:

180 × 25 mm flat chisel
150 × 6 mm cross-cut chisel.

Common types of chisel are described below.

The *flat chisel* (Fig. 36) is used for chipping flat surfaces, trimming castings and forgings, cutting thin sections of metal, and for many general purposes such as cutting off rivet heads, bolt heads or splitting nuts when dismantling machinery.

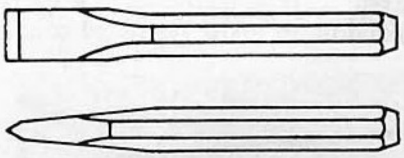


**Figure 36** Flat chisel

The *cross-cut chisel* (Fig. 37) is used for cutting keyways and grooves requiring a flat bottom and square walls. To prevent it from jamming, the blade is made wider at the cutting end.

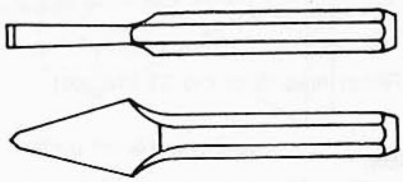


**Figure 37** Cross-cut chisel

The *round-nose chosel* (Fig. 38) is used for cutting oil grooves in bearing surfaces, and also for drainage channels. It may also be used to chip a groove in the countersink produced by a drill in order to draw the drill over if it is out of position.

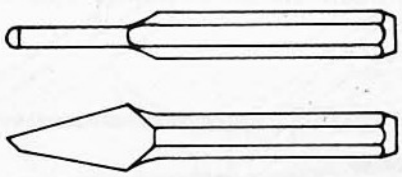


**Figure 38** Round-nose chisel

The *diamond-point chisel* (Fig. 39) is used for cutting V-shaped grooves and sharp corners, as well as for preparing cracked parts for welding.

The blade is forged square in section and is tapered to the cutting end. The diamond point is formed by grinding the end diagonally.

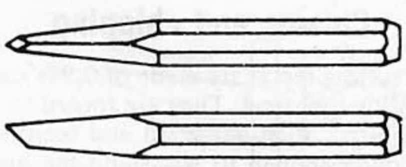


**Figure 39** Diamond-point chisel

The *side-cutting chisel* (Fig. 40) is in some ways similar to the flat chisel, but has only one bevel at the cutting end. It is used for chipping in places unsuitable for a flat chisel (see Fig. 41).

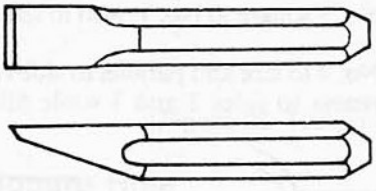


**Figure 40** Side-cutting chisel

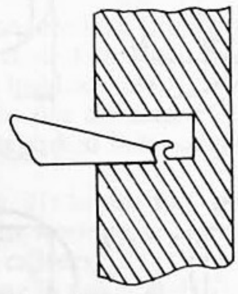


**Figure 41** Application of a side-cutting chisel

## Cutting Angles on Chisels

The cutting angle, or the angle of the cutting edge, is usually formed by two bevels or facets equal in angle and width (see Fig. 42).

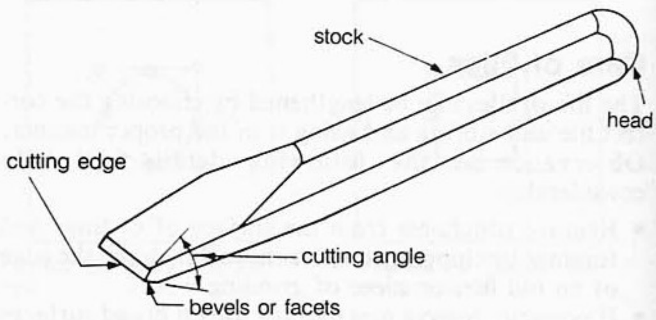



**Figure 42** Terms used in reference to chisels

The average cutting angle is 65°, but may be varied from 55° to 85° to suit the metal to be cut. The harder the metal to be cut, the stronger, and therefore the larger the cutting angle. Commonly used cutting angles are:

| *Brass* | *Mild steel* | *Cast iron* |
|---|---|---|
| 50°–60° | 60°–70° | 70°–80° |

### Sharpening a Chisel

A chisel made of *carbon tool steel* should be sharpened on a grinding wheel, care being taken not to apply too much pressure, nor to keep it against the wheel for too long a period before cooling it in water.

If the chisel is overheated the temper of the steel will be drawn, and the chisel will be too soft to use. Chisels should be ground on the face of the wheel (Fig. 43). The grinding wheel should be fitted with a spark-guard, and safety glasses should be worn.

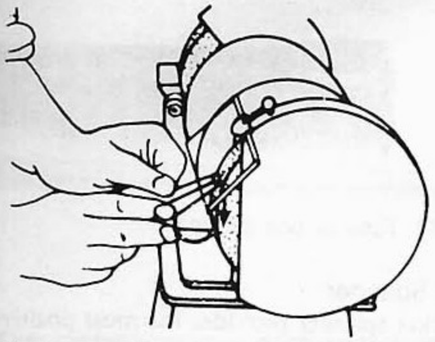


Figure 43 Correct position when grinding

*Alloy steel chisels* are affected by temperatures generated by grinding and should be sharpened with a file. Although they appear to be fairly soft they work harden as they are used, and maintain their cutting edge very well.

## Using a Chisel

1 If possible, grip the workpiece firmly in a vice, using a supporting block if necessary.
2 Stand directly in front of the work and in line with the direction of the chipping, with the left foot forward and the right foot about 200 mm to the rear. The weight should be evenly balanced on both feet.
3 If you are right-handed, hold the chisel in your left hand and as near as possible to the head to give better control and a clear view of the cutting edge. The muscles of your thumb and first finger should be relaxed, and the chisel held firmly with the palm and three fingers.
4 Hold the hammer in the other hand, near the end of the handle (Fig. 44).
5 Look at the cutting edge of the chisel and the guide-lines on the work.
6 Make the stroke by swinging the hammer in an arc from or over the right shoulder, and then bringing it down with an easy, free motion (not with a jerk).
7 For parallel cuts, hold the chisel at such an angle to the work that the lower or guiding bevel keeps the depth of cut uniform.

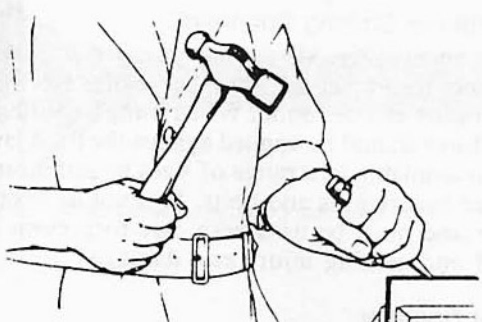


Figure 44 Method of holding hammer and chisel (R.H.)

To increase or decrease the depth of cut raise or lower the chisel as required.

### Chipping a Wide Flat Surface

When a wide, flat surface has to be chipped, narrow grooves are cut with a cross-cut chisel and the remaining portions removed with a flat chisel.

The depth to be chipped and the position of the grooves are marked out first (Fig. 45). Both the width of the grooves and their spacing depend on the size of the work and the widths of the cutting edges of the chisels.

The edges should be bevelled with a file to prevent them from breaking away during the chipping. As an additional precaution the cuts should be stopped about three-quarters of the way across, and the remainder of the metal removed by chipping from the opposite side (See Fig. 45).

The surface should be tested with a straight edge and any large high spots chipped off before the file is used.

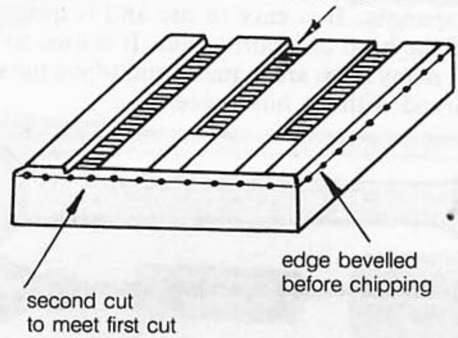



Figure 45 Method of chipping a wide flat surface

## Spanners

The correct size spanner should always be used in a way that will ensure that it will not round off the corners of the nut or bolt head. The length of a spanner is made to suit the strength of its jaws; a spanner could be damaged if a piece of pipe or another spanner were used to gain more leverage. Never hammer a spanner, unless you are using a single-end spanner, which is designed for just this purpose. There is such a large range of spanners that anyone starting a tool kit must look carefully at the type of work that will be done and select spanners to suit. A good tradesperson will get many years of service from a set of spanners. In fact, some spanners are guaranteed unconditionally, provided they are not used in conjunction with power tools.

*Note*: It is dangerous to use a tool that does not fit correctly. Skinned knuckles or even worse injury could occur, not to mention damage to the work and tool.

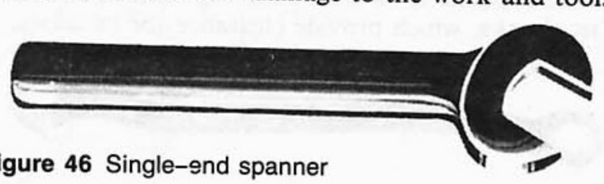


Figure 46 Single-end spanner

## Types of Spanner

### Single-end Spanner

Single-end spanners (Fig. 46) are made in the larger sizes and are used only where it is normal to gain maximum tightness by hammering. They are often used in conjunction with large machinery and also on construction work.

## Podge Spanner

Podge spanners (Fig. 47) have a pinch-bar point on one end for pipe flange work and for girder assembly on new construction. They are used on building sites and field construction work.

**Figure 47** Podge spanner

## Double-ended Open-end Spanner

The double-ended open-end spanner (Fig. 48) is the most common spanner. It is easy to use and is quick to slip on and off the head of a bolt or nut. It is used to advantage where many turns are required and where the spanner can be turned without hindrance.

**Figure 48** Double–ended open jaw spanner

## Combination Ring and Open-end Spanner

When the combination ring and open-end spanner (Fig. 49) is used the ring spanner loosens the nut and the open end is then used to quickly undo the nut. This spanner has open jaws at one end and a 12 point (double hexagon) ring at the other end.


**Figure 49** Combination ring and open–end spanner

## Ring Spanner

The ring spanner (Fig. 50) is similar to a socket spanner in that they both have a positive grip on the job. Ring spanners have thin walls and provide access where open-end spanners may not fit. They are generally longer than open-end spanners, have six points of contact, and have offset shanks, which provide clearance for knuckles.

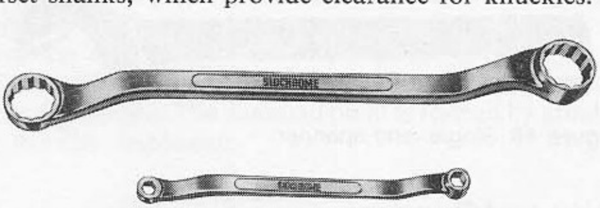


**Figure 50** Ring spanner

## Tube or Box Spanner

This is a special spanner for use in confined spaces where a socket is restricted by a long bolt (Fig. 51).

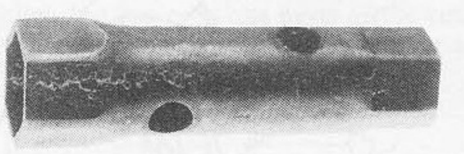


**Figure 51** Tube or box spanner

## Socket Spanner

The socket spanner provides the most positive grip and the quickest action of all the spanners. The 12 point (double hexagon) (Fig. 52) is the most often used of the socket spanners because it provides location at 12 different angular positions. These spanners are available in a number of drives, namely:

- $\frac{1}{4}$ in. for light applications, refrigeration, air-conditioning, etc.
- $\frac{3}{8}$ in. and $\frac{1}{2}$ in. for most engineering applications, automotive work, etc.
- $\frac{3}{4}$ in. and 1 in. for heavy industrial, trucking, earth-moving equipment, etc.

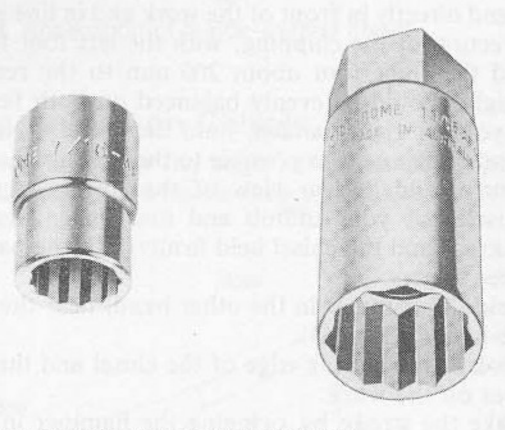


**Figure 52** Double–hex socket spanner

Sockets often require the use of many accessories and are usually kept in sets all having the same sized square drive. (Fig. 53.)

## Adjustable or Shifting Spanners

These spanners (Fig. 54) are not intended for heavy use and are not recommended if a spanner of correct size and configuration can be found. When using a shifting spanner the force should be applied against the fixed jaw. The shifter is available in a range of sizes to suit most hexagons and square nuts and bolts. It is not as strong as a spanner and must be used with care to prevent it slipping off and causing injury and damage.

## Ratchet Spanner

The ratchet spanner (Fig. 55) is used in conjunction with sockets and a wide range of socket accessories. It helps to speed up the turning motion when doing up and undoing nuts. It is also used in tight spots where the range of arc is small.

## Torque Wrench

The torque wrench (Fig. 56) is used where a prescribed

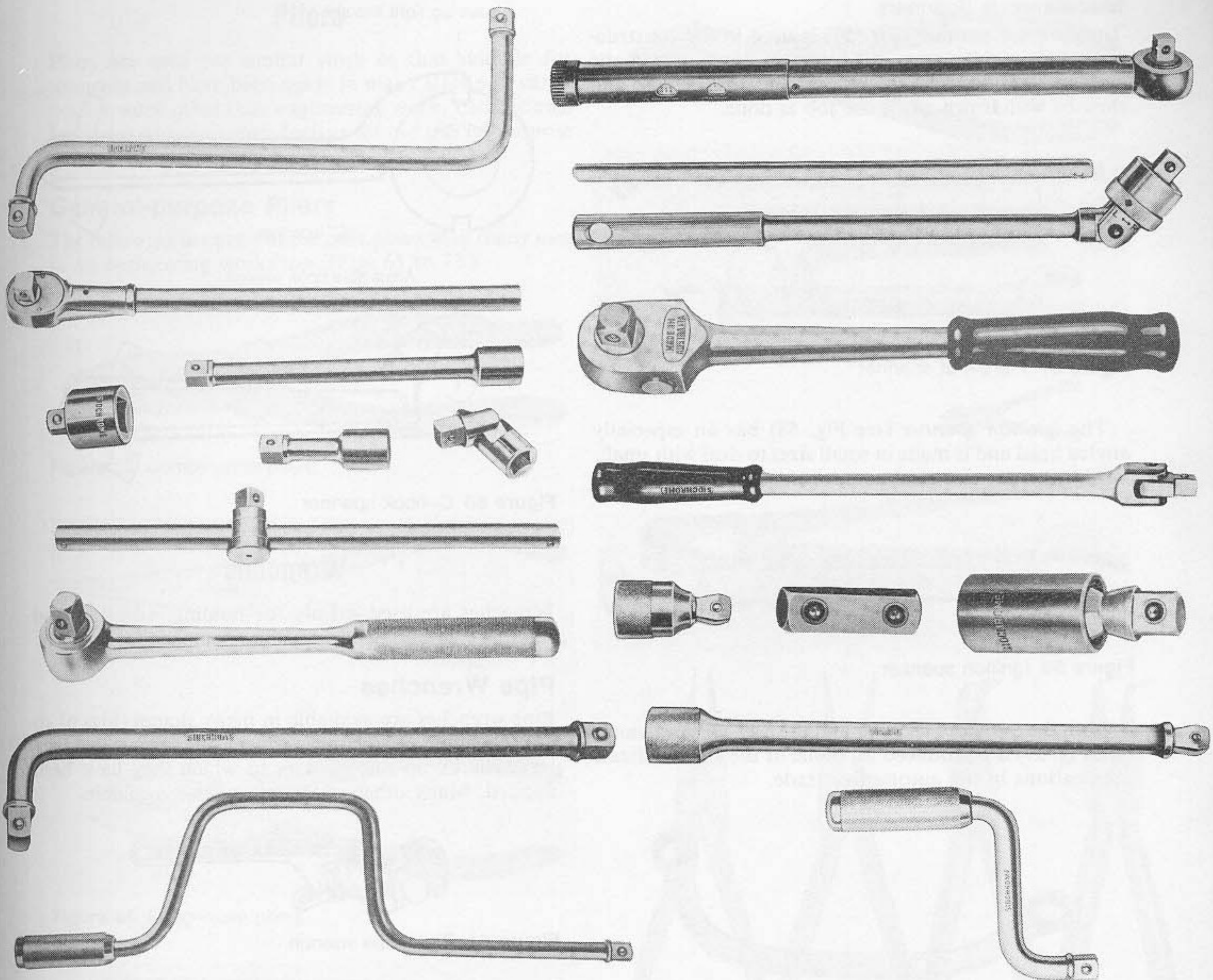


Figure 53 Socket set accessories

Figure 54 Adjustable or shifting spanner

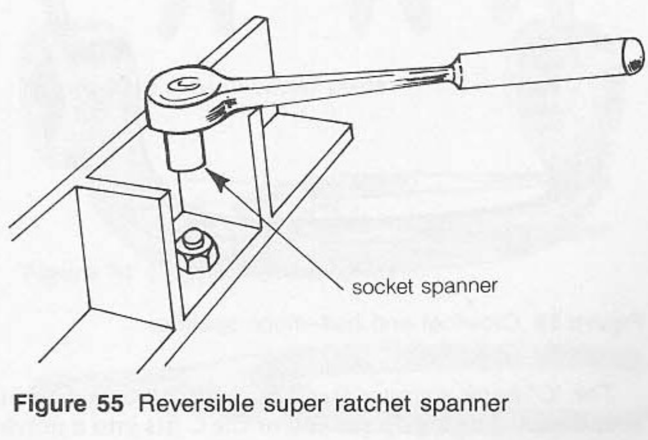



Figure 55 Reversible super ratchet spanner



Figure 56 Torque wrench

amount of torque is specified for the final tightening. It is used with sockets and can be pre-set to a predetermined force (Nm) to tension nuts on wheels, motor car heads, and machinery.

### Miscellaneous Spanners

The *flare nut spanner* (Fig. 57) is used in the construction and maintenance of hydraulic and pneumatic systems. It is designed to slip over the pipe or hose and then be withdrawn when the job is done.

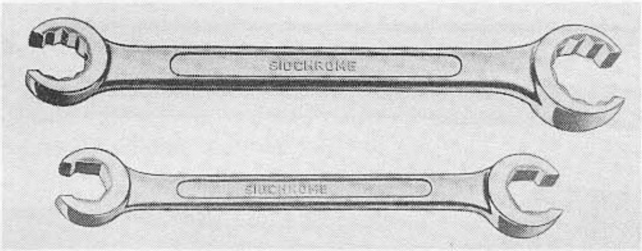



**Figure 57** Flare–nut spanner

The *ignition spanner* (see Fig. 58) has an especially angled head and is made in small sizes to deal with small, hard-to-get-at, electrical components.

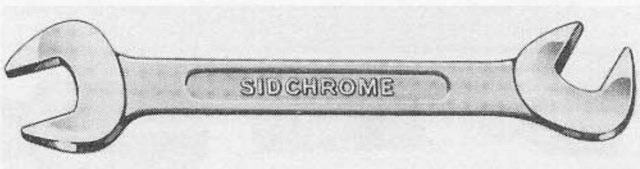



**Figure 58** Ignition spanner

Both the *crowfoot spanner* and the *half-moon spanner* (see Fig. 59) are produced for some of the more difficult applications in the automotive trade.

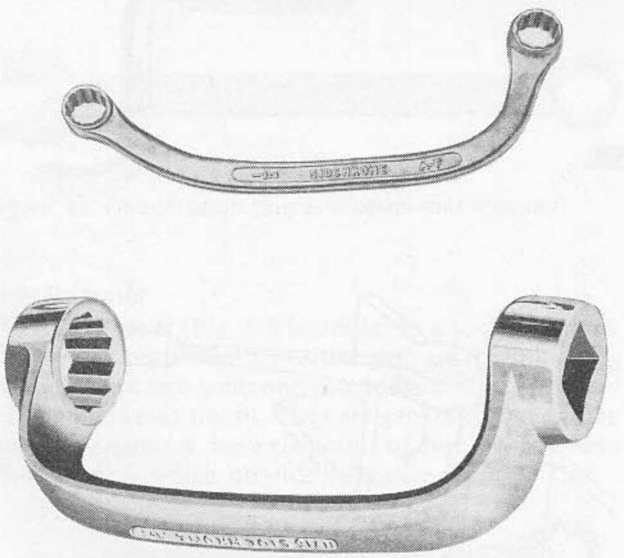


**Figure 59** Crowfoot and half–moon spanner

The *'C' hook spanner* (see Fig. 60) is designed to fit round nuts. The lug on the end of the C fits into a notch cut into the nut.

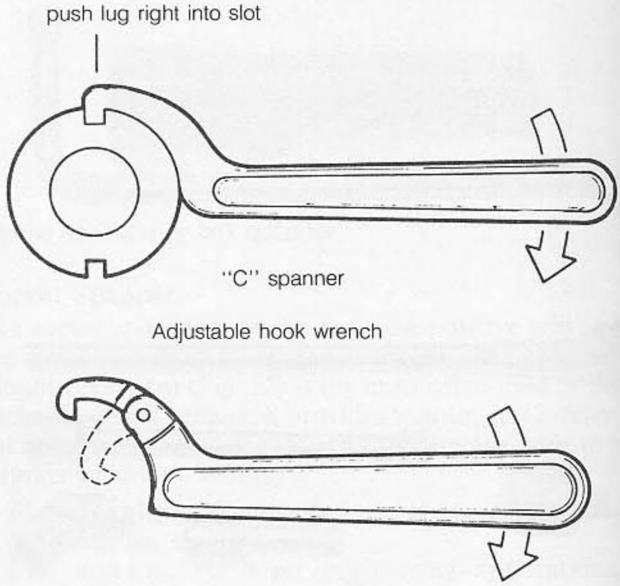



**Figure 60** C–hook spanner

## Wrenches

Wrenches are used mainly for holding, adjusting and rotating engineering parts that are not made for spanners.

### Pipe Wrenches

Pipe wrenches are available in many shapes (Figs 61 to 64). The main disadvantage when using them is that they leave marks on the surfaces to which they have been applied. Many other wrenches are also available.

**Figure 61** Rigid pipe wrench

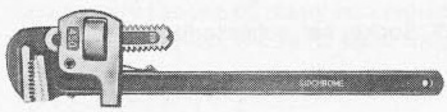


**Figure 62** Stillson pipe wrench

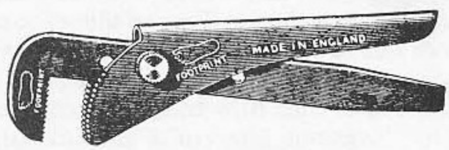



**Figure 63** Footprints

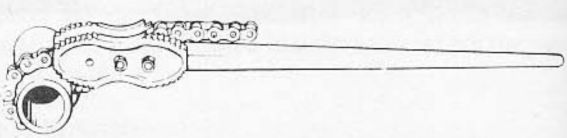


**Figure 64** Chain tongs

## Pliers

Pliers are used for similar work to that suitable for wrenches and have been made in many sizes and varieties for work other than engineering work. Electricians, fencing contractors and dentists all use special-purpose pliers.

### General-purpose Pliers

The following are general-purpose pliers with many uses in an engineering workshop. (Figs 65 to 73.)

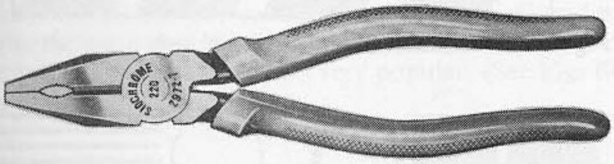


**Figure 65** Combination pliers

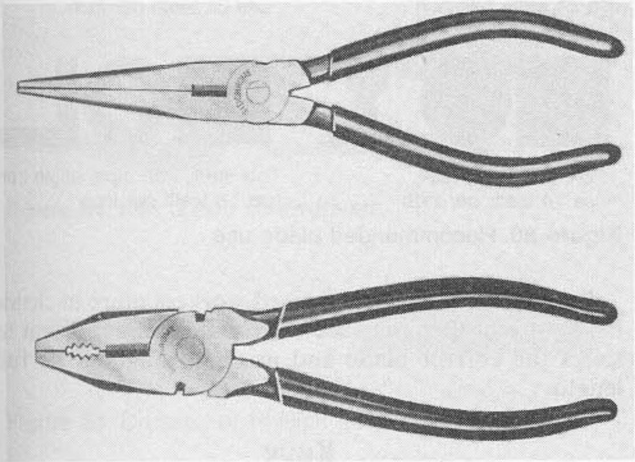


**Figure 66** Long-nose pliers

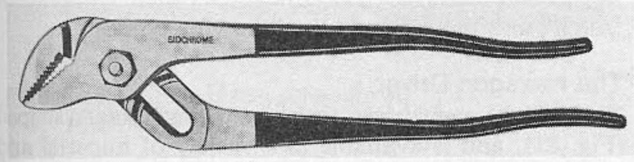


**Figure 67** Multi-grip pliers

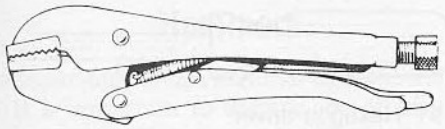


**Figure 68** Straight-jaw vice-grip pliers

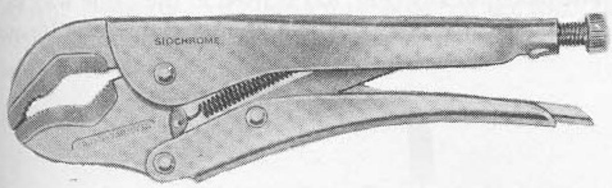


**Figure 69** Curved-jaw vice-grip pliers

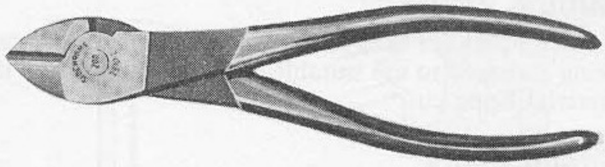


**Figure 70** Diagonal cutting pliers

**Figure 71** Nippers or pincers

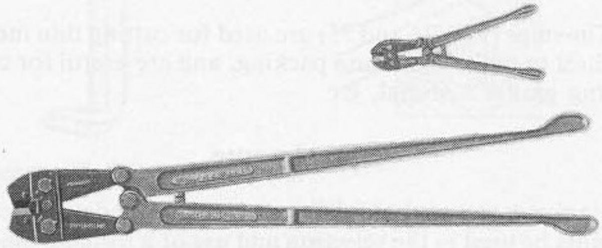


**Figure 72** Bolt cutters

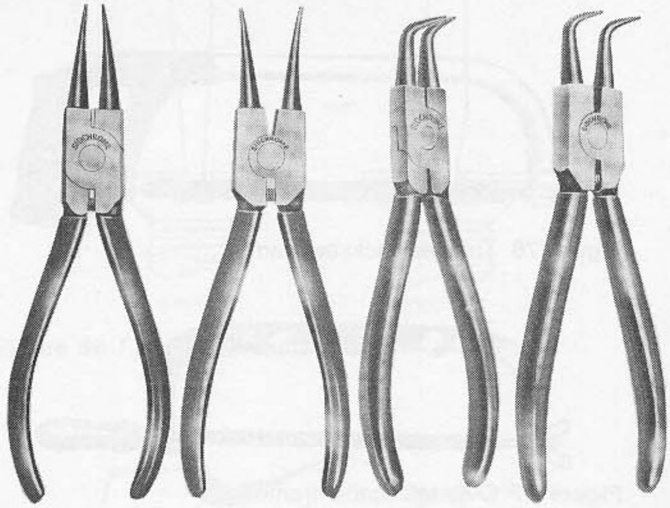


**Figure 73** Types of circlip pliers

**Figure 74** Straight tinsman snips

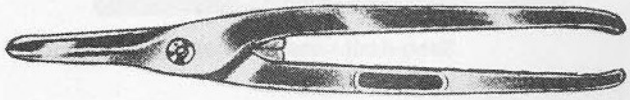


**Figure 75** Straight hand shears

## Cutting Pliers

Cutting pliers are used to cut wire and small rods, care being exercised to use suitable pliers for the job and the material being cut.

## Circlip Pliers

The following types are essential for inserting and removing circlips:

- straight pattern for inside rings;
- bent pattern for inside rings;
- straight pattern for outside rings;
- bent pattern for outside rings.

## Tin-snips

Tin-snips (Figs 74 and 75) are used for cutting thin metal sheet to make shims and packing, and are useful for cutting gasket material, etc.

## Hacksaws

Hacksaw frames hold different types of blades and care must be used in the selection and use of a suitable blade. (See Figs 76 to 78.) A blade can be fitted to the hacksaw frame and held in four different positions. This enables the user to cut out long or difficult shapes.

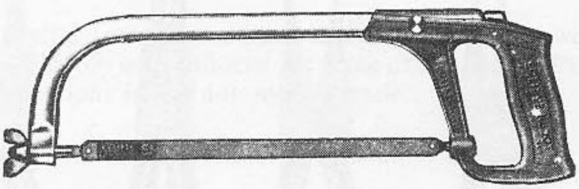


**Figure 76** Tubular hacksaw frame

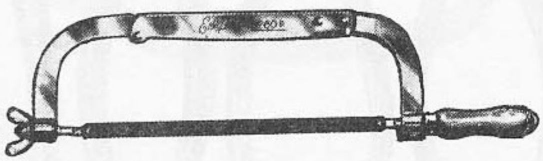


**Figure 77** Oval telescopic frame

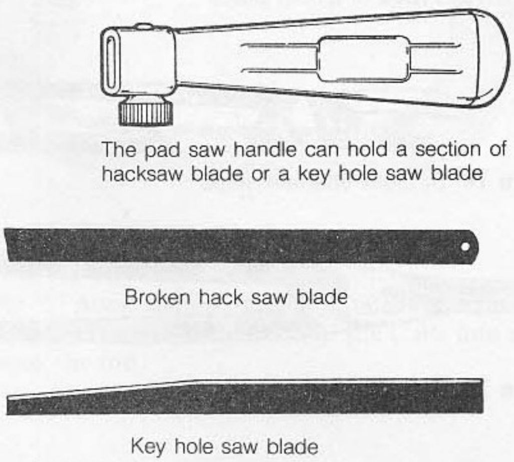



**Figure 78** Pad saw handle

Hacksaw blades are made with various numbers of teeth per inch. Eighteen teeth per inch is best for general use but there is no such thing as an all-purpose blade.

*Note:* Fine-pitch blades are used for pipe and thin materials and coarse-pitch blades are more efficient on solid or thick sections. (See Figs 79 and 80.)

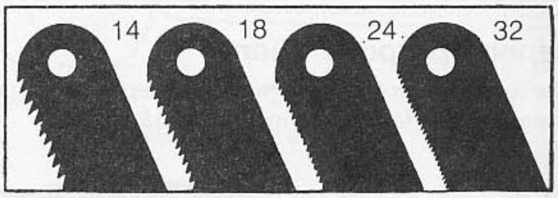



**Figure 79** Hacksaw blade teeth per inch

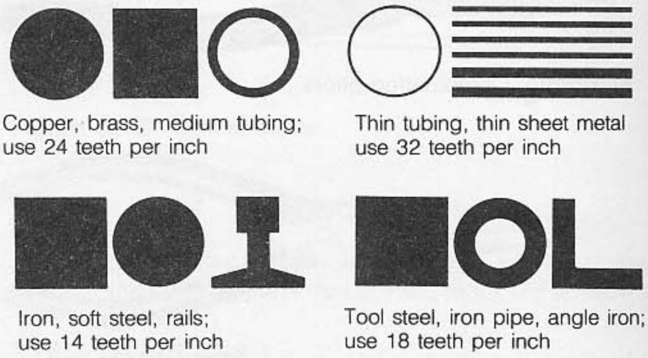



**Figure 80** Recommended blade use

In the hands of inexperienced workers more hacksaw blades are broken than are worn out. It is important to select the correct blade and use it throughout its full length.

## Keys

Small turning devices used for specially made engineering parts are referred to as keys, often called 'Unbrako' or 'Allen', and they include the following types.

### The Hexagon Driver

This is like a screwdriver, the shank being hexagon shaped (Fig. 81), and is available in a variety of imperial and metric sizes. It is used to tighten socket screws. The handle may be T-shaped.

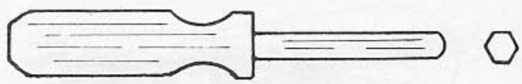


**Figure 81** Hexagon driver

### The Hexagon Key

The hexagon key (Fig. 82) is used in the same way as in the hexagon driver, but has greater tightening torque.

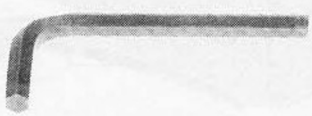


**Figure 82** Hexagon key

Spherical-ended Hexagon Key

This enables socket screws to be spun in, when the screws cannot be tightened axially. (Fig. 83.)

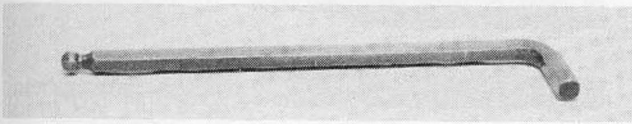


**Figure 83** Spherical–ended hexagon key

## Screwdrivers

Screwdrivers are very common tools used in all trades, with the main type being called the flat tip, but the cross tipped (Phillips head) is also very popular. (See Figs 84 to 88.)

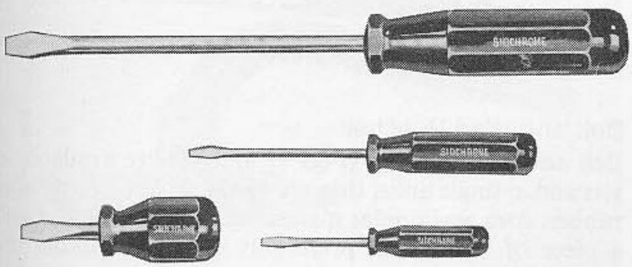


**Figure 84** Flat tipped screwdrivers

**Figure 85** Crossed or Phillips head screwdriver

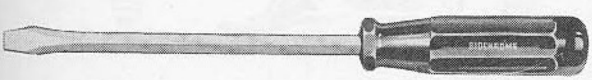


**Figure 86** Square Blade screwdriver

The tip of the blade of a screwdriver must be kept in good condition or the screw slot will be damaged.

## Hammers

Most tradespersons have a hammer of some kind in their toolkits. It is important to use the correct size hammer for each occasion. When witness marking a piece of material a small hammer should be used. When undertaking heavy maintenance work a larger hammer may be sought, depending of course on the size of the job. The more common types of engineering hammers are shown in Figures 89 to 92.

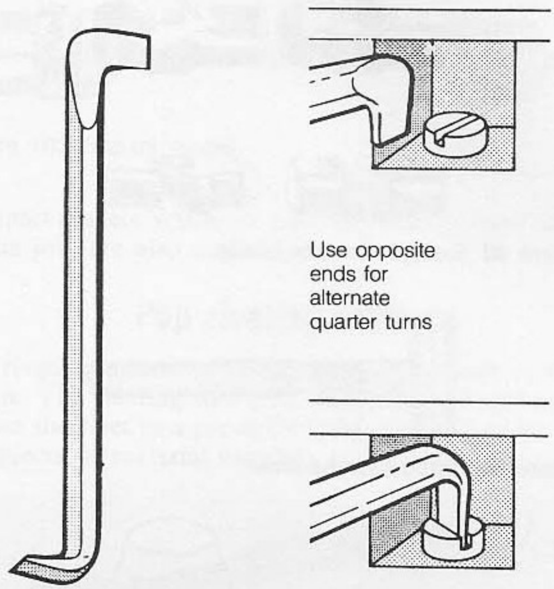



**Figure 87** Offset screwdriver

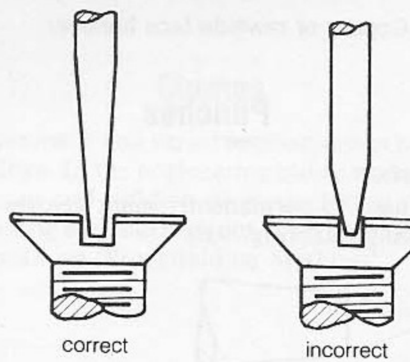



**Figure 88** Fit of screwdriver in slot

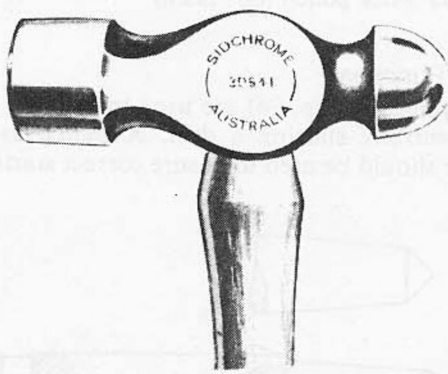



**Figure 89** Engineers hammer (ball pein)

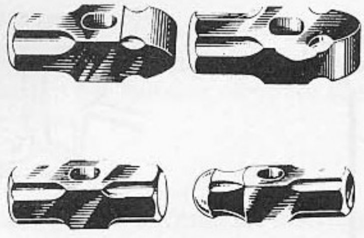


**Figure 90** Sledge hammer heads

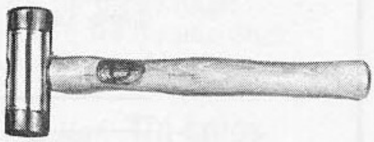


**Figure 91** Nylon face hammer

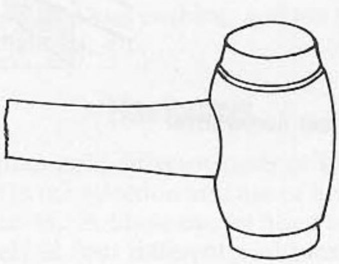


**Figure 92** Copper or rawhide face hammer

# Punches

## Prick Punches

These are used to permanently mark centres and lines when marking out. (Fig. 93.)

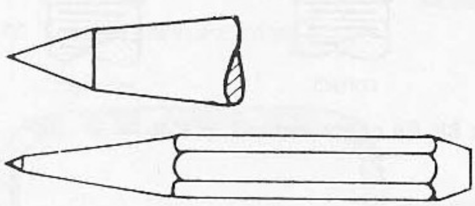


**Figure 93** Prick punch (60° point)

## Centre Punches

Centre punches (Fig. 94) are used to increase the prick when centrally starting a drill. A punch as large as possible should be used to ensure correct starting of the drill.

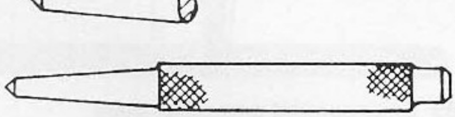


**Figure 94** Centre punch (90° point)

## Pin Punches

Parallel pin punches (Fig. 95) are used to drive pins and dowels in an assembly.

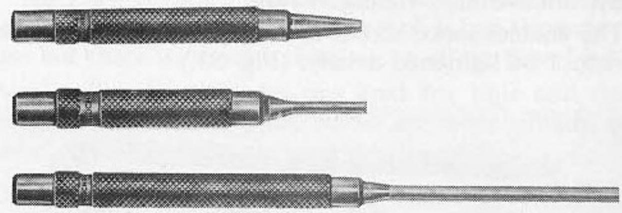


**Figure 95** Pin punches

## Starter Drift Punches

Tapered starter drift punches (Fig. 96) are used to star the removal of a tight pin. They do not flex as the paralle punch would.

**Figure 96** Starter drift punch

## Belt and Wad Punches

Belt and wad punches (Figs 97 and 98) are available in sets and in single units; they are used to cut holes in fabric, rubber, cork and similar materials. Always use them with a piece of hardwood, preferably end grain, under the material being cut.

**Figure 97** Hollow punch

**Figure 98** Wad punch

## Pinches and Crow Bars

Pinches and crow bars (Fig. 99) are used for lifting and moving. They are available in many sizes and types.

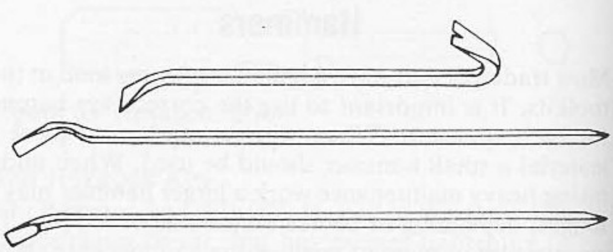


**Figure 99** Pinch bars and crow bars

## Drifts

Drifts (Fig. 100) are used to release gib-head keys from keyways, and are also used to release taper-shank tools from sockets and machine spindles.

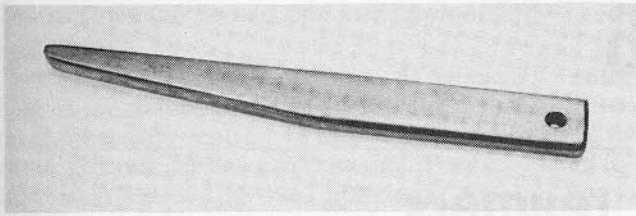


Figure 100 Drift tapered

## Wheel or bearing pullers

Bearing pullers can be operated mechanically through a screw or hydraulically with the assistance of a power cylinder. These pullers are able to grip the inside or outside of bearings, pulleys, gears, etc. that are normally difficult to remove. (See Figs 101 to 103.)

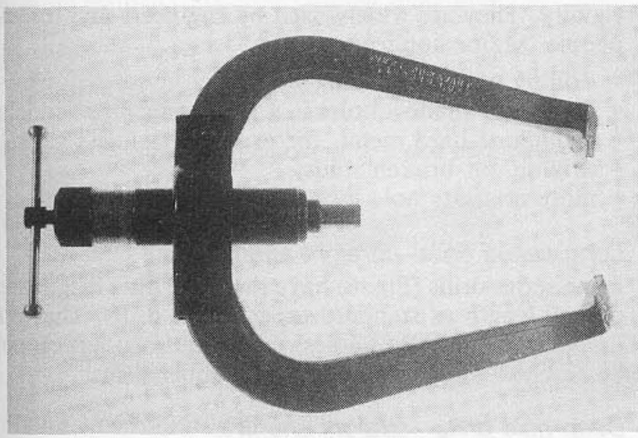


Figure 101 Hydraulic puller

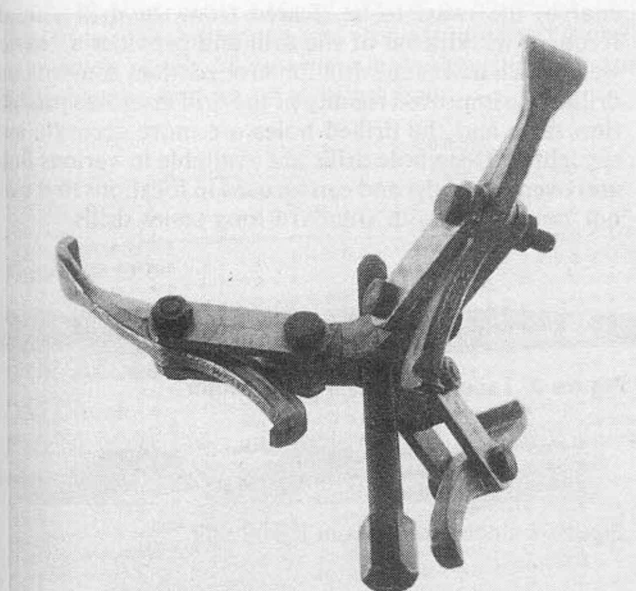


Figure 102 Mechanical puller (bearings)

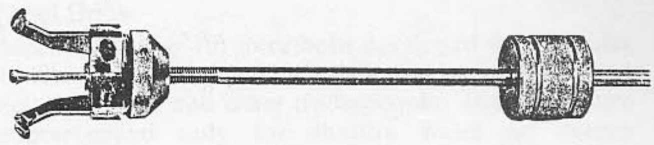


Figure 103 Impact model

Impact models, which use a sliding weight to exert force on the job, are also available.

## Pop riveting tools

Pop riveting is used to fabricate projects made of thin metals. The riveting tool (Fig. 104) expands and compresses the rivet in a pre-drilled hole and so fastens the two pieces of material together.

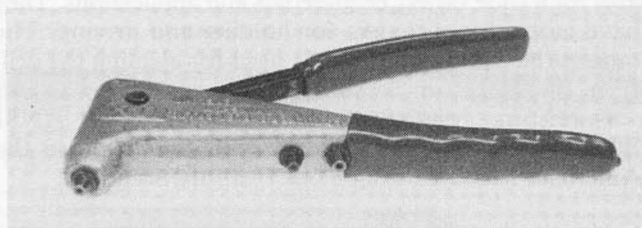


Figure 104 Pop rivet setting tool

## Clamps

Clamps have many and varied applications in many trades and industries. In the engineering industry they are used in the setting and holding of work during machining, welding, fitting and marking out. This usage is described in Chapter 18 on 'Workholding Methods'.

# 16

# Drills and reamers

## Drills

### Drill Types

#### Taper Shank Drills

Taper shank drills (Fig. 1) are general purpose drills suitable for a wide variety of materials and applications. They have morse taper shanks for holding and driving. The tang at the end of the shank is used for ejecting the drill from the socket or sleeve.

Fractional drills are manufactured to ANSI B94.11-1967 Standard. Metric drills are made to the American Metal Cutting Tool Institute Standard.

*Extra length drills—taper shank*

Extra length taper shank drills (Fig. 2) are used for deep holes and for locations that cannot be reached with standard length drills. Various combinations of diameter, overall length and flute length are available.

*Core drills—taper shank*

Taper shank four-flute core drills (Fig. 3) are used to enlarge drilled, punched or pre-cored holes in a wide range of materials. A core drill cannot produce a hole from the solid. The advantages of core drills are: increased productivity, superior surface finish, and greater accuracy in the hole size and location.

#### Straight Shank Drills

*Jobber drills—straight shank*

Jobber drills (Fig. 4) are the most popular drills, used by engineers, tradespeople and at home. These drills are designed to give optimum performance in a wide range of materials. They are manufactured to ANSI B94.11 1967 Standard.

*Stub drills—straight shank*

Stub drills (Fig. 5) are shorter overall and have a shorter flute length than jobber drills. Therefore they have greater rigidity. They are widely used by engineers and tradespeople. Major applications are:

- drilling of sheet metal;
- drilling of shallow holes in a wide range of materials;
- drilling of hard metal, for example stainless steel;
- drilling out broken studs;
- more accurate hole location.

*Long series drills—straight shank*

Long series drills (Fig. 6) have the same flute length and overall length as standard taper shank drills. They are used for drilling deep holes or in locations that cannot be reached with standard length jobber drills.

*Deep hole drills—straight shank*

Deep hole drills (Fig. 7) have been specially designed for deep hole drilling applications. The parabolic flute design enables the swarf to be cleared from the drill without frequent withdrawal of the drill and provides a heavier web, which makes the drill far stronger than conventional drills. The improved rigidity of the drill improves production rates and the drilled holes are more accurate and straighter. Deep hole drills are available in various flute and overall lengths and can be used in locations that cannot be reached with standard long series drills.

**Figure 1** Taper shank drill

**Figure 2** Taper shank drill extra length

**Figure 3** Taper shank core drill

**Figure 4** Jobber or straight shank drill

**Figure 5** Stub drill or straight shank drill

**Figure 6** Long series straight shank drill

**Figure 7** Deep hole straight shank drill

### Centre Drills (combined drill and countersink)—Plain Type

Centre drills (Fig. 8) are used to drill female 60° centre holes in the ends of shafts and components that will later revolve between centres. Centre drills are also used to ensure accurate starting and centering. They are manufactured to ANSI B94.11-1967 Standard.

### Masonry Drills—Tungsten Carbide Tipped

Masonry drills (Fig. 9) are used for drilling holes in masonry materials. These drills are available in three different lengths: type SF for short fixing devices; type SB for drilling through $4\frac{1}{6}$ in. (29 cm) brick plus render and tile; and type DB for drilling through a double cavity brick wall plus render and tile. All drills are suitable for use in portable electric drills, hand drills and drill presses. A specially designed IMP drill is available for use in rotary-impact portable drilling machines.

### Panel Drills

Panel drills (Fig. 10) have been developed to drill holes for rivets in flat and curved panels and are used by sheet metal workers, and other tradespeople. These drills are recommended only for shallow holes no deeper than $1\frac{1}{4}$ times the drill diameter. They can also be used for drilling hard materials such as stainless steel. They may be either single ended ('Bulls-eye') or double ended ('Twin-point'). When using twin-point drills, ensure that the chuck jaws are fully tightened.

### Reduced Shank Drills

Reduced shank drills (Fig. 11) are designed to increase the drilling capacity of $\frac{1}{4}$ in., $\frac{3}{8}$ in. and $\frac{1}{2}$ in. diameter drill chucks. These drills must be used with extreme care and run at recommended speeds to avoid overheating of the drill point.

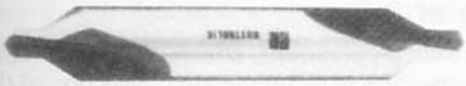


**Figure 8** Centre drill (combined drill and countersink)

**Figure 9** Masonry drill

**Figure 10** Panel drills

**Figure 11** Reduced shank drill

### D Bit

The D bit (Fig. 12) is a round tool bit of hardened steel ground to the required size and shape (Fig. 12). It is used as a quick means of making a hole-sizing tool or for flattening the bottom of a drilled hole.

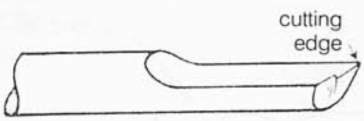



**Figure 12** D bit

## Drill Accessories

### Drill Chuck

Parallel shank drills and tools are held in a drill chuck

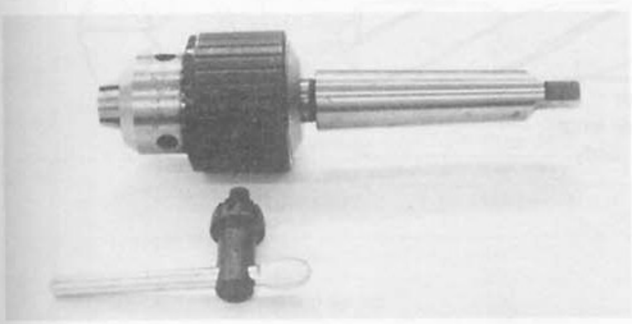


**Figure 13** Drill chuck and key

(Fig. 13). Fig. 13 shows the keyed type commonly called Jacobs (who has been the largest manufacturer). Keyless chucks are also used, but lack gripping power.

### Drill Sleeves

Drill sleeves (Fig. 14) are used to increase the taper size of a tool to suit the machine being used.

**Figure 14** Drill sleeve, No. 1–5 inside 2–6 outside

### Drill Drift

The drill drift (Fig. 15) is used to remove taper shank drills

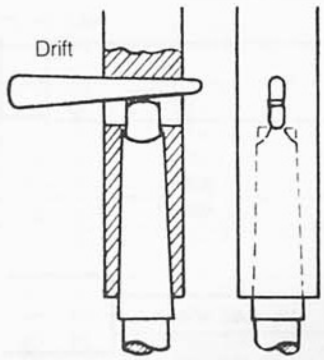



**Figure 15** Taper shank and socket

from the machine or sleeve. Never use a file tang or similar tool. Always place a piece of wood or similar material on the machine table or work for the tool to land on as it is drifted out. It must not fall free.

## Nomenclature (Fig. 16)

**Body** The portion of the drill extending from the extreme cutting end to the start of the shank.

**Body clearance** The portion of the body reduced in diameter to provide diametral clearance.

**Chisel-edge angle** The obtuse angle between the tangent to the projection of the chisel edge at the axis, and the projection of the line through either outer corner and the corresponding chisel edge corner on a plane normal to the (drill) axis. This angle lies in a plane normal to the drill axis.

**Drill diameter** The measurement across the cylindrical lands at the outer corners of the drill.

**Flute length** The axial length from the outer corners of the cutting lips to the extreme back end of the flutes.

**Helix angle** The acute angle between the tangent to the helical leading edge of the flute at a point in this edge and a plane containing the (drill and helix) axis and the point in question. This angle lies in a plane normal to the radius at the point on the edge. The helix angle is usually measured at a point close to or coincident with the outer corner.

**Lip clearance angle** The acute angle between a plane normal to the (drill) axis and the tangent, at a point on the lip, to the drill flank in a plane normal to the radius at the point in question. This angle is usually specified and measured at the outer corner.

**Lip length** The minimum distance between the outer corner and the chisel edge corner or inner corner. (For a straight lip it is the true length of the lip.)

**Overall length** The distance between two planes normal to the drill axis at the extreme ends of the cutting diameter and shank respectively.

**Point angle** The included angle between the projections of the lines joining the outer corners and the corresponding chisel edge corners on a plane parallel to one (or both) of these lines and the drill axis.

**Web (core) thickness** The diameter of the circle normal to the axis through the roots of the flutes at the point end of the drill.

**Flutes** The grooves in the body of the drill to provide lips and to permit the removal of chips and allow cutting fluid to reach the lips.

## Operation of drills

For efficient drilling operations, adherence to the following guiding principles is recommended. Selection of the correct drill for the application is most important. Most drills have a point angle of 118°, which is suitable for most materials. However, performance can be improved when drilling some materials by repointing the drill. Next it is important to select the correct speed and feed. The choice of speed and feed are restricted by the degree of hardness of the work material. Initially, use moderate speed and feed, increasing one or both to achieve maximum production for a reasonable drill life before resharpening.

The workpiece must be securely held and supported as close as possible to the drill. Always clamp the work, never hold it by hand. When using a straight shank drill

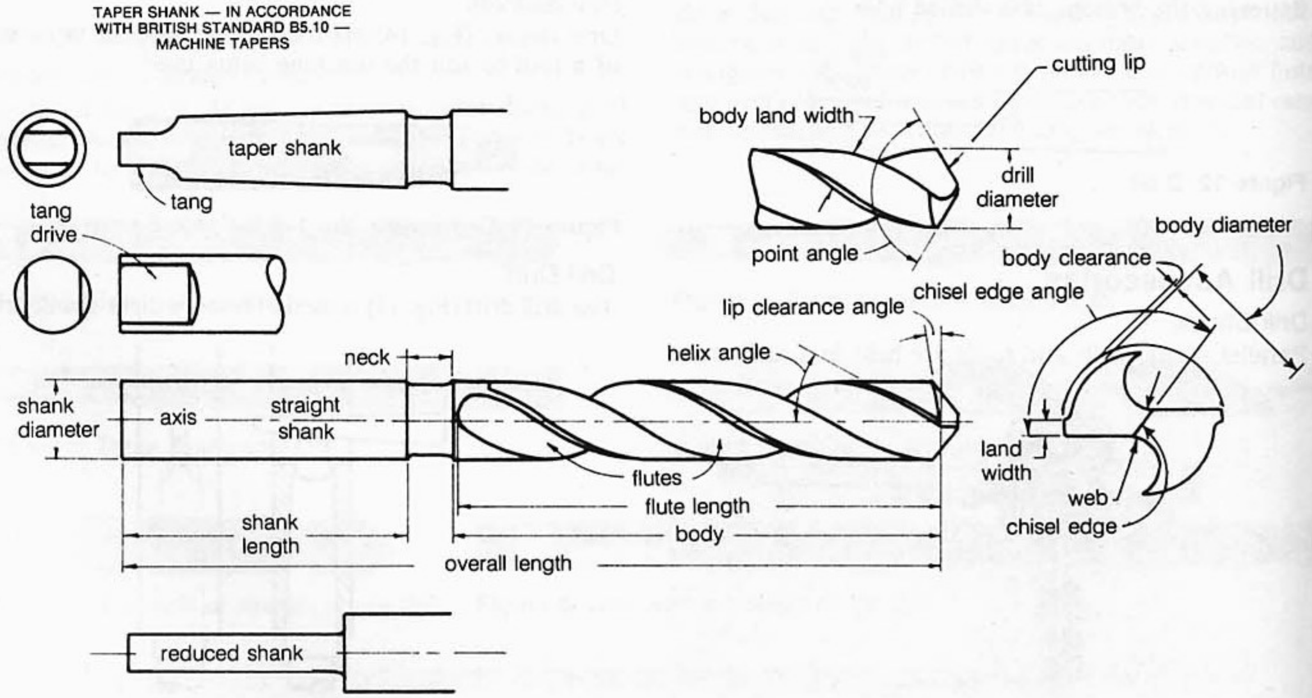



**Figure 16** The important features of a drill

hold it firmly in the chuck as slippage will inevitably cause drill breakage.

Taper shank drills are driven by the taper and not the tang. The tang is designed for ejection not driving. It is essential that the drill shank and socket are a good fit and free of burrs and grit, otherwise slippage will twist the tang. When removing a taper shank drill ensure that the correct sized drift is used and take precautions against damaging the drill point when it falls from the sleeve.

When drilling by hand apply a constant pressure. Do not allow the drill to 'dwell' as this will cause dulling of the cutting edge. Some materials harden by being worked and immediately destroy the cutting lips. The flutes of the drill must be kept clear. Clogging of the drill flutes prevents sufficient lubricant from reaching the drill point. The drill flutes may be cleared occasionally by withdrawing the drill after penetrating about two or three diameters in depth.

Excessive heat damages the drill cutting lips. Use a plentiful, well directed flow of cutting fluid to absorb the heat generated during cutting.

## Deep-hole Drilling

Deep holes are usually defined as holes having greater depth than four times the diameter of the drill. Specially designed deep-hole drills are available, which are more rigid than standard drills and clear the swarf more efficiently. The advantage of deep-hole drills is that faster feed can be used and deeper holes can be drilled before swarf has to be cleared from the drill flutes. Oil-hole drills are also recommended for drilling deep holes.

Deep holes can be drilled using standard drills but it is necessary to use slower speeds and feeds and to frequently withdraw the drill to clear the flute of swarf. When using standard drills select the speed and feed, and reduce by the percentage reduction listed in Table 1.

## Some Criteria for Drill Usage

Limits of tolerance on the diameter of twist drills are listed in Table 2.

A guide for selection and use of drills is given in Table 3.

Recommended feeds for various diameter drills are shown in Table 4.

**Table 1** Recommended speed and feed reduction when deep drilling with standard drills

| Depth of hole in drill diameters | Feed reduction (%) | Speed reduction (%) |
|---|---|---|
| 5 | 10 | 12.5 |
| 6 | 12 | 15 |
| 7 | 14 | 17.5 |
| 8 | 16 | 20 |
| 9 | 18 | 22.5 |
| 10 | 20 | 25 |
| 11 | 22 | 27.5 |
| 12 | 24 | 30 |
| 13 | 26 | 32.5 |
| 14 | 28 | 35 |
| 15 | 30 | 37.5 |
| 16 | 32 | 40 |
| 17 | 34 | 42.5 |
| 18 | 36 | 45 |
| 19 | 38 | 47.5 |
| 20 | 40 | 50 |

**Table 2** Limits of tolerance on the diameter of twist drills

| Drill diameter at point | | | | Back taper on diameter |
|---|---|---|---|---|
| Over | Up to and including | Tolerance | | Tolerance |
| 0.32 mm | $\frac{1}{8}$ | + .0000 | − .0005 | .0000 to .0008 per inch |
| $\frac{1}{8}$ | $\frac{1}{4}$ | + .0000 | − .0007 | .0002 to .0008 per inch |
| $\frac{1}{4}$ | $\frac{1}{2}$ | + .0000 | − .0010 | .0002 to .0009 per inch |
| $\frac{1}{2}$ | 1 | + .0000 | − .0012 | .0003 to .0011 per inch |
| 1 | 2 | + .0000 | − .0015 | .0004 to .0015 per inch |
| 2 | 3 | + .0000 | − .0020 | .0004 to .0015 per inch |

* ANSI B94.11 1967

**Table 3** Guide for selection and use of drills

| Material and hole condition | | Hardness range (B.H.N.) | Included point angle | Speed (ft/min) | Speed (m/min) | Cutting fluid |
|---|---|---|---|---|---|---|
| Aluminium alloys | Deep hole | 50–140 | 118° | 200–300 | 61– 91 | |
| Alum alloys cast | High silicon | 45–120 | 118° | 80–120 | 24– 37 | Soluble oil |
| | Low silicon | 35–110 | 118° | 140–200 | 43– 61 | |
| Aluminium forged | Shallow hole | 50–140 | 118° | 200–500 | 61–153 | |
| Alum alloys forged | | | | | | Kerosene |
| | Deep hole | 50–140 | 118° | 200–500 | 61–153 | |
| Brass | Leaded free machining | 100–150 | 118° | 200–300 | 61– 91 | |
| Bronze | Castings | 80–120 | 118° | 60– 90 | 18– 27 | |
| | Wrought | 120–220 | 118° | 35– 80 | 11– 24 | Soluble oil |
| Cast iron | Chilled or white | 400 | 150° | 15– 25 | 4.6–7.6 | |
| | Hard grey iron | Over 200 | 118° | 45– 50 | 14– 15 | |
| Cast iron | Medium grey iron | 150–200 | 90°–110° | 80–110 | 24– 34 | Dry or compressed air |
| | Soft grey iron | Below 150 | 90° | 140–150 | 43– 46 | |
| | Malleable | 140 | 118° | 80–100 | 24– 34 | |
| Cast Iron S.G. | As cast | 220 | 118° | 40– 50 | 12– 15 | |
| | Annealed-ferritic | 190 | 118° | 45– 65 | 14– 20 | Soluble oil |
| Copper | | 45–110 | 100° | 70–100 | 21– 30 | |

*Continued on next page*

Table 3 (cont)

| Material and hole condition | | Hardness range (B.H.N.) | Included point angle | Speed (ft/min) | Speed (m/min) | Cutting fluid |
|---|---|---|---|---|---|---|
| Die castings (zinc base) | | 70- 90 | 118° | 300-400 | 91-122 | |
| Gunmetal leaded & brass castings | | 45- 55 | 118° | 150-300 | 46- 91 | Soluble oil |
| Magnesium and alloys | | 40- 70 | 118° | 200-500 | 61-153 | Soluble oil and kerosene |
| R Monel, nickel | | 110-200 | 118° | 40-100 | 12- 30 | |
| K Monel | | 160-275 | 135° | 20- 60 | 6- 18 | Sulphur base oil |
| Nickel alloys | $3\frac{1}{2}$% nickel steel | 190-240 | 135°-140° | 30- 50 | 9- 15 | Soluble oil |
| Plastics | Thermo-plastics | | 90° | 100-300 | 30- 91 | Soapy water |
| Steel | Free Cutting | 110-130 | 118° | 120-150 | 37- 46 | |
| | Mild 30 ton | 130 | 118° | 120-140 | 37- 43 | |
| | Medium carbon 35 ton | 155 | 118° | 100-115 | 30- 35 | Soluble oil |
| | Medium carbon 45 ton | 210 | 118° | 65- 90 | 20- 27 | |
| Steel | Tool and spring | 200-400 | 140° | 25- 65 | 7.6-20 | |
| Steel, alloy | 55 tonne | 250 | 118° | 50- 70 | 15- 21 | |
| | 65 tonne | 300 | 118°-140° | 40- 55 | 12- 17 | |
| | 75 tonne | 340 | 130°-150° | 30- 40 | 9- 12 | |
| Steel, stainless | Ferritic | 150-200 | 118° | 50- 90 | 15- 27 | Sulphur based oil |
| | Martensitic | 250 | 125°-135° | 35- 50 | 11- 15 | |
| | Austenitic, | 170 | 118° | 20- 30 | 6- 9 | |
| | Mart. free machining | 250 | 125°-135° | 40- 55 | 12- 17 | |
| | Aust. free machining | 170 | 118° | 25- 40 | 7.6-12 | |
| Wood | | | 60°-90° | 300-500 | 92-153 | None |

**Table 4** Recommended feeds for various diameter drills

| Diameter of drill (inches) | Feed (inches per revolution) |
|---|---|
| Under $\frac{1}{8}$ | .001 to .003 |
| $\frac{1}{8}$ to $\frac{1}{4}$ | .002 to .006 |
| $\frac{1}{4}$ to $\frac{1}{2}$ | .004 to .010 |
| $\frac{1}{2}$ to 1 | .007 to .015 |
| 1 inch and over | .015 to .025 |

*Note:* It is best to start with a moderate speed and feed, increasing either one, or both, after observing the action and condition of the drill.

* Use conversion tables for metric equivalents.

## Drill Sharpening

Most drilling problems are due to improper sharpening of the drill. For general purpose drilling the point angle is 118°. The angle must be equal on both sides of the axis (59°) and the cutting edge lip must be the same length on both sides of the drill axis (Fig. 17). If the two cutting edges are not equal in length and/or the angles are not equal, the drill will cut an oversized hole and breakage may occur. The drill must be sharpened with a lip clearance of 12° to 15° (Fig. 18). If the lip clearance is excessive, the strength of the cutting edge is reduced and may result in fracture of the cutting edge.

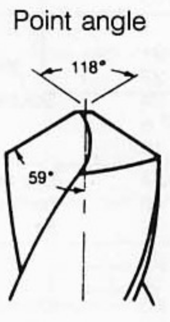



**Figure 17** The point angle

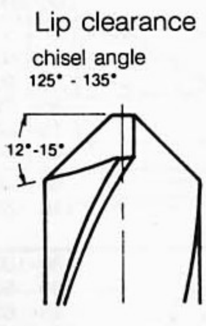



**Figure 18** The lip clearance

### *Hand-grinding drills*

Whenever possible drills should be sharpened on a drill-pointing machine, but when this is not possible the following guidelines will help when sharpening drills by hand. The thumb and forefinger of the left hand are used as a pivot, as illustrated and the back of the drill is held with thumb and forefinger of the right hand, as shown in Figure 19. The drill is rotated in a clockwise direction, advancing into the wheel.

The intense local heat that can be generated in grinding operations frequently results in surface cracking because of uneven thermal expansion and contraction. Grinding pressures should therefore be moderate when pointing drills and the use of a free-cutting wheel and a copious supply of water is desirable. When water is not available grinding can be done dry by taking very light cuts. If excessive heat is generated the drill should not be cooled in water but left to cool in air. Grinding cracks that seem invisible can enlarge under working conditions and quickly lead to tool breakdown.

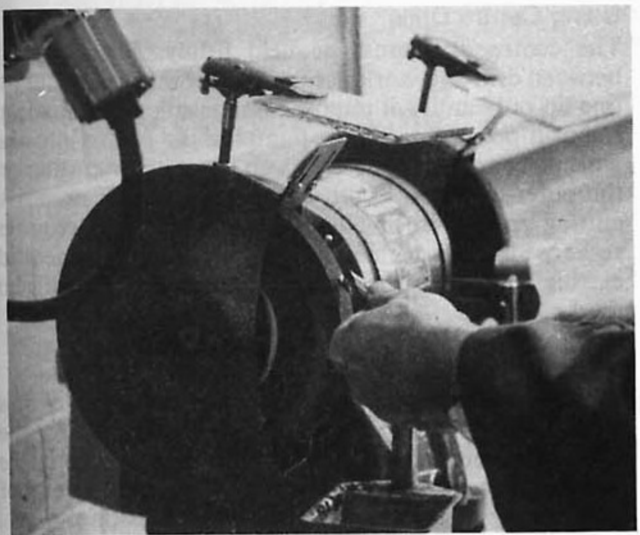


**Figure 19** Sharpening by hand

### *Web thinning*

Most drills have a web that is thin near the point of the drill. As a drill is resharpened it becomes shorter, the web thickness becomes greater, and the drill point develops a much longer chisel edge. This longer chisel edge will result in more pressure being required for penetration, resulting in greater heat generation and a reduction in the life of the drill. The chisel edge can be reduced by web thinning.

For correct web thinning it is important that equal amounts of material be ground from either side of the chisel edge until the total length of the edge returns to the same value as that found on a new drill. (Excessive web thinning weakens the point of the drill and splitting of the web may occur.)

The ground surface produced by web thinning must blend evenly into the flutes without ending abruptly. The web thinning should extend 50% to 100% of the drill diameter along the flute. (See Fig. 20.)

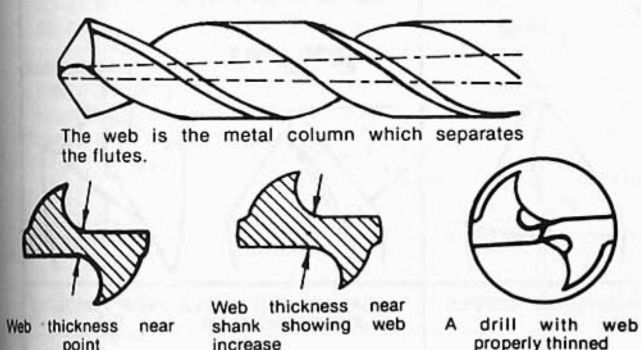



**Figure 20** The web and thinned web

### *Point geometry*

Drills are given points on precision automatic grinding machines. The standard point geometry on drills has an included angle of 118° with a lip relief angle of 12° to 15°. Such a drill is suitable for most materials. However, a user will sometimes find it necessary to give the drill a point that is better suited to the material being machined. (Fig. 21.)

### *Split pointing*

Split pointing is recommended to reduce the point pressure and greatly improve the cutting action of the chisel edge. (Fig. 22.)

## Trouble Shooting

A useful chart, which can be used to identify and then remedy a variety of possible drilling problems, is shown in Table 5.

**Table 5** Trouble-shooting chart for high-speed steel drills

| Problem | Possible cause | Suggested remedy |
|---|---|---|
| Short point-life | Speed too fast, blues cutting lips | Reduce speed<br>Apply cutting fluid |
| | Metal is hard, wears cutting lips | Reduce speed<br>Apply cutting fluid |
| | Insufficient lip relief, drilling dry | Repoint<br>Apply cutting fluid |
| Blue cutting lips outer corners burnt off | Speed too fast | Reduce speed |
| | No coolant | Apply cutting fluid |
| Chipped cutting lips or outer corners | Excessive lip relief | Regrind |
| | Excessive feed | Reduce feed |
| | Grinding cracks from plunge cooling | Regrind without overheating |
| Drill breaks | Feed too high | Reduce feed |
| | Flutes packed with chips | Withdraw frequently to clear |
| | Misaligned or unclamped fixture | Realign and clamp firmly |
| | Blunt drill | Resharpen sooner |
| | Spring in work | Pack and clamp more rigidly |
| | Machine spindle end-play | Adjust/replace machine bearings |
| | Worn front-taper on diameter lands, jams drill in hole | Shorten drill, repoint |
| Hole oversize | Cutting lip length not equal | Repoint |
| | Angle, axis to cutting lips differ | Repoint |
| | Point thinning not central | Repoint then thin |
| | Worn machine conditions | Recondition machine |
| | Drill guide bush worn | Replace guide bush |
| Rough hole finish | Blunt drill | Resharpen |
| | Point poorly sharpened | Resharpen |
| | Feed too high | |
| | Incorrect or no cutting fluid | Apply cutting fluid |
| Drill splits up | Feed too high | Reduce feed |
| | Insufficient lip relief | Regrind |
| | Work deflection upwards at break through | Support and clamp work firmly |
| | Thick web increases pressure | Thin web |
| Tang twisted | Matching tapers or shank and sleeve dirty, burred or worn | Clean up shanks, ream sleeves or spindles |
| Metal welds to diameter land or flute face | Heat from high revolutions, incorrect or no cutting fluid | Use flow of correct coolant; if trouble persists, reduce speed |

*Continued on next page*

Table 5 (cont)

| Problem | Possible cause | Suggested remedy |
|---|---|---|
| Excessive feed pressure | Web too thick<br>Drill blunt<br>Insufficient lip relief | Thin web<br>Repoint<br>Regrind |
| Unequal chips from cutting lips | Point has unequal lip lengths and/or point angles | Repoint |
| Drill squeaks | Insufficient lip relief<br>Front-taper worn on diameter lands | Regrind<br>Shorten drill, repoint |
| Multi-sided hole through thin material | Excessive lip relief | Reduce lip relief to about one degree; drill through thin metal into supporting metal or hardwood base; clamp the work |
| Burrs on hole underside | Blunt drill<br>Feed too high | Repoint<br>Reduce feed |
| Reduced shank broken from drill | Feed too high, flutes clogged, pistol drill leaned sideways jamming drill in hole | Reduced feed, clear flutes frequently, keep drill aligned |

## Using Centre Drills

The centre drill must be held firmly. Misalignment between drill and workpiece will allow the drill to cut on one lip only and will impose an uneven cutting load on the drill point. Forcing or pumping the centre into the workpiece will split the drill web. Dulling or cutting on the outer corners or cutting lips indicates an excessive cutting speed is being used or that the drill requires resharpening. A plentiful supply of the recommended cutting fluid must be applied to the centre drill and workpiece.

## Countersinking

Making a cone-shaped enlargement at the entrance of a drilled hole for the purpose of providing a seat for the head of a countersunk screw, a bearing surface in the work for a centre lathe, or a recess in which the end of a rivet may be spread, is called countersinking.

Figure 23 shows the common countersinking drill used for this purpose. For large holes a countersink having a pilot to fit the previously drilled hole is necessary to keep the drill true and to prevent chatter (see Fig. 24).

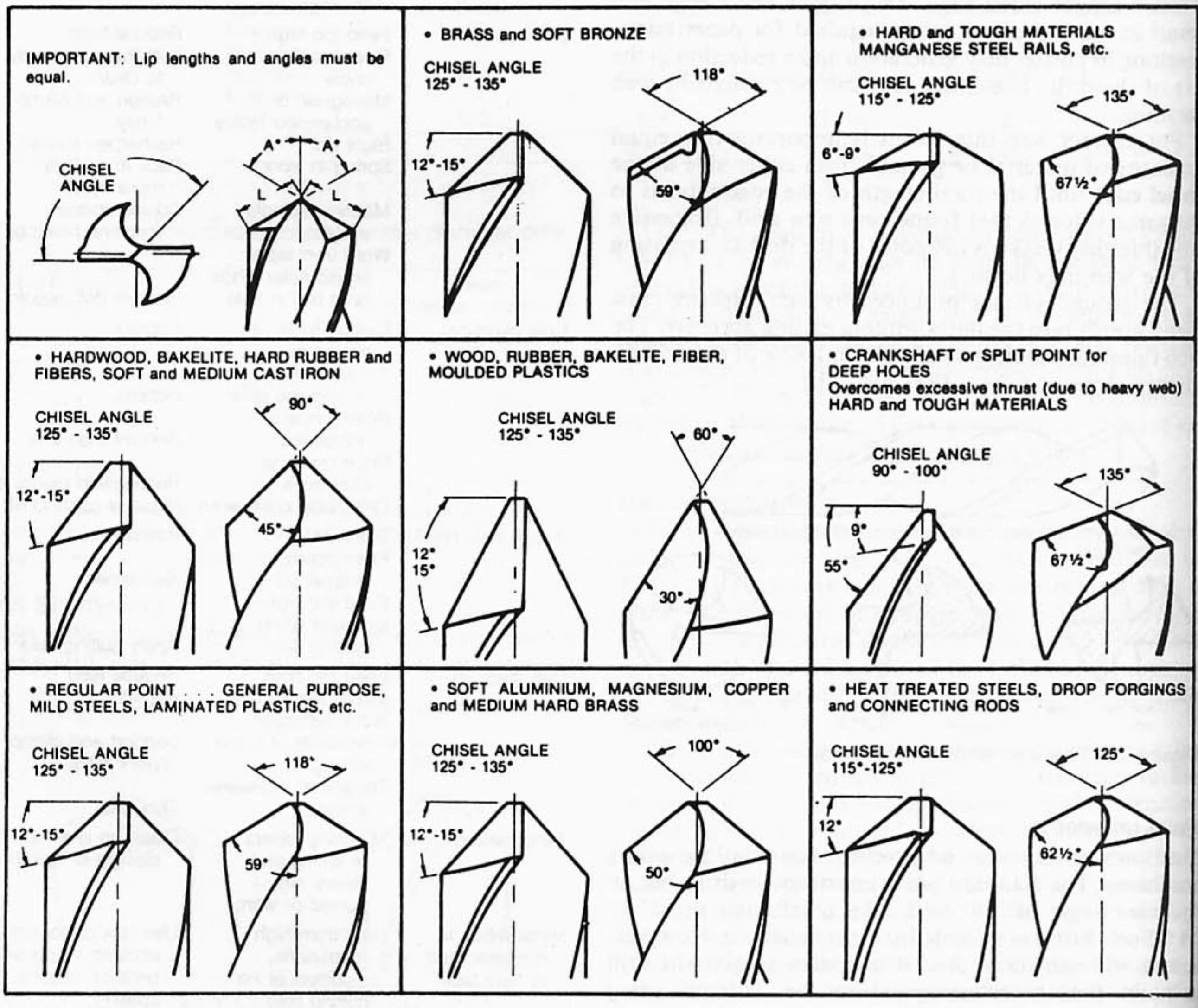



**Figure 21** Point geometry for various materials

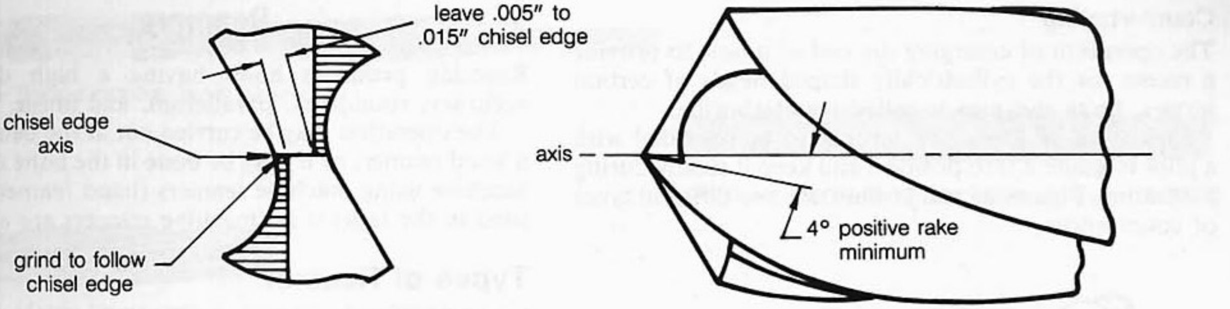



**Figure 22** Geometry of the split point

Table 6 Recommended speeds for centre drilling

| Material | Speed (feet/ min) | Speed (metres/ min) | Number size of centre drill 1 | 2 | 3 | 4 | 5 | 6 | 7 | Cutting fluid |
|---|---|---|---|---|---|---|---|---|---|---|
| Aluminium and its alloys | 250 | 76 | 20537 | 15278 | 10213 | 7640 | 5093 | 3820 | 3055 | Kerosene and soluble oil |
| Brass & bronze, ordinary | 225 | 69 | 18382 | 13750 | 9191 | 6876 | 4582 | 3438 | 2749 | Dry |
| Bronze, high-tensile | 110 | 34 | 8986 | 6722 | 4493 | 3361 | 2246 | 1680 | 1344 | Dry |
| Iron cast: | | | | | | | | | | |
| Soft | 100 | 30 | 8170 | 6111 | 4085 | 3056 | 2037 | 1528 | 1222 | Dry, air blast |
| Medium | 75 | 23 | 6112 | 4584 | 3056 | 2292 | 1528 | 1146 | 917 | or |
| Hard (chilled) | 15 | 4.6 | 1224 | 918 | 612 | 459 | 306 | 229 | 183 | Soluble oil |
| Malleable | 85 | 26 | 6944 | 5194 | 3472 | 3598 | 1732 | 1208 | 1039 | Soluble oil |
| Monel metal or high nickel steel | 40 | 23 | 3268 | 2445 | 1634 | 1222 | 815 | 611 | 489 | Mineral lard oil |
| Plastics | 200 | 61 | 16340 | 12222 | 8170 | 6112 | 4074 | 3056 | 2444 | Dry |
| Steels: | | | | | | | | | | |
| Mild .2–.3C | 95 | 29 | 7761 | 5806 | 3880 | 2902 | 1938 | 1451 | 1161 | Soluble or |
| Mild .4–.5C | 75 | 23 | 6112 | 4584 | 3056 | 2292 | 1528 | 1146 | 917 | Sulphurized oil |
| Tool | 55 | 17 | 4493 | 3361 | 2246 | 1680 | 1123 | 840 | 672 | Sulphurized oil |
| Forgings | 45 | 14 | 3676 | 2750 | 1838 | 1375 | 917 | 687 | 550 | Sulphurized oil |
| Alloy | 25 | 7.6 | 2042 | 1527 | 1021 | 762 | 509 | 382 | 305 | Sulphurized oil |
| High tensile: | | | | | | | | | | |
| 35–40 Rc. | 35 | 10.7 | 2860 | 2138 | 1430 | 1070 | 713 | 534 | 428 | Sulphurized oil |
| 40–45 Rc. | 30 | 9.1 | 2452 | 1833 | 1226 | 917 | 611 | 458 | 367 | Sulphurized oil |
| 40–45 Rc. | 20 | 6.1 | 1634 | 1222 | 817 | 611 | 407 | 306 | 244 | Sulphurized oil |
| Stainless steel: | | | | | | | | | | |
| Free machining | 55 | 17 | 4493 | 3361 | 2246 | 1680 | 1123 | 840 | 672 | Sulphurized oil |
| Work hardening | 35 | 10.7 | 2860 | 2138 | 1430 | 1970 | 713 | 534 | 428 | Sulphurized oil |

Table 7 Recommended feed rates for centre drilling

| Drill number | Feed (inches per revolution) | Feed (millimetres per revolution) |
|---|---|---|
| No. 1 to 4 | .001 to .003 | .025 to .076 |
| No. 4 to No. 6 | .002 to .006 | .051 to .152 |
| No. 6 to No. 7 | .004 to .010 | .102 to .254 |

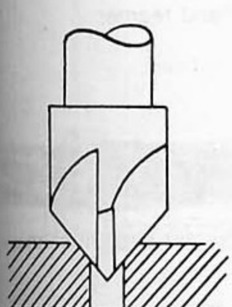


**Figure 23** Countersink

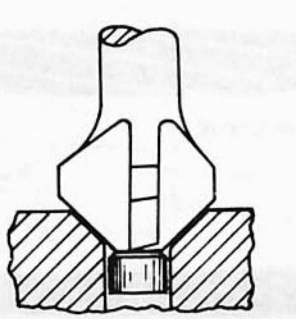


**Figure 24** Countersink with pilot

### Counterboring

The operation of enlarging the end of a hole to provide a recess for the cylindrically shaped heads of certain screws, bolts and pins is called counterboring.

It is essential for a counterbore to be provided with a pilot to guide it into position and keep it steady during the cutting. Figures 25 and 26 illustrate two different types of counterbore.

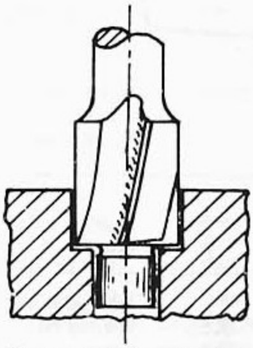


**Figure 25** Counterboring

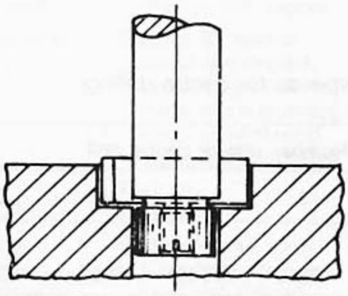


**Figure 26** Inserted cutter type of counterbore

### Spot facing

The operation of facing the surface around the end of a hole to provide a flat seat for a bolt head, the shoulder on a shaft, or similar fitting, is called spot facing (Fig. 27).

Spot facing may be performed using some counterboring tools.

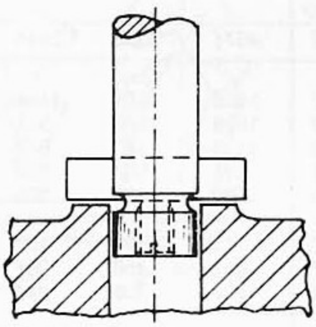


**Figure 27** Spot facing

# Reamers

Reaming produces holes having a high degree of accuracy, roundness, parallelism, and finish.

The operation may be carried out at the bench, using a hand reamer, or it may be done in the lathe or drilling machine using machine reamers (hand reamers may be used in the lathe if no machine reamers are available).

## Types of Reamer

### Hand Reamers

Hand reamers (Fig. 28) are right-hand cutting tools with left-hand helical flutes. The cutting end of the hand reamer is ground with a starting taper to provide easy entry of the reamer into the hole. The reamer is operated by using a tap wrench on the square-ended shank.

### Adjustable Hand Reamers

As the name implies, adjustable hand reamers are adjustable for diameter (Fig. 29). They are invaluable in the jobbing shop where a part is required to have a bore of non-standard size, for example a $\frac{1}{2}$ in. reamer can be adjusted from $\frac{15}{32}$ in. to $\frac{17}{32}$ in. (12 to 13.5 mm).

### Machine Reamers

Machine reamers (Fig. 30) also are right-hand cutting tools with left-hand helical flutes; they have a 45° bevel lead, and a morse taper shank.

### Chucking Reamers

Chucking reamers (Fig. 31) also are right-hand cutting tools with left-hand helical flutes and a 45° bevel lead. They are designed for use in drill presses, turret lathes and automatic machines.

### Taper Pin Reamers

Taper pin reamers (Fig. 32) have a taper of $\frac{1}{4}$ inch per foot and are designed to ream holes for standard taper pins. The best results are obtained if the hole to be reamed is drilled a few thousandths of an inch smaller than the small diameter of the finished ream hole. The point of each reamer will enter the hole reamed by the next smallest size.

**Figure 28** Hand reamer

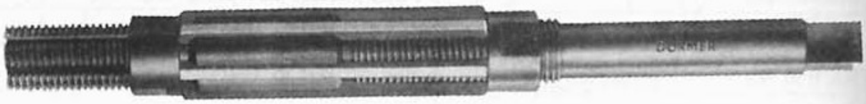


**Figure 29** Adjustable hand reamer

**Figure 30** Machine reamer taper shank

**Figure 31** Chucking reamer straight shank

**Figure 32** Taper pin hand reamer


**Figure 33** Bridge reamer taper shank


**Figure 34** Morse taper socket reamers—roughing


**Figure 35** Morse taper socket reamers—finishing

### Bridge Reamers

Bridge reamers (Fig. 33) have been specifically designed for reaming rivet and bolt holes in structural iron and steel work. The cutting end of the flutes is tapered to permit the reamer to enter holes that are out of alignment, thus facilitating the reaming operation.

### Morse Taper Socket Reamers

Morse taper socket reamers (Figs 34 and 35) are right-hand cutting tools with left-hand helical flutes. Both roughing and finishing types are available.

### Shell Reamers

The shell reamer (Fig. 36) is a short reamer, approximately twice as long as its diameter, and made in sizes of 1 in. to $2\frac{1}{2}$ in., with a tapered bore and driving slot enabling it to be mounted onto a suitable shank for machine reaming. The cutting lead is the same as that of a machine reamer and the flutes are backed off or cylindrically ground. Cylindrical grinding is also referred to as rose grinding.

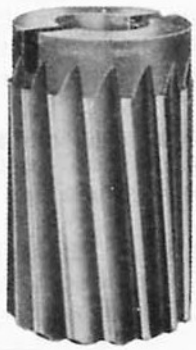


**Figure 36** Shell reamer

### Adjustable Machine Reamer

Many types of single-blade, two-cutting-edge reamers are available for machine reaming, mainly in mass production applications. Three of the many designs are illustrated in Figures 37, 38 and 39.

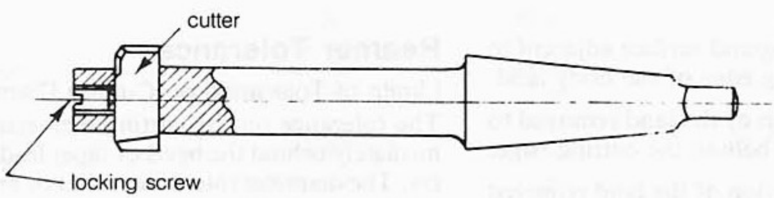


**Figure 37** Double-ended cutter

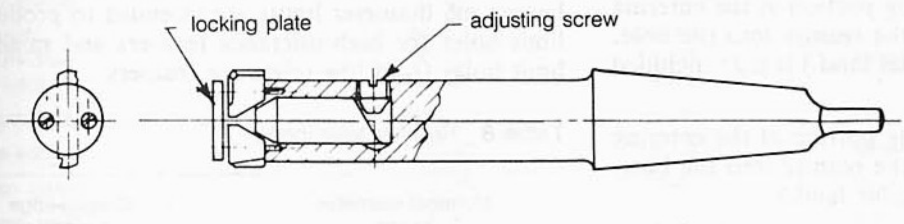


**Figure 38** Adjustable double-ended cutter

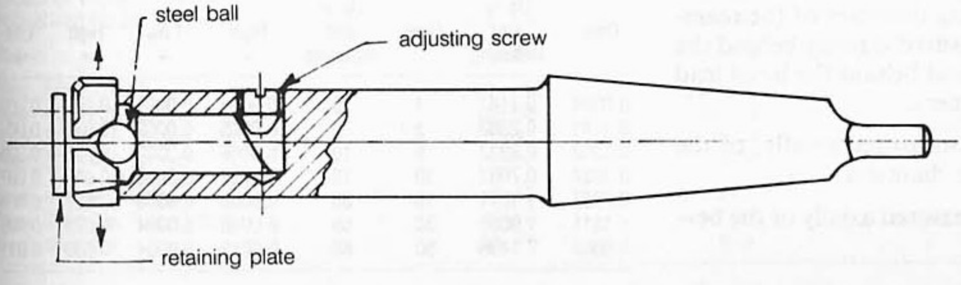


**Figure 39** Floating double-ended cutter

## Reamer Nomenclature (Figs 40 and 41)

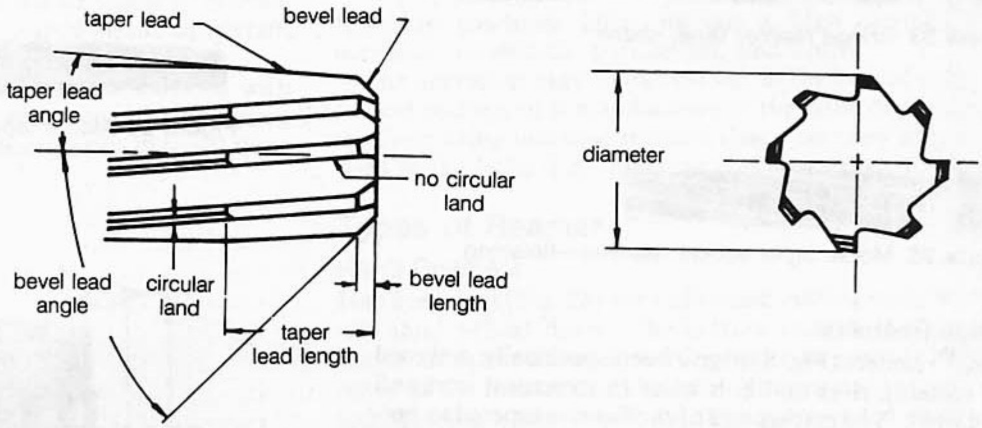



**Figure 40** The important features of a hand reamer

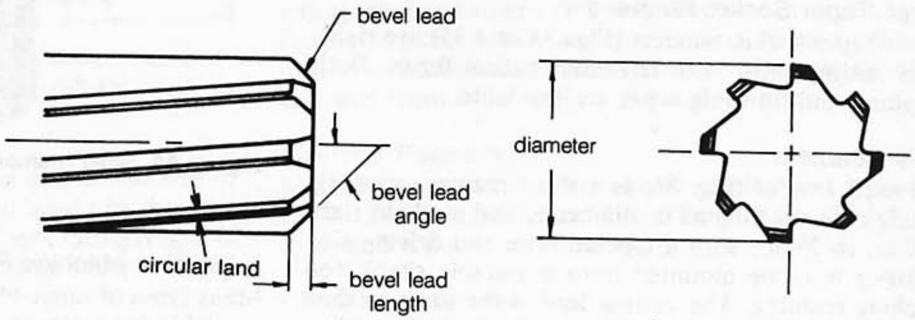



**Figure 41** The important features of a machine reamer

Circular land The cylindrical ground surface adjacent to the cutting edge, on the leading edge of the body land.

Primary clearance That portion of the land removed to provide clearance immediately behind the cutting edge.

Secondary clearance That portion of the land removed to provide clearance behind the primary clearance.

Taper lead The tapered cutting portion at the entering end to facilitate the entry of the reamer into the hole. (It is not provided with a circular land.) It is 2° included angle.

Bevel lead The angular cutting portion at the entering end to facilitate the entry of the reamer into the hole. (It is not provided with a circular land.)

Back taper The reduction in diameter of the reamer from the entering end towards the shank.

Diameter The maximum cutting diameter of the reamer at the entering end. It is measured directly behind the tapered lead on hand reamers and behind the bevel lead on machine and chucking reamers.

Taper lead length The length, measured axially, of the taper lead, usually $1\frac{1}{2}$ times the diameter.

Bevel lead length The length measured axially of the bevel lead.

## Reamer Tolerances

### Limits of Tolerance on Cutting Diameter

The tolerance on the cutting diameter is measured immediately behind the bevel or taper lead for parallel reamers. The diameter tolerance is that of an m6 shaft to British Standard 1916, as stated in B.S. 122: Part 2: 1964, also Australian Standard B43, Part 2-1967. Reamers having m6 diameter limits are intended to produce H8 limit holes for high-tolerance reamers and smaller H7 limit holes from low-tolerance reamers.

Table 8 Reamer tolerances

| Nominal diameter range (inches) | | (mm) | | Cutting-edge diameter (inches) | | (mm) | |
|---|---|---|---|---|---|---|---|
| Over | Up to and including | Over | Up to and including | High + | Low + | High + | Low + |
| 0.0394 | 0.1181 | 1 | 3 | 0.0004 | 0.0001 | 0.009 | 0.002 |
| 0.1181 | 0.2362 | 3 | 6 | 0.0005 | 0.0002 | 0.012 | 0.004 |
| 0.2362 | 0.3937 | 6 | 10 | 0.0006 | 0.0002 | 0.015 | 0.006 |
| 0.3937 | 0.7087 | 10 | 18 | 0.0007 | 0.0003 | 0.018 | 0.007 |
| 0.7087 | 1.1811 | 18 | 30 | 0.0008 | 0.0003 | 0.021 | 0.008 |
| 1.1811 | 1.9685 | 30 | 50 | 0.0010 | 0.0004 | 0.025 | 0.009 |
| 1.9685 | 3.1496 | 50 | 80 | 0.0012 | 0.0004 | 0.030 | 0.011 |

## Operation of Reamers

The conditions under which reamers are used vary considerably and the figures given in the following paragraphs are intended as a guide only.

### Correct Hole Size

The correct amount of stock must be left for removal by the reamer if true holes with good surface finish are to be produced. For machine reaming, 0.15 to 0.25 mm (0.006 to 0.010 inch) for reamers up to 10 mm ($\frac{3}{8}$ inch) diameter and 0.25 to 0.4 mm (0.010 to 0.015 inch) for reamers 10 to 25 mm ($\frac{3}{8}$ inch to 1 inch) is generally satisfactory. For these sizes, and particularly those larger, the amount of stock required is determined by such factors as type of material, feed, finish required, depth of hole and chip capacity of the reamer.

For hand-reaming stock, allowances are much smaller and a nominal allowance would be 0.075 to 0.15 mm (0.003 to 0.006 inch).

### Avoid Chatter

Reamer chatter must be eliminated to obtain the best results in finish and size. While the geometry of a reamer includes features to reduce the probability of chatter, lack of rigidity in the machine jig or holder, or an excessive distance between the holder and the work, will promote chatter (the material being cut will also affect chatter). Some ways to reduce chatter include: reducing the speed, increasing the rigidity of the tool holder, chamfering the entering end of the hole, using a piloted reamer, reducing the angle of clearance.

### Selecting Speeds and Feeds

Speeds and feeds for reaming are governed by the finish required, the material, rigidity of set-up and the cutting fluid used.

Generally, the feed is two to three times, and the speed two-thirds to three-quarters that of a drill of the same diameter.

When close tolerances and fine finish are required, it may be necessary to finish reaming at considerably slower speeds than normal.

The amount of feed required will vary with the material being cut. A good starting point is between 0.025 and 0.10 mm (0.001 and 0.004 inches) per tooth per revolution.

Too low a feed may result in glazing, excessive wear, and occasionally chatter. Too high a feed tends to reduce the accuracy of the hole and may lower the quality of the surface finish.

It is recommended that the highest feed to produce the required finish and accuracy be used. Table 9 lists recommended speeds and cutting fluids.

### Avoid Reversing

Reamers are intended to be passed through the work: never reverse the rotation of the reamer, even when withdrawing from the work.

Table 9 Recommended speeds and cutting fluids for reaming

| Material | Speed (ft/min) | Speed (m/min) | Cutting fluid |
|---|---|---|---|
| Aluminium | 150–200 | 46–61 | Kerosene, kerosene and oil, or soluble oil |
| Aluminium alloys | 135–160 | 41–49 | |
| Brass, free cutting leaded | 140–200 | 43–61 | |
| Brass | 120–160 | 37–49 | |
| Bronze, ordinary | 130–200 | 40–61 | Soluble oil or lard oil |
| Bronze, high-tensile | 45–65 | 14–20 | |
| Cast iron, soft | 70–110 | 21–34 | Dry or compressed air |
| Cast iron, medium | 55–75 | 17–23 | |
| Cast iron, hard | 50–70 | 15–21 | |
| Cast iron, chilled | 15–25 | 5–8 | |
| Copper, soft | 80–130 | 24–40 | Kerosene, soluble or sulphurized oil |
| Copper, medium | 45–65 | 14–20 | |
| Copper, hard | 30–45 | 9–14 | |
| Magnesium and magnesium alloys | 150–250 | 45–76 | Dry or compressed air |
| Malleable iron | 50–60 | 15–18 | Mineral oil or soluble oil |
| Maganese copper | 10–15 | 3–5 | Soluble oil or sulphurized oil |
| Manganese steel | 8–12 | 2–4 | Sulphurized oil |
| Monel metal | 25–40 | 8–12 | Soluble, lard, or sulphurized oil |
| Phosphor bronze, soft | 140–170 | 43–52 | Soluble lard or lard oil |
| Phosphor bronze, medium hard | 100–130 | 30–40 | Soluble oil |
| Plastic | 65–80 | 20–24 | |
| Steel, free cutting | 80–100 | 24–30 | Soluble oil or sulphurized oil |
| Steel, 100–200 Brinell | 65–85 | 20–26 | |
| Steel, 200–300 Brinell | 30–45 | 9–14 | |
| Steel, 300–400 brinell | 20–30 | 6–9 | |
| Steel, over 400 Brinell | 8–15 | 2–5 | Sulphurized oil |
| Steel, stainless, free cutting | 40–50 | 12–15 | |
| Steel, stainless | 20–30 | 6–9 | |

## Sharpening of Reamers

When resharpening reamers, grind only the lead at the leading end, ensuring that the original angle of clearance is maintained. Care should be taken so that each tooth is ground exactly even, as any lack of concentricity or unevenness in the position of the chamfer will promote rapid tool wear, poor finish and oversize cutting.

## Storage of Reamers

Storage and handling of reamers when not in use should be given particular attention. Since they are delicate tools, easily damaged, they should be transported and stored in containers with separate compartments for each reamer. They should be covered with a good rust preventive compound when not in use.

# 17

# Threading tools

## Taps and dies

### Tap Range

#### Hand Taps—Chrome steel

Chrome steel taps are manufactured from high-quality chromium tool steel. The threads are formed using precision-ground circular rolls. The flutes are polished to give a smooth cutting surface and sharp cutting edges. After heat treatment the chamfer lead is machine-ground very precisely to ensure even cutting and quality threads. (Fig. 1.)

**Figure 1** Hand tap

#### Hand Taps—Ground-thread high-speed steel

Ground-thread hand taps have straight flutes and are suitable for both hand and machine operation in materials in which the chips break up readily and present no disposal problems. (Fig. 2.)

**Figure 2** Hand tap ground thread

#### Gun Nose Taps

Gun nose ground-thread taps are designed for through-hole machine tapping at higher speeds than those used for straight fluted taps. This tap is also known as a chip-driver or gun tap because the chips are driven ahead of the tap by the cutting action. This tap has shallow flutes and therefore is stronger than a straight fluted tap. The ejection of chips ahead of the tap allows a free flow of cutting fluid to the cutting chamfer.

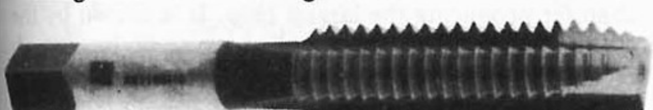


**Figure 3** Gun or chipdriver tap

#### Spiral Fluted Taps

Ground-thread spirally fluted taps are designed for the machine tapping of blind holes. The right-hand fast spiral flutes direct the swarf back out of the hole and minimize clogging at the cutting chamfer. This tap is particularly recommended for tapping materials that present chip disposal problems with straight fluted taps, and for holes that may incorporate a keyway slot or gap in the hole to be threaded. (Fig. 4.)

**Figure 4** Spiral fluted tap

#### X-press Taps

Ground-thread X-press taps produce a cold-formed internal thread. The absence of chips helps to eliminate tap breakages. X-press taps are stronger than fluted taps, which is especially important in the smaller sizes. Stronger threads are produced, and better control of the tapped hole size is possible because this type of tap cannot be forced into lead error, or tap oversize when changes occur in machine or operator feed pressures. These taps are recommended for copper, brass, die castings, aluminium, leaded low-carbon steel, magnetic iron and other ductile materials. (Fig. 5.)

**Figure 5** X-press tap–fluteless

#### Nut Taps

Ground-thread nut taps are designed for the machine tapping of nuts, and the length of thread to be tapped should not exceed one and a half times the thread diameter. The long shank is smaller than the minor diameter of the nut, and this allows for the nuts to pass onto the tap shank for storage purposes. The tap is designed for passing through the work, and reversing of the tap is not recommended. (Fig. 6.)

**Figure 6** Nut tap

### Sets of Taps

Taps are normally used in sets of three to allow progressive cutting of the threads. Hand taps are used for most general work. Each set consists of a taper, an intermediate and a bottoming tap. All the taps in a set have identical lengths and thread measurements and only the tapered lead is different. (See Fig. 7.)

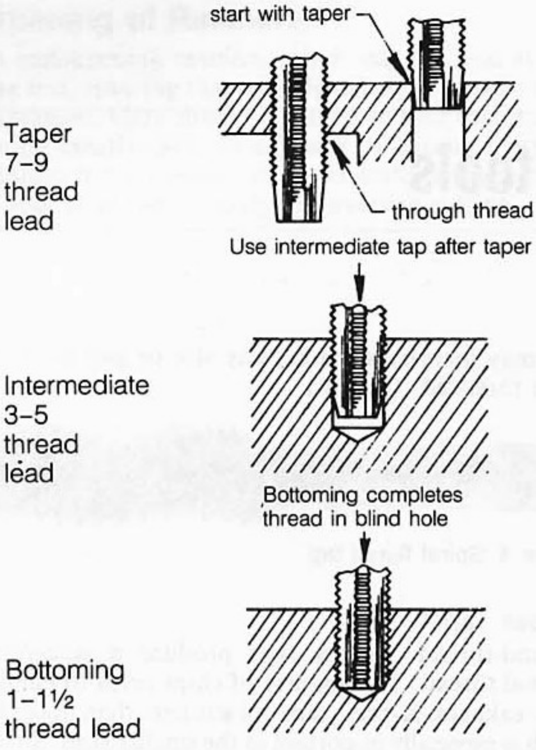



**Figure 7** The three tap types

Always use the taper tap to start the thread. Through holes can be completely threaded with the taper tap.

Always use the intermediate tap to follow in the holes that are not completed by the taper tap. Use the intermediate tap in deep through holes and in blind holes.

Use the bottoming tap to complete the thread to the correct depth in a blind hole.

## Tap Nomenclature (See Fig. 8)

Back taper A back taper is a slight taper on the threaded portion of the tap, making the pitch diameter near the shank smaller than that at the chamfer.

Basic This is the theoretical or nominal standard size from which all variations are made. Nut and therefore tap sizes are always larger than basic, bolt sizes always smaller.

Chamfer lead The chamfer lead is the tapered and relieved cutting teeth at the front end of the threaded section. Common types of chamfer are taper, intermediate and bottoming.

Flute This refers to the longitudinal channels formed on a tap to create cutting edges on the thread profile.

Hook face This is a concave face of the land (see below). It may be varied for different materials and conditions.

Land The land is one of the threaded sections between the flutes of a tap.

Major diameter This is the largest diameter of the screw, nut or tap on a straight screw thread.

Minor diameter This is the smallest diameter of the screw, nut or tap on a straight screw thread.

Pitch Pitch is the distance from a point on one thread to a corresponding point on the next thread, measured parallel to the axis.

Pitch diameter The pitch diameter on a straight screw thread is the diameter of an imaginary cylinder where the width of the thread and the width of the space between threads is equal.

Rake This is the angle of the cutting face of the land in relation to an axial plane intersecting the cutting face at the major diameter.

Relief Refers to the condition created by removing metal from behind the cutting edge to produce clearance and reduce friction.

Shank A shank is that portion of the tap by which it is held and driven.

Spiral point This is an oblique cutting edge ground into the lands to provide a shear cutting action on the first few threads.

Square This is the squared end of the tap shank for driving purposes.

Thread This refers to the helical formed tooth of the tap, which produces the thread in a tapped hole.

Thread helix angle This is the angle made by the helix of the thread at the pitch diameter, with a plane perpendicular to the axis.

## Tap Sharpening

For best tap performance and longest tap life, the edge of both high-speed steel taps and of chrome steel taps must be maintained in the best condition by correct and frequent resharpening.

To reproduce the original grinding of the tap manufacturer, a tap grinding machine or special purpose attachment is desirable. A new tap should also be used for comparison.

Sharpening is normally needed on the threads of the chamfer, yet at times a touch-up of the cutting edges by grinding in the flutes could be required as well.

A regular resharpening procedure, correctly performed, reduces tapping problems caused by blunt or chipped taps.

### Hints on Tap Resharpening

*Chamfer wear*

Chamfer wear occurs in direct relationship to the work done by each tooth, with the second cutting tooth on the chamfer producing the largest chip. It is shown by the cutting edges being worn, rolled over, or broken. A rechamfering grind when this type of wear first becomes apparent will prolong the life of the tap.

*Chamfer relief*

The accuracy of chamfer relief grinding affects the size of the tapped hole, the hole finish and also the tap life. Cutting relief must be uniformly ground on all lands for the tap to cut to size.

*Hand grinding*

Regrinding by hand is not recommended, unless the alternative is the continued use of very blunt or chipped

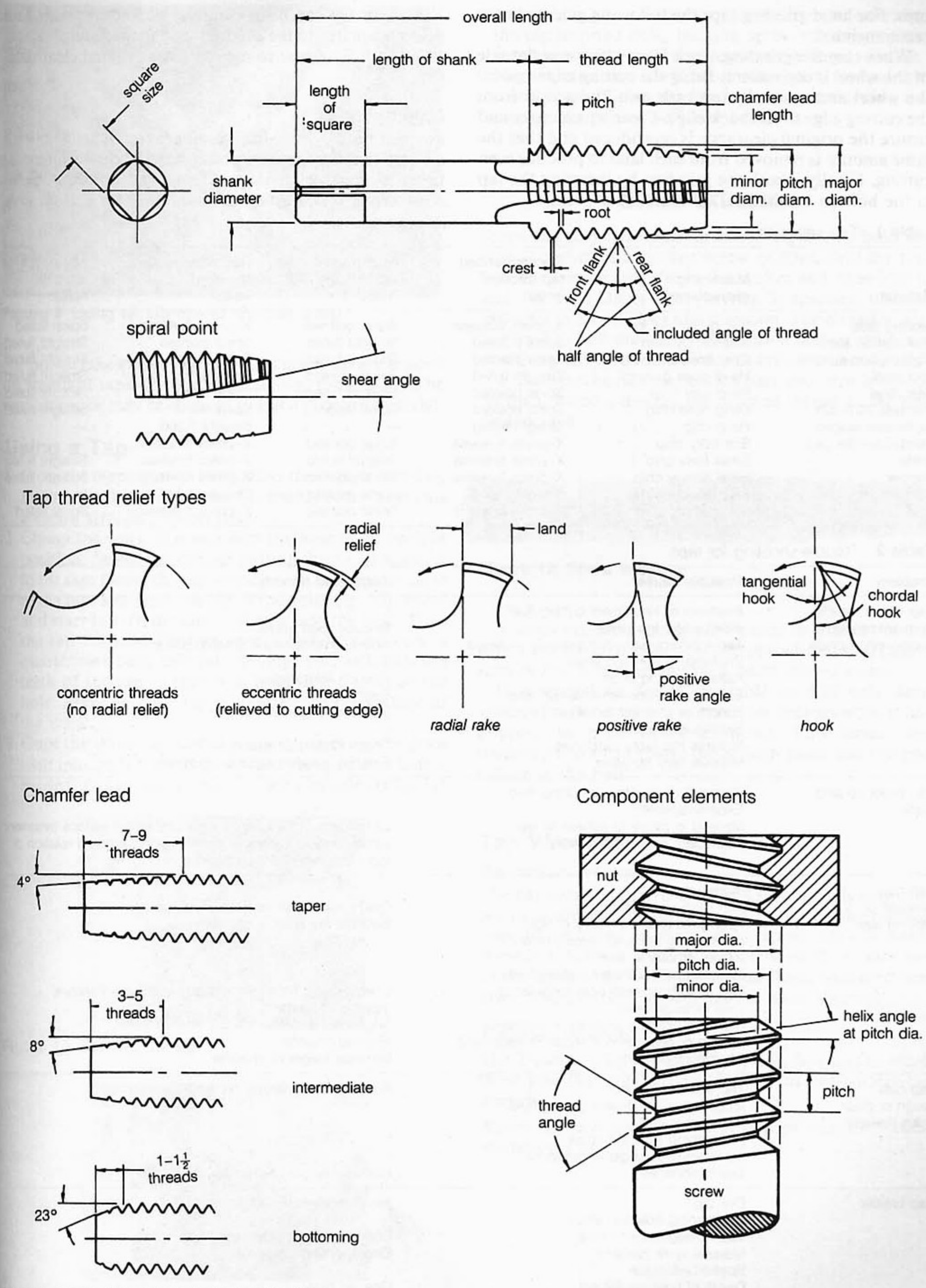



**Figure 8** The important features of a tap

taps. For hand grinding taps the following guidelines are recommended.

When chamfer grinding, work from which ever flat side of the wheel is convenient. Bring the cutting edge against the wheel and move the tap with cam-like action from the cutting edge to the back edge. Clean up chamfer and ensure the original clearance is reproduced and that the same amount is removed from each land to produce even cutting. Finally, check the grinding by inserting the tap in the hole to ensure that all lands bear evenly.

A sharp tap can be maintained by frequent use of an oilstone applied to the chamfer lead immediately it starts to get dull. Use care to maintain the original clearance. (Fig. 9.)

### *Flute grinding*

For best results, machine grinding is recommended (with a set up that is accurately positioned and closely aligned), using a suitable coolant to prevent grinding burn. *Normally a touch-up of the cutting edges is sufficient.*

**Table 1** Tap selection

| Material | Machining characteristics | Recommended tap through holes | Alternative tap through holes | Recommended tap blind holes | Alternative tap blind holes |
|---|---|---|---|---|---|
| Leaded steel | Soft gummy chip | X-press fluteless | Spiral pointed | X-press fluteless | Spiral fluted |
| Low carbon steel | Soft stringy chip | Spiral pointed | Straight fluted | Spiral pointed | Straight fluted |
| High carbon steel | Chip breaks readily | Spiral pointed | Straight fluted | Spiral fluted | Straight fluted |
| Tool steel | Hard close grained | Straight fluted | Spiral pointed | Spiral fluted | Straight fluted |
| Cast steel | Hard wiry chip | Spiral pointed | Straight fluted | Spiral fluted | Straight fluted |
| Stainless 301–321 | Long hard chip | Spiral pointed | Spiral fluted | Spiral fluted | Straight fluted |
| Aluminium–silicon | Hard chip | Straight fluted | — | Straight fluted | — |
| Aluminium–die cast | Soft flaky chip | X-press fluteless | Spiral pointed | X-press fluteless | — |
| Brass | Small flaky chip | X-press fluteless | Straight fluted | X-press fluteless | Straight fluted |
| Copper | Hard stringy chip | X-press fluteless | Spiral pointed | X-press fluteless | Straight fluted |
| Cast iron | Fine powdery chip | Straight fluted | Spiral pointed | Straight fluted | — |
| Zinc die cast | Soft gummy chip | X-press fluteless | Spiral pointed | X-press fluteless | Spiral fluted |

**Table 2** Trouble-shooting for taps

| Problem | Possible cause | Suggested remedy |
|---|---|---|
| Tap wears rapidly, frequent regrinds, cutting edge chips | Incorrect or insufficient cutting fluid | |
| | Relief angle too large | Reduce relief angle |
| | Tap too frequently or carelessly reversed | Advise maintaining a smooth drive |
| | Pre-tapping hole too small | |
| | Rake angle too large | Reduce rake angle |
| | Excessive or uneven chamfer relief | Regrind chamfer |
| | Length of chamfer too short | Increase length of chamfer |
| | Excessive speed | |
| | Material has work hardened | Check drilling operation |
| | Material very abrasive | Select a suitable surface treatment |
| Tap picks up and loads | Incorrect or insufficient cutting fluid | |
| | Excessive speed | |
| | Material is prone to adhere to tap | Obtain technical advice for a suitable tap surface treatment |
| | Insufficient or excessive relief | Increase relief if loading occurs during forward rotation of tap. Reduce relief if on reverse |
| Tap cuts oversize or varying size | Incorrect speed | |
| | Tap running eccentrically | Check tap holder and machine spindle |
| | Feed pressure too heavy or light | Balance the spindle pressure |
| | Pre-tapping holes too small, or out of round, or vary in size | |
| | Incorrect or insufficient cutting fluid | |
| | Tap misaligned with hole (angular or axial misalignment) | Check set-up for alignment and rigidity or improve tapping attachment |
| | Relief on chamfer uneven or excessive | Regrind chamfer |
| | Length of chamfer not equal on each land | Regrind chamfer |
| | Chamfer too short | Increase length of chamfer |
| Tap cuts rough or poor finish threads | Tap dull or chipped | Resharpen; preferably replace with new tap |
| | Incorrect or insufficient cutting fluid | |
| | Incorrect speed | |
| | Pre-tapping hole too small | |
| | Incorrect rake angle for material | |
| | Tap overloaded | Increase length of chamfer |
| Tap breaks | Dull tap | More frequent tap regrinds |
| | Pre-tapping hole too small | |
| | Tap misaligned with hole | Check set-up for alignment and rigidity |
| | Material work hardens | Check drilling operation |
| | Speed unsuitable | |
| | Depth of hole insufficient | Deepen hole |

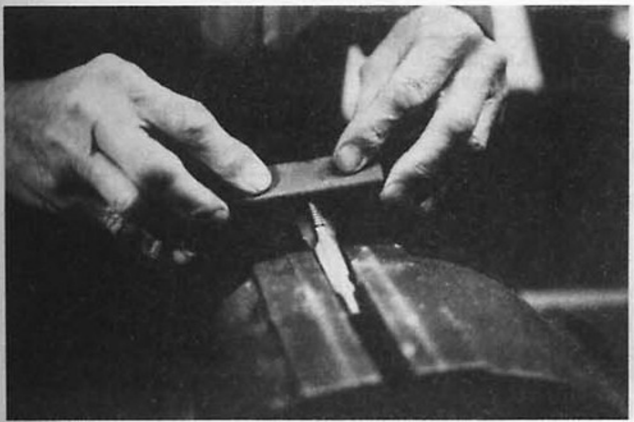


**Figure 9** Using an oilstone to sharpen a tap

Positive rake angles that suit most materials are ground on standard taps. Proved satisfactory, these should be reproduced or may be changed to suit a problem material.

## Using a Tap

1. From the tapping drill charts select the correct drill size. Ensure the drill is sharpened correctly and that it cuts a clean, straight, round hole.
2. Clamp the work in a vice with the hole in an upright position. Select the correct cutting fluid and apply it to the tap. Grasp the tap wrench with both hands close to the tap, and place the tap in the hole (Fig. 10). Press and start to turn the tap clockwise into the hole. Turn the tap forward until resistance is felt, then turn a quarter-turn back to break the chip. This will cause the teeth of the tap to take firm hold in the sides of the hole. Make sure the tap is square with the surface of the work.
3. Once the thread is started properly, the tap will draw itself into the work and downward pressure is no longer needed. Grasp the wrench by both handles (Fig. 11) and, with a slow steady movement, continue turning the tap into the hole, backing up occasionally (when increased resistance is felt) to allow the chips to break. Never force a tap; it will become so tightly wedged that it will break. Using too much pressure and letting the tap get out of line will also break it.

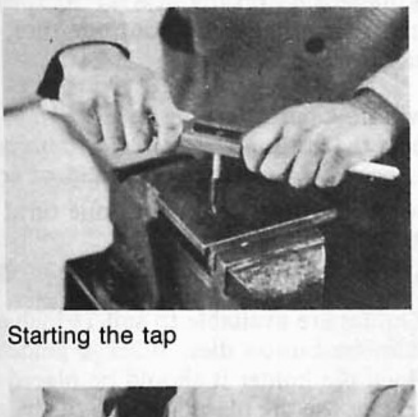


**Figure 10** Starting the tap

**Figure 11** Tapping the hole

## Screw extractors

Screw extractors are used for extracting screws, bolts and pipe. To remove a broken screw or stud, drill the hole to the recommended size in the broken end. (See Fig. 12 and Table 3.) Using a tap-wrench or spanner, turn the extractor in an anticlockwise direction. The extractor does not have to be hammered in because it takes a quick and positive grip, 'feeds' itself into the hole and should 'start' the most stubbornly embedded part and turn it out on its own threads, leaving the original thread in the hole undamaged.

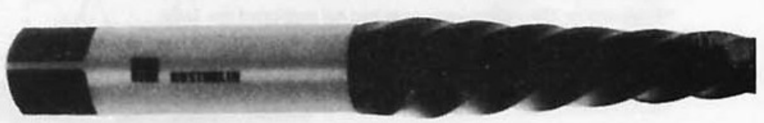


**Figure 12** Screw extractor

A screw extractor should not be used to remove a screw with a left-hand thread, a broken press-fitted stud (interference fit), a broken tap or a badly rusted screw.

It is sometimes found desirable to drill only deep enough for the extractor to reach the bottom when it has gripped the piece to be extracted. This lessens the tendency for it to expand the broken piece and become tighter in the hole.

## Tap Wrenches

### Bar-pattern Wrench

The bar-pattern tap wrench (Fig. 13) is robustly constructed to withstand the torque applied during the tapping operation. Correct selection of the tap wrench will ensure there is a positive holding grip between the square end of the tap and the V-shaped hardened and tempered steel jaws. The knurled handles reduce hand slippage.

### T-pattern Wrench

The T-pattern tap wrench (Fig. 14) is designed to reach those jobs that are inaccessible with the bar-pattern tap wrench.

*Note:* Always use the smallest wrench that will accommodate the tap.

Table 3* Recommended size screw extractor and drill size

| Extractor number | For screws and bolts (inches) | For pipe sizes (inches) | Size drill to use (inches) | Length overall (inches) | Diam. at small end | Diam. at large end | Safe torque load (lbs/ft) |
|---|---|---|---|---|---|---|---|
| 1 | $\frac{5}{32}-\frac{3}{16}$ | | $\frac{5}{64}$ | $2\frac{1}{8}$ | .050 | .159 | 12 |
| 2 | $\frac{7}{32}-\frac{1}{4}$ | | $\frac{7}{64}$ | $2\frac{7}{16}$ | .080 | .205 | 24 |
| 3 | $\frac{5}{16}$ | | $\frac{5}{32}$ | $2\frac{13}{16}$ | .125 | .265 | 54 |
| 4 | $\frac{3}{8}-\frac{1}{2}$ | | $\frac{7}{32}$ | $3\frac{1}{16}$ | .185 | .341 | 60 |
| 5 | $\frac{9}{16}-\frac{3}{4}$ | $\frac{1}{8}-\frac{1}{4}$ | $\frac{19}{64}$ | $3\frac{11}{16}$ | .262 | .495 | 75 |
| 6 | $\frac{7}{8}-1$ | $\frac{3}{8}$ | $\frac{27}{64}$ | $3\frac{15}{16}$ | .390 | .609 | 105 |
| 7 | $1-1\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{17}{32}$ | $4\frac{1}{4}$ | .500 | .742 | 134 |
| 8 | $1\frac{3}{8}-1\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{13}{16}$ | $4\frac{3}{8}$ | .750 | 1.000 | 200 |
| 9 | $1\frac{3}{4}-2\frac{1}{8}$ | 1 | $1\frac{1}{16}$ | $4\frac{5}{8}$ | 1.000 | 1.281 | 266 |
| 10 | $2\frac{1}{8}-2\frac{1}{2}$ | $1\frac{1}{4}$ | $1\frac{5}{16}$ | 5 | 1.250 | 1.562 | 330 |
| 11 | $2\frac{1}{2}-3$ | $1\frac{1}{2}$ | $1\frac{9}{16}$ | $5\frac{7}{8}$ | 1.500 | 1.875 | 396 |
| 12 | $3-3\frac{1}{2}$ | 2 | $1\frac{15}{16}$ | $6\frac{1}{2}$ | 1.875 | 2.312 | 450 |

*To September 1991, the manufacturer had not metricated this Table.

**Figure 13** Tap wrench–bar pattern

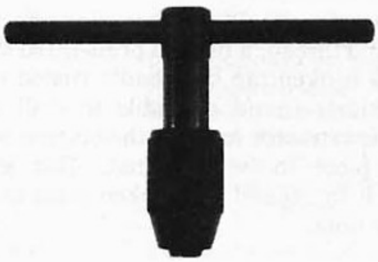


**Figure 14** Tap wrench–T-pattern

# Dies

Dies are made in a wide variety of designs, by a number of different manufacturers.

## Adjustable Button Dies

Button dies are manufactured from high-quality chromium tool steel. Quality thread and size accuracy are assured by the use of precision-ground-thread master taps to produce the threads. All cutting faces are ground after heat treatment to give high performance and quality threads. Button dies are adjustable tools in that the thread sizes can be altered within narrow limits. When ordering, specify the size, thread type and outside diameter of the die. (See Figs 15 and 16.)

### *Adjustment procedures for button dies*

Die holders provide for the die to be placed in either the Continental or American position. (See Fig. 17.)

To mount the die in the die holder, the side screws are rotated anticlockwise until the die can be inserted into the holder, with the V in the die being placed on the centre screw. The side screws are then tightened onto the die until finger tight, the screws entering the dimple holes adjacent to the V slot. The die is now retained in the holder.

The centre screw is now tightened down into the V slot and the side screws nipped tight with a screw driver. The die will now cut to its nominal size.

To increase the cutting size:

1 release the tension on the side screws;
2 screw the centre screw in about one turn;
3 re-tension the side screws.

The die will now cut a larger size.

To reduce the cutting size:

1 release the tension on the side screws;
2 unscrew the centre screw, about one turn;
3 re-tension the side screws.

The die will now cut a smaller size.

Guides Guides are available to suit $1\frac{1}{2}$ inch and 2 inch outside diameter button dies. When a guide is used in a $1\frac{1}{2}$ or 2 inch die holder it should be placed in the die holder first and the die placed on top of the guide with the die size visible. The guide ensures accurate alignment when cutting the thread.

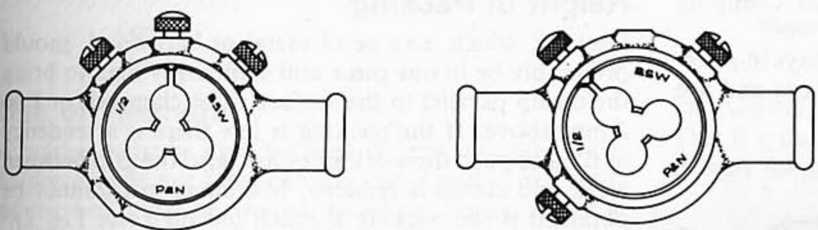
## Die Nuts

Die nuts (Fig. 18) are made of high-quality chromium tool steel to exacting specifications.

The hexagonal shaped die nuts are used with a spanner or wrench for repairing damaged external threads. They are not recommended for cutting an original thread.

**Figure 15** Adjustable button die

**Figure 16** Button die holder or stock




Screws shown in Continental position

Screws shown in American position

**Figure 17** Two types of die holder

**Figure 18** Hexagon die nut

Warragul Dies

Warragul square dies (Fig. 19) are manufactured from high-quality chromium tool steel. The guide is replaceable.

The die holder is robust and the ratchet mechanism is enclosed to minimize entry of dirt or sand. It is designed to allow a quick change-over of dies. Just release a knurled screw on the holder and the die slides out. No adjustments are necessary. Warragul dies are only made for pipe and conduit threads.

## Using a Die

1 First grind or file a small bevel on the end of the rod or pipe to be threaded; this makes starting the die easier. Fasten the work in a vice either vertically or horizontally, depending on the length of the piece. Grasp the die holder with both hands near the die and place the starting side of the die over the end of the rod or pipe (Fig. 20). Select the correct cutting fluid and apply it to the die. Press down firmly on the work and at the same time slowly turn the die clockwise, backing up when resistance is felt just as you do with a tap. Be sure the die goes on squarely.

2 After the thread is started, grasp the die holder by both handles (Fig. 21) and, with a steady forward and backward movement, continue turning the die onto the work, advancing only slightly with each turn. It is no longer necessary to press down because the die will draw itself onto the work when the thread is started.


**Figure 19** Warragul die

**Figure 20** Starting the die

**Figure 21** Cutting the thread

# 18

# Work-holding methods

## Holding work-pieces on machines

Holding the workpiece is an important part of the machining process, because the accuracy of the finished work and the safety of the operator depend on skilful application of the operator's knowledge of clamping equipment and how to use it.

Correct setting-up and clamping avoid delays in resetting, avoid wasteful production of scrap parts and are major safety factors.

## Clamping principles

Clamps are used to hold the work firmly so that it will not fall and will not shift under the cutting action. Stops are used to resist the major cutting forces.

The pressure of the clamps must not be so great as to bend or spring the work. This would produce inaccuracy in the product and also a reduction in the holding power of the clamps.

### Clamping Devices

Screws, cams, levers and pneumatic or hydraulic clamps are the means by which force may be applied and maintained, either directly or through clamp plates.

### Application of Force

Direct application exerts the available force in the required situation and direction.

Clamp plates are used when the force point must be applied away from the workpiece. This may result in some loss of force because of the bending of the clamp plate.

The distribution of the force along a clamp plate is illustrated in Figure 1.

A force of 1200 N exerted by the bolt and nut is distributed along the clamp plate to exert approximately 800 N at the workpiece and 400 N at the packing block.

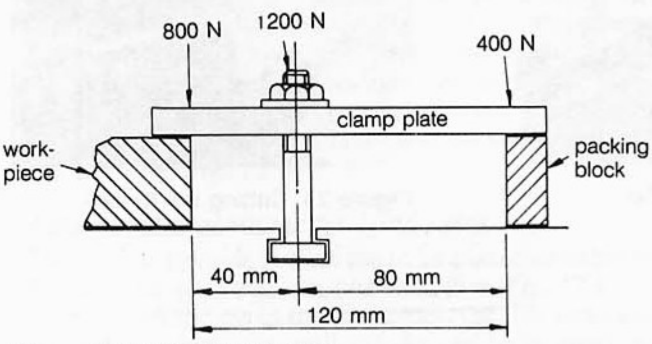



**Figure 1** Application of force

The greater force on the workpiece is a result of having the bolt close to it. This effect is increased as the workpiece is moved closer to the bolt, and the heel further from the bolt.

### Height of Packing

Packing, which may be of metal or hardwood, should preferably be in one piece and sufficiently high to bring the clamp parallel to the surface to be clamped, or 1 to 2 mm above. If the packing is low there is a tendency to tilt and push the work sideways, also the grip between work and clamp is reduced. Maximum grip cannot be obtained if the packing is much too high (see Fig. 2).

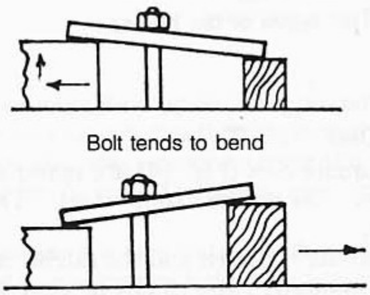



**Figure 2** Incorrect packing height

### Position of Clamps

The clamps must be applied in positions where the work rests on the table, or where the work has been supported on the table by shims, wedges, jacks or parallel strips. (See Fig. 3.) Failure to do this may result in the work moving or springing during the cut, both of which cause inaccuracy. Figure 4 explains why the correct method exerts the most force.

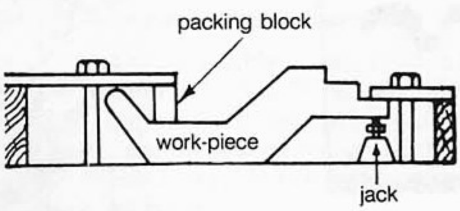



**Figure 3** Supporting the workpiece and clamp

### Thickness of Clamps

The clamp must be sufficiently thick to withstand appreciable distortion when the force of the bolt is exerted. Mild steel clamp plates should be as thick as the bolt diameter and not less than three times as wide.

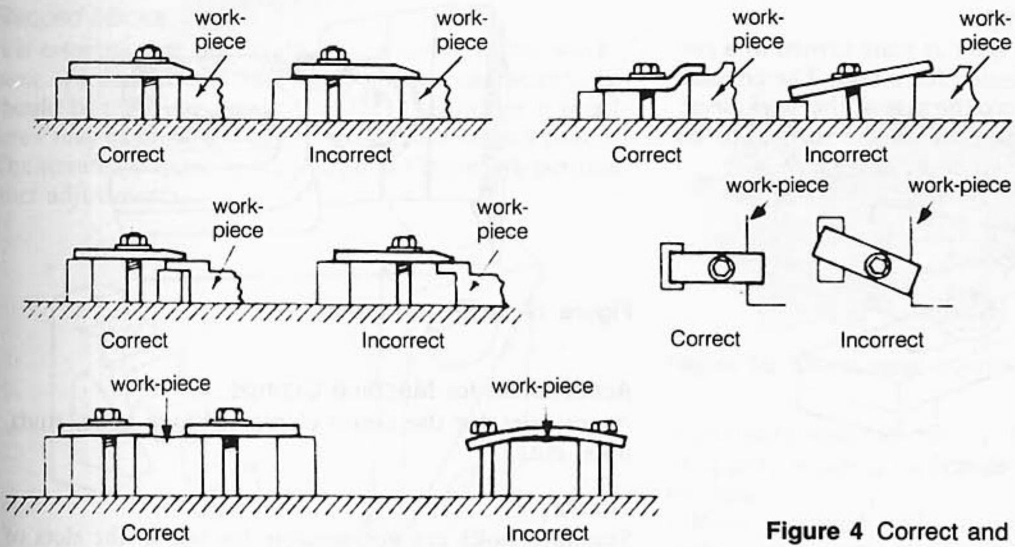



**Figure 4** Correct and incorrect ways of clamping

## Use of Washers

A washer must be used between the nut and the clamp to prevent the nut from moving the clamp. The length of the bolt must be enough to allow the nut and the washer to cover the thread.

## Number of Clamps and Stops

The size and shape of the workpiece, the positions where clamps may be placed, and the direction of the cutting forces will determine the number of clamps to be used.

For 'heavy' machining operations the work should be located against stops, which are set to resist the thrust of the cutting force (see Fig. 5).

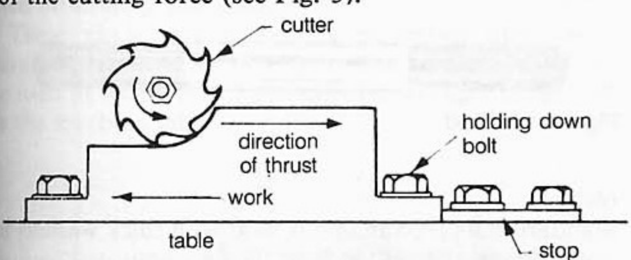



**Figure 5** Stop resists direction thrust

Since the cutting forces are generally the principal forces to be overcome, correctly located stops are important in workpiece fixing. Stops reduce the number of clamps required.

Clamps are placed in positions clear of the path of the cutting tools and moving parts. They must develop enough friction between the workpiece and the machine table to resist those forces that cannot be overcome by the use of stops. A sheet of paper between a machined surface and the table considerably reduces the tendency of the work to slip.

# Types of clamps and accessories

## Clamps for Machining

The type of clamp used depends mainly on the shape of the part and the surface to be machined.

### Flat Clamp

This is a flat plate with a hole or a slot for the bolt. It is used for most plain work (see Fig. 6).

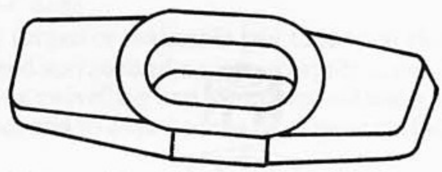


**Figure 6** Forged flat clamp

### Bent Clamp

This clamp is a bent plate with a hole or a slot. The bend sets the head of the bolt below the clamp's surface to avoid interference with the path of the cutting tool (see Fig. 7).

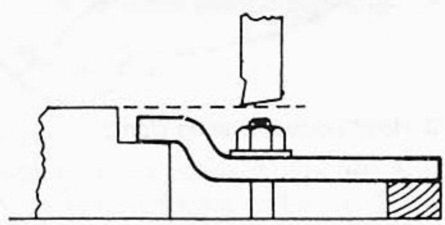


**Figure 7** Use of the bend clamp

### U-clamp

A U-clamp is a flat plate with a slot open at one end so that it can be removed without taking the nut off the bolt (see Fig. 8).

The U-clamp is useful for clamping either side of a drill, which can pass through the slot. Washers must be used under the nut. U-clamps are made from forged spring steel.

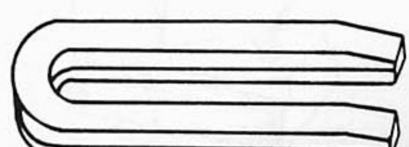


**Figure 8** U-clamp

## Pin Clamp or Finger Clamp

This type of clamp (Fig. 9) is a flat plate turned to a circular pin at one end and slotted for a bolt. The circular end fits into a hole drilled into the side of the workpiece; this permits clamping to be beneath the surface to be machined.

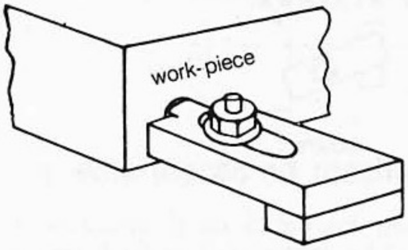



**Figure 9** Application of pin clamp

## Height-compensating Clamp

The height-compensating or 'boat' clamp is an ideal holding-down clamp as its design allows the heel packing to be dispensed with, or it need not be so accurately selected, depending on the thickness of the work (Fig. 10).

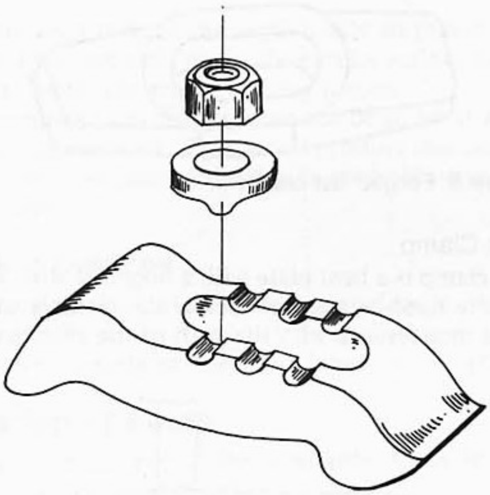


**Figure 10** Height-compensating clamp

## Vice Clamp

The vice clamp is used in a vice-like action on the edge or ends of the work, leaving the surface of the work clear of obstructions. Two types are illustrated (Figs 11, 12). Always use a sheet of paper between the table clamp and the machine table.

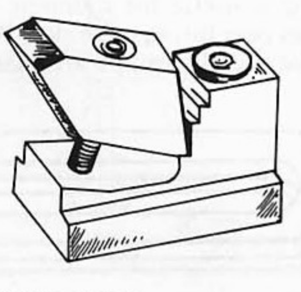


**Figure 11** T-slot vice clamp

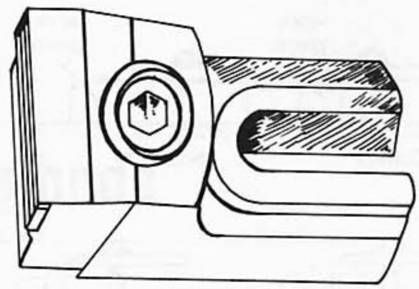


**Figure 12** Table vice clamp

## Accessories for Machine Clamps

Accessories for the above clamps include bolts, studs, nuts, etc.

### *T-bolts*

Standard bolts are not suitable for use in the slots of machine tables; special bolts are necessary. The largest bolts that will fit the T-slots should be selected. The length of thread should allow it to pass through the nut by about 3 to 6 mm (Fig. 13).

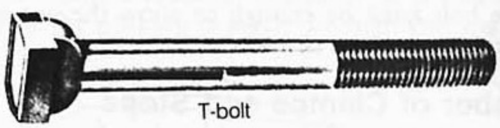



**Figure 13** T-bolt

### *Studs*

A stud (see Fig. 14) is threaded at each end and is used together with T-slot nuts and/or coupling nuts.

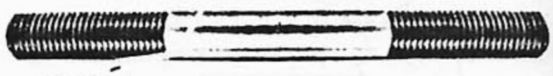


**Figure 14** Stud

### *Nuts*

Standard nuts are suitable if used with thick washers in contact with the slotted hole in the clamp.

Various kinds of special nuts are shown in Figure 15. A flanged nut (Fig. 15a) is sometimes used, but is costly to manufacture.

A T-slot nut (Fig. 15b) into which a stud has been screwed fits into the T-slot.

A coupling nut (Fig. 15c) is used to join studs together for workpieces requiring greater length.

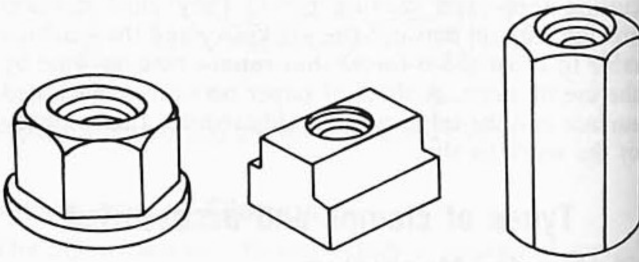



**Figure 15** Types of nut

*Stepped blocks*

It is essential that the clamp acts squarely to the workpiece. To do this, the packing block and the workpiece should be the same height. Parallel packing or a small screw may be used, but stepped blocks are simpler to use. The serrated stepped block shown in Figure 16b permits finer adjustments.

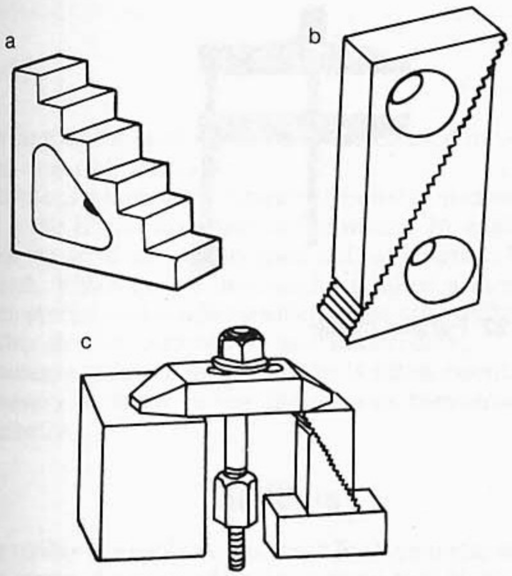



**Figure 16** Stepped blocks

## Machine Vices

### Main Vice

The types of machine vice shown in Figure 17 are often used on drilling machines.

These vices have accurately machined slide faces parallel to the base surface. The slide face can therefore be used to locate the underside of a workpiece parallel to the machine table.

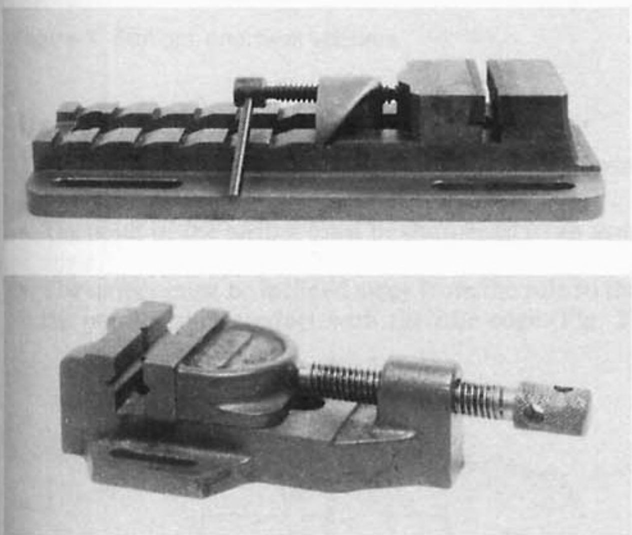


**Figure 17** Two types of machine vice

### Swivel-base Vice

This vice (Fig. 18) has an additional base plate to enable the vice to be swivelled to an angle. Accurate machine

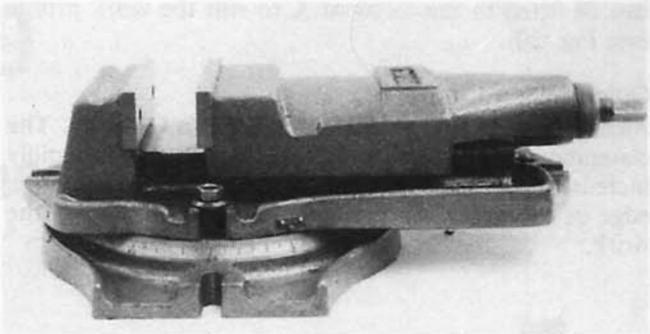


**Figure 18** Swivel base machine vice

vices have a slide face parallel to the base and a hardened fixed jaw, which is surface ground flat and is square to the base.

Both the fixed and the movable jaw pads may be replaced if worn beyond acceptable limits of accuracy.

There are many other designs of machine vice, too numerous to mention here.

## General Purpose Clamps

### C- or G-clamp

This is a forged or malleable cast G-shaped clamp. It has a flat, fixed surface and a screw to apply force. The screw head has a swivelling cap to prevent rotation against the workpiece and to adjust to the workpiece surface (see Fig. 19).

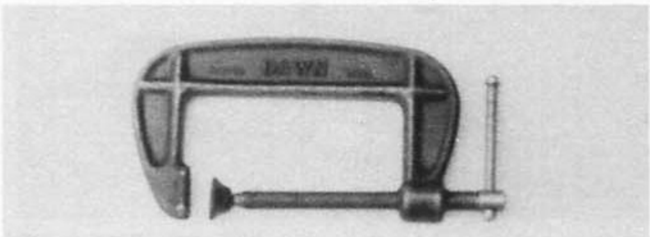


**Figure 19** C- or G-clamp

### Toggle Clamp

Toggle clamps are quick-acting clamps, which are sometimes bolted to the work table or fixture. These clamps are operated by a lever and can exert enough force on the work. A screw at the pressure point can be adjusted to suit the height of the work. Pads of various shapes

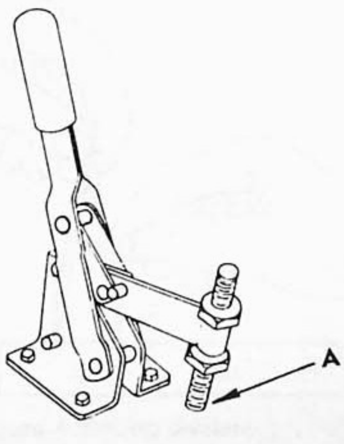



**Figure 20** Toggle clamp

can be fitted to the screw at A to suit the work profile (see Fig. 20).

### Quick Action Clamp

As can be seen in Figure 21, this is like a G-clamp. The clamping screw section can be slid along the bar to rapidly increase or decrease the opening; it engages teeth on the edge of the bar when tightened and securely holds the work.

**Figure 21** Quick action clamp

### Parallel Clamp

This is the clamp more commonly used by the toolmaker and those working on more precise work. The jaws are moved parallel to each other, by holding both screws, one in each hand, and cranking; it can be rapidly opened or closed (Fig. 22).

**Figure 22** Parallel clamp

# 19

# Marking and measuring tools

Marking and measuring tools are often used in conjunction, one with the other.

In the international system of units of measurement (S.I.) the length standard is the metre. In engineering work the most commonly used unit of length is the millimetre, which is one thousandth ($\frac{1}{1000}$) of a metre. For more precise and smaller measurements the millimetre is further divided into tenths and hundredths.

Because accurate measurement is often essential, it is necessary to learn to use the various measuring tools efficiently.

## Scribers

The scriber is a tool used to mark lines on metal surfaces. It is made of hardened and tempered tool steel and has a fine point. To sharpen, grind metal from behind the point and finish the point with an oilstone.

Figure 1 illustrates straight and bent scribers. The bent type is useful in holes, and in positions where a straight scriber cannot be used.

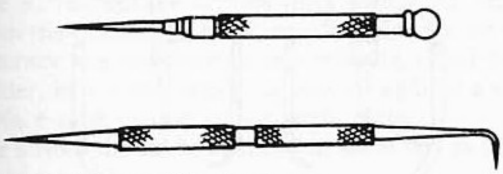


**Figure 1** Straight and bent scribers

### Using a Scriber

To obtain a single, fine, straight line, the following precautions should be taken:

- The point of the scriber must be sharpened to an acute angle.
- The scriber must be inclined away from the rule so that the point makes contact with the rule edge (Fig. 2).

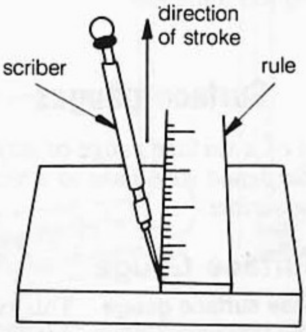



**Figure 2** Scriber inclined away from rule edge

- The scriber should be inclined in the direction of the stroke.
- The stroke should be made with an arm movement rather than with a movement of the wrist or fingers.
- Only one stroke should be made for any one line.

## Dividers

Dividers are used for scribing circles and arcs, dividing lines and circles, and transferring dimensions from the rule to the workpiece. The most common type used for engineering work is the spring divider shown in Figure 3.

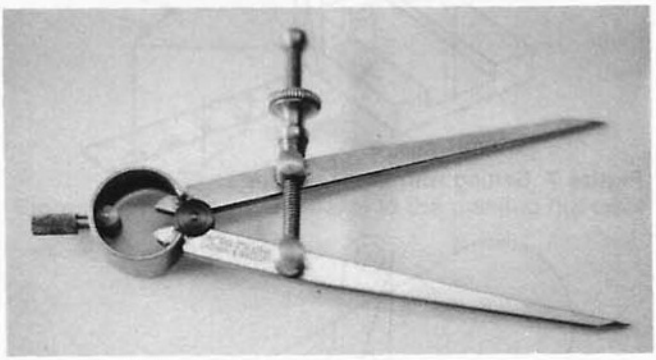


**Figure 3** Spring dividers

Dividers should have sharp, fine points of equal length and should be adjusted as indicated in Figure 4. The points should be set in the centre of the required graduation marks and be kept parallel to the edge of the rule.

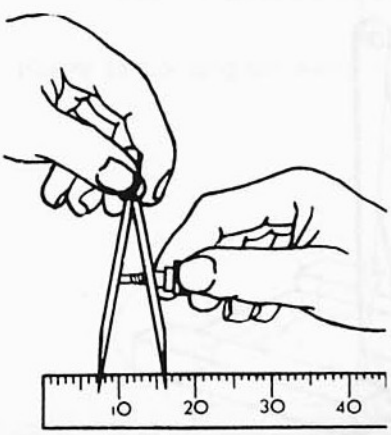



**Figure 4** Setting dividers

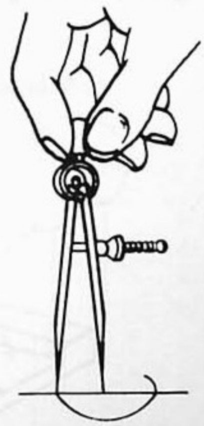


**Figure 5** Using dividers

## Hermaphrodite calipers

These are often referred to as jenny calipers, jennies, or odd legs. They are used for setting out distances from an edge, marking lines parallel to an edge, and for finding the centre of round work. (See Figs 6 to 10.)

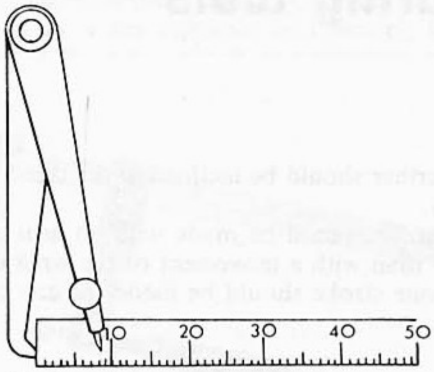



**Figure 6** Setting odd leg calipers

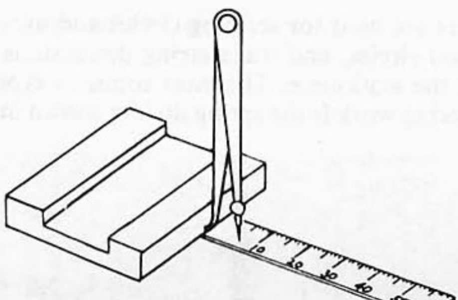


**Figure 7** Setting with legs reversed

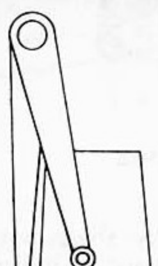


**Figure 8** Scribing a line parallel to an outside edge

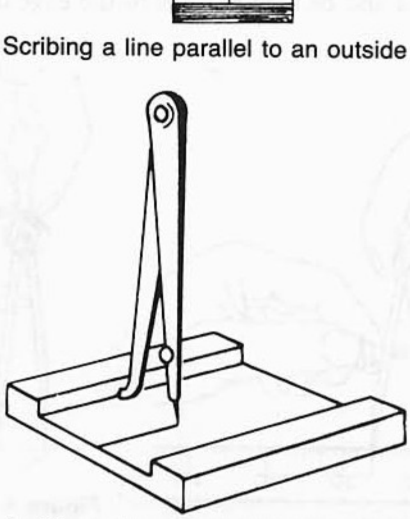


**Figure 9** Scribing a line parallel to an inside edge

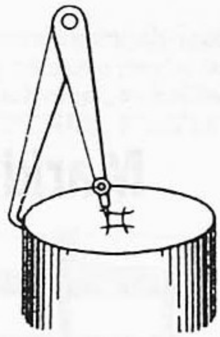


**Figure 10** Locating the centre

## Trammels

Trammels are used for the same purpose as dividers, but for larger dimensions. When provided with interchangeable legs, they may be used as 'odd legs' or calipers. (See Figs 11 to 13.)

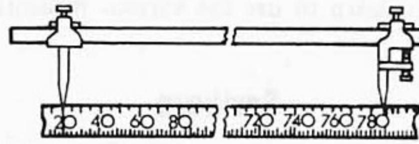



**Figure 11** Setting trammels

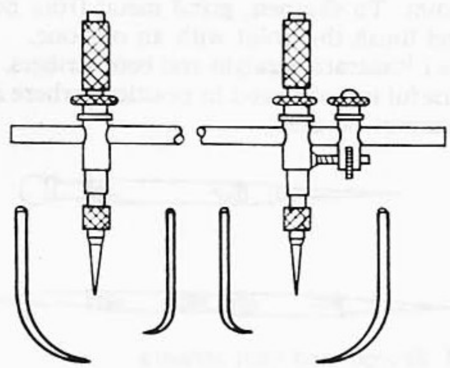


**Figure 12** Rod trammels

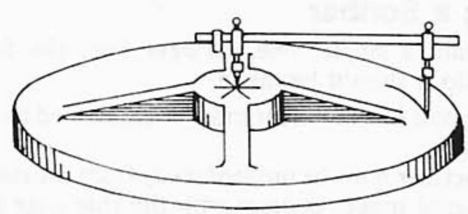


**Figure 13** Using rod trammels

## Surface gauges

The main parts of a surface gauge or scribing block are a cast iron or hardened steel base to which are attached a spindle and a scriber.

### Types of Surface Gauge

**Simple round base surface gauge** This type of gauge is shown in Figure 14a.

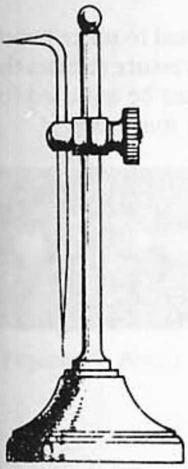


Figure 14a Simple surface gauge

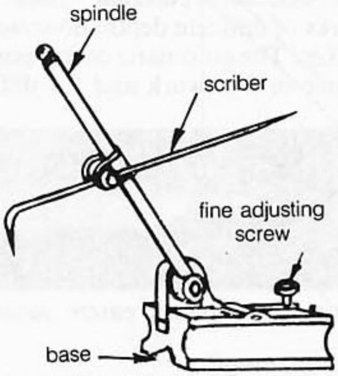



Figure 14b Universal surface gauge

Universal surface gauge This gauge (Fig. 14b) has the following advantages:

- It has a fine adjusting screw, which operates a spring-loaded lever, which pivots about an axis. The spindle, with its scriber, is fitted to the opposite end of the lever.
- The spindle may be adjusted to angular or vertical positions. A vertical groove in the front of the base provides for other spindle positions below the base surface.
- A V-groove along the underside of the base enables the gauge to be located on cylindrical surfaces.
- Pins in the base can be used as a guide on a machined edge.

## Setting a Surface Gauge

1 The surface gauge scribes lines measured vertically from the horizontal marking-off table. So, to ensure accuracy, the rule must be set vertically, either in a rule holder, in a combination square, or against a vertical surface such as that of an angle plate.
2 The scriber should be clamped as short and as horizontal as possible.
3 An approximate setting is made and then the clamping screws are tightened.
4 Finally, the fine adjustment is used to set to the centre of the required graduation.

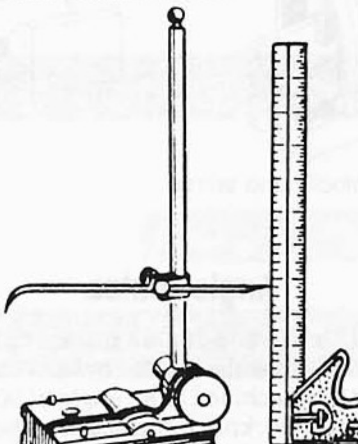


Figure 15 Setting to a combination square

## Using a Surface Gauge to Mark Lines

1 See that the surface of the marking-out table and the base of the surface gauge are clean, so that the surface gauge will slide freely.
2 Keeping the base of the surface gauge firmly in contact with the marking-out table, incline the scriber to cut the line in a dragging action.
3 For single, sharp lines make one stroke only.

## Uses of a Surface Gauge

These are illustrated in Figures 16 to 19.

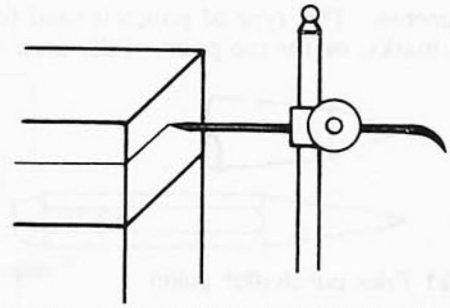


Figure 16 Marking lines parallel to the marking out table

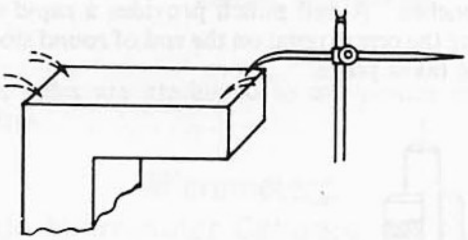


Figure 17 Setting work parallel to the marking out table

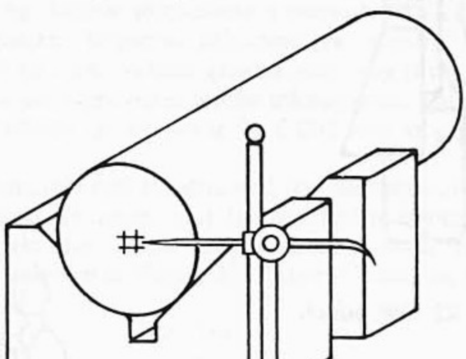


Figure 18 Locating the centre of a round shaft

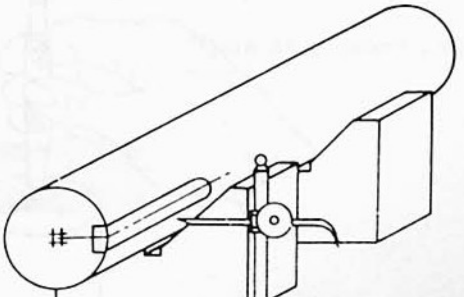


Figure 19 Marking out a keyway

## Punches (Figs 20 to 24)

**Centre punches** These punches are used for marking centre points for drilling.

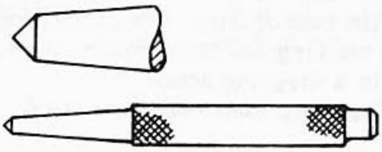


**Figure 20** Centre punch (90° point)

**Prick punches** This type of punch is used for making witness marks, or for the point of dividers.

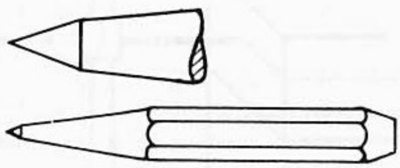


**Figure 21** Prick punch (60° point)

**Bell punches** A bell punch provides a rapid means of marking the centre point on the end of round stock before drilling takes place.

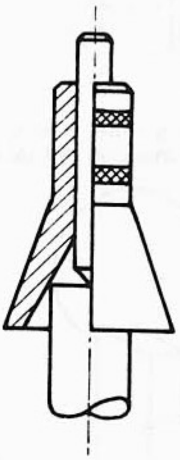


**Figure 22** Bell punch

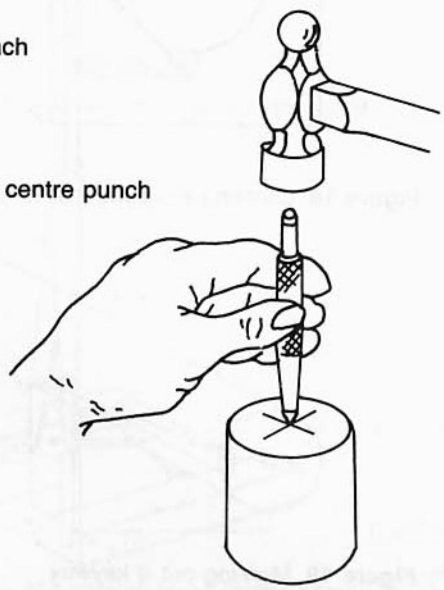


**Figure 23** Using a centre punch

**Automatic centre punches** These are used to make punch marks of uniform depth; downward pressure releases the striker. The automatic centre punch can be adjusted for coarse or fine work and for different materials.

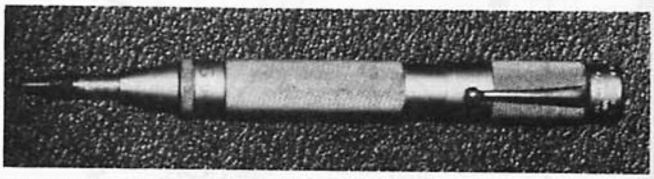


**Figure 24** Automatic centre punch

## Parallel strips

These strips are usually made of steel, hardened and ground flat and parallel. (Fig. 25) They are made in pairs and are used for setting work parallel to a surface, such as that of a marking-out or machine table. They may be obtained in various lengths and cross-sections.

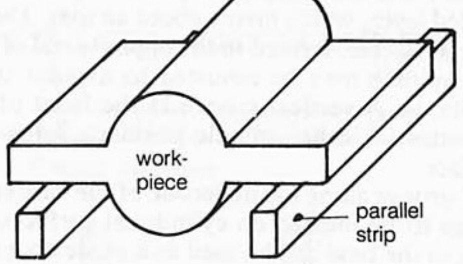



**Figure 25** Work supported on parallel strips

## V-blocks

V-blocks (Fig. 26) are also made in pairs, and are of cast iron or hardened steel. They are used for setting and holding cylindrical work parallel to a marking-out table or a machine table.

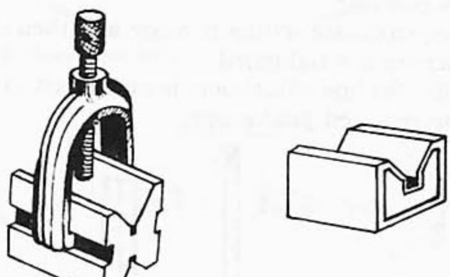


**Figure 26** V-blocks and stirrup

## Angle plates

Angle plates (Figs 27 and 28) are made of cast iron and are usually provided with slots for bolts. The outer faces and the edges are machined to an angle of 90°. They are used to support a workpiece surface at right angles to a marking-out or machine table.

Angle plates can also be used for other machining operations.

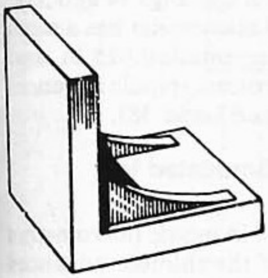


Figure 27 Angle plate

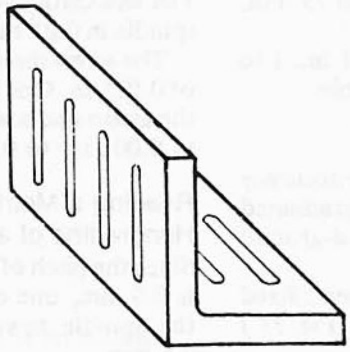


Figure 28 Slotted angle plate

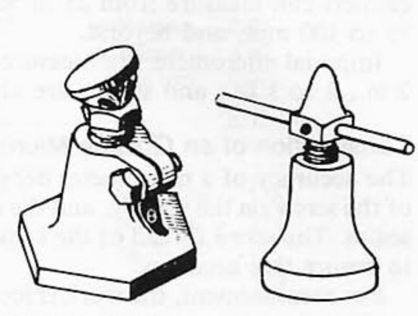


Figure 29 Screw jacks

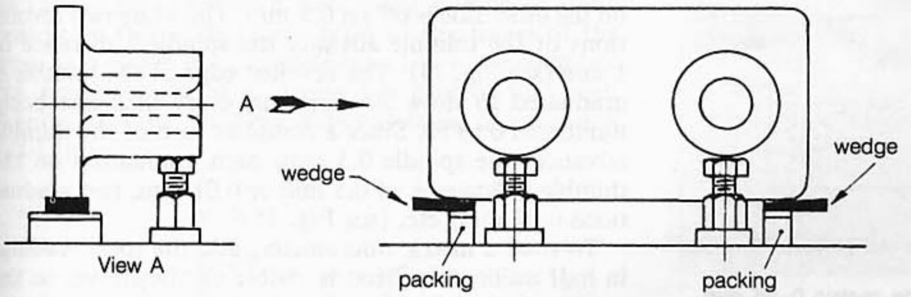



Figure 30 Using screw jacks, wedges, and packing

## Screw jacks

Screw jacks (Figs 29 and 30) are used for similar purpose to wedges to set work on the marking table. They are more easily adjusted, but need more space.

## Steel rules

The simplest tool for measuring is the graduated rule, which, for engineering work, is made of steel.

Common types of steel rule are illustrated in Figures 31 and 32. For general use, metric rules are made in 150 and 300 mm lengths, but may be obtained up to 2 m long. (Imperial rules are in 4, 6, and 12 in. lengths, but may be obtained up to 6 ft long.) For lengths greater than 2 m, steel tapes are used. These may be 3, 10, 15, 20, 30 m in length.

Metric rules are graduated in millimetres and half millimetres.

## Micrometers

### Outside Micrometer Calipers

Micrometers are indispensable tools for accurately measuring. Metric micrometers measure in $\frac{1}{100}$ (0.01) of a millimetre. Imperial micrometers usually measure in $\frac{1}{1000}$ of an inch. Where greater accuracy is required, a vernier scale is provided on the micrometer. This enables measurements to be made in 0.001 mm or $\frac{1}{10\,000}$ of an inch.

Micrometers can be obtained for reading outside and inside measurements, and for measuring depths.

A metric micrometer caliper made to read from 0 to 25 mm is shown in Figure 33. Other outside micrometer

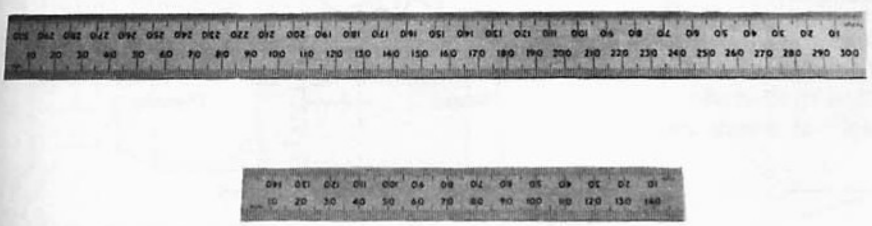


Figure 31 Engineer's steel rules metric

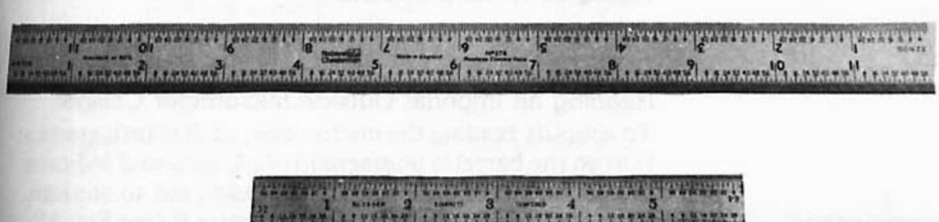


Figure 32 Engineer's steel rules imperial

calipers can measure from 25 to 50 mm, 50 to 75 mm, 75 to 100 mm, and beyond.

Imperial micrometers to measure from 0 to 1 in., 1 to 2 in., 2 to 3 in., and so on, are also obtainable.

### Construction of an Outside Micrometer

The accuracy of a micrometer depends on the accuracy of the screw on the spindle, and the associated graduated scales. The screw thread of the spindle is thread-ground to ensure this accuracy.

For measurement, the work is located between a fixed anvil on the micrometer caliper and the spindle. (Fig. 33.)

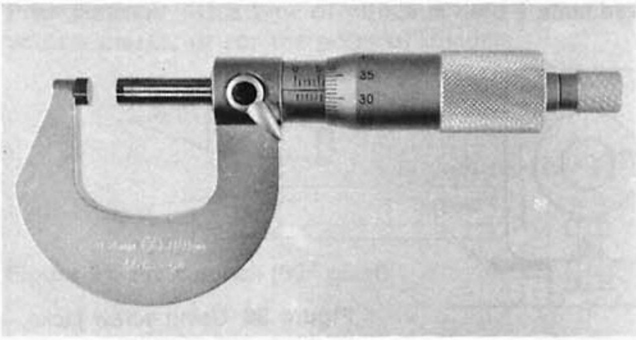


**Figure 33** Micrometer caliper, outside metric 0–25 mm

The workpiece and the measuring surfaces must be clean and close to normal room temperature.

The spindle is closed on the work by means of a thimble or a ratchet, and a light pressure is exerted. In fine measurements this pressure is very important. The ratchet may be used to give a constant pressure, but it must not be assumed that the pressure of the ratchet will always produce an accurate reading.

The screw used in a metric micrometer has a pitch of 0.5 mm. One turn therefore advances the spindle 0.5 mm.

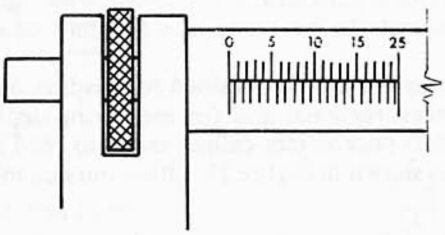



**Figure 34** Metric micrometer sleeve graduations

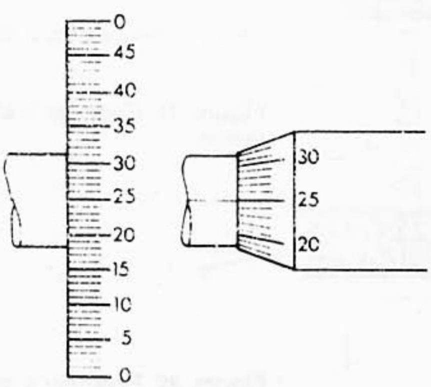



**Figure 35** Metric micrometer thimble graduations

The associated scales indicate parts of one turn of the spindle in 0.01 mm to each 0.5 mm (see Figs 34 and 35).

The screw thread in an imperial micrometer has a pitch of 0.025 in. One turn advances the spindle 0.025 in. and the associated scales are used to indicate spindle advances in 0.001 in. to 0.025 in. (see Figs 37 and 38).

### Reading a Metric Micrometer Graduated in Hundredths of a Millimetre

Since the pitch of the spindle screw in metric micrometers is 0.5 mm, one complete turn of the thimble advances the spindle towards or away from the anvil exactly 0.5 mm.

The longitudinal line on the sleeve is graduated on one side in millimetres from 0 to 25 mm, and each millimeter on the other side is off-set 0.5 mm. Therefore two revolutions of the thimble advance the spindle a distance of 1 mm (see Fig. 34). The bevelled edge of the thimble is graduated to show 50 divisions, every fifth line being numbered 0 to 50. Since a complete turn of the thimble advances the spindle 0.5 mm, each graduation on the thimble indicates $\frac{1}{50}$ of 0.5 mm or 0.01 mm; two graduations 0.02 mm; etc. (see Fig. 35).

To read a metric micrometer, add the total reading, in half millimetres, that is visible on the sleeve, to the reading, in hundredths of a millimetre, indicated by the graduation on the thimble that coincides with the longitudinal line on the sleeve.

*Reading 5.78 mm*

| | |
|---|---|
| *Example:* Refer to Figure 36. The 5 mm graduation is visible, representing: | 5.0 mm |
| There is one additional 0.5 mm line visible, representing: | + 0.5 m |
| Line 28 on the thimble coincides with the longitudinal line on the sleeve, each thimble line representing 0.01 mm; 28 × 0.01 mm: | + 0.28 mm |
| The micrometer reading is: | 5.78 mm |

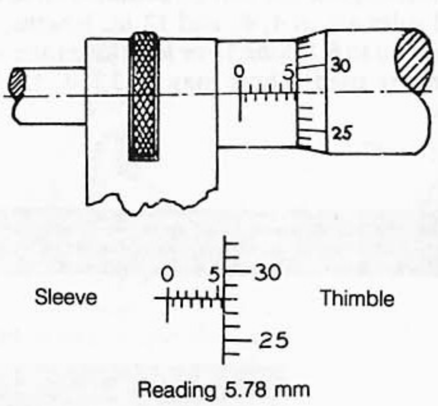



**Figure 36** A metric micrometer

### Reading an Imperial Outside Micrometer Calliper

To simplify reading the micrometer, each fourth graduation on the barrel is numbered 1, 2, 3, etc., and indicates measurements of 0.1 in., 0.2 in., 0.3 in., etc. to one inch. Each intermediate graduation indicates 0 (see Fig. 37).

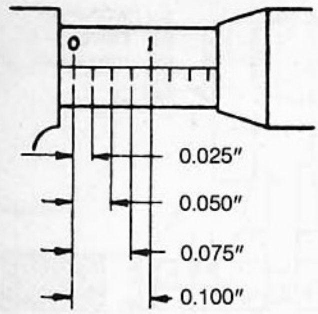



**Figure 37** Imperial micrometer, graduations on sleeve

The bevelled edge of the thimble is divided into 25 equal parts (Fig. 38), each fifth part being numbered. One division on this scale represents $\frac{1}{25}$ of the travel of the screw, as it makes one complete turn. Since one complete turn represents $\frac{25}{1000}$ of an inch, it is evident that each division on the thimble represents $\frac{1}{1000}$ of an inch (0.001 in.).

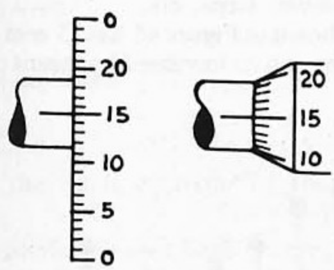



**Figure 38** Imperial micrometer, graduations on thimble

*Reading to 0.283 in.*

| | |
|---|---|
| *Example:* Refer to Figure 39. The $\frac{2}{10}$ in. graduation is visible on the barrel scale representing: | 0.200 in. |
| Beyond this mark, three $\frac{1}{40}$ in. divisions are visible each of 0.025 in., 3 × 0.025: | + 0.075 in. |
| Line 8 on the thimble coincides with the longitudinal line on the barrel, each line representing 0.001 in., 8 × 0.001 in: | + 0.008 in. |
| The micrometer reads | 0.283 in. |

(For further examples, see Fig. 40.)

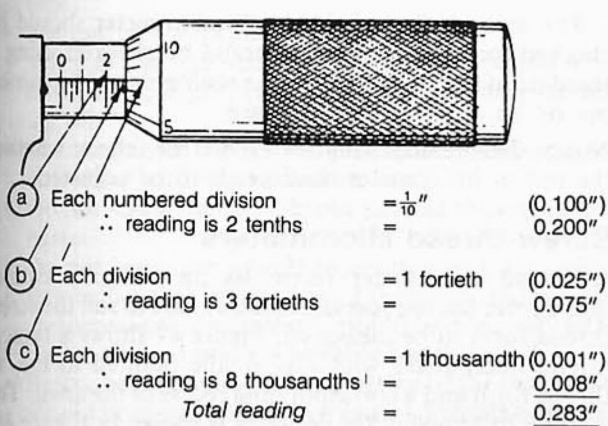



**Figure 39** How to read an imperial micrometer

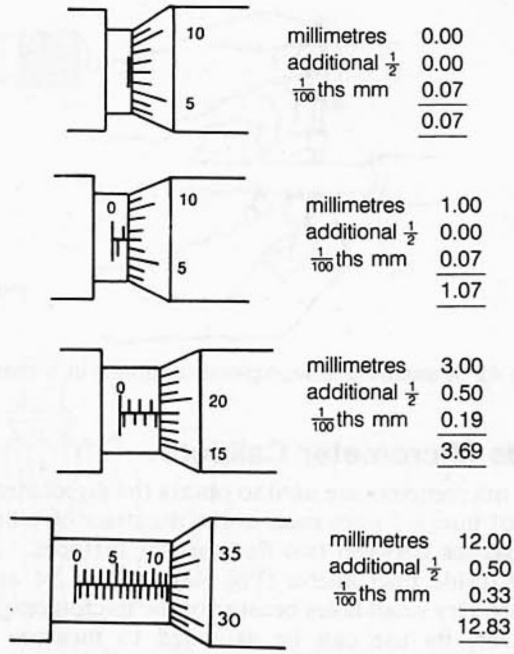



**Figure 40** Examples of metric micrometer readings

## Using an Outside Micrometer

The ability to take accurate measurements using a micrometer depends on the correct application of the micrometer to the workpiece and to the development of correct feel.

Feel when using a micrometer is the ability to apply a micrometer to a workpiece by turning the thimble, so that, without strain, the faces of the spindle and the anvil are parallel to and in contact with the surfaces of the workpiece.

Constant practice is the only way to develop the correct feel. Until the operator is skilled in using a micrometer, the same piece, measured at the same place several times, may give a different reading each time.

Remember also that excessive force can result in strain in the screw, distortion of the frame, and rapid wear generally.

Some micrometers are fitted with a ratchet, the use of which reduces differences in personal touch. More accurate measurements may be made using the ratchet, provided that the micrometer is kept square to the work faces. Since the accuracy of measurement is dependent on feel, it is wise to compare the reading obtained with a known standard.

Methods of holding and applying outside micrometers are shown in Figures 41 and 42.

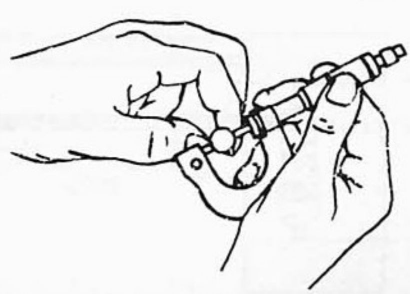


**Figure 41** Measuring a workpiece held in the hand

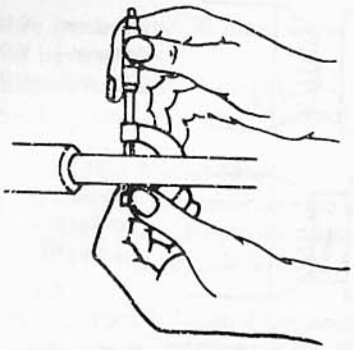


Figure 42 Measuring a workpiece mounted in a machine

## Inside Micrometer Calipers

These micrometers are used to obtain the direct measurement of internal sizes such as the diameter of a hole or the distance between two flat parallel surfaces.

The inside micrometer (Fig. 43), cannot be used to measure very small holes because of the micrometer body. However, its use can be extended to measure large diameter holes by selecting the appropriate extension rod and sleeve.

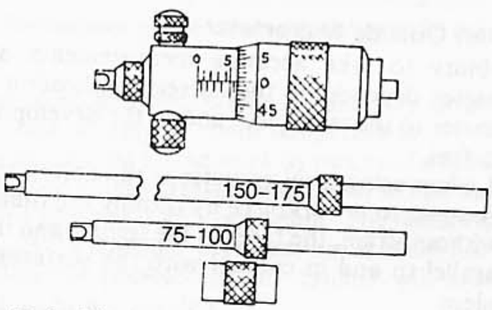



Figure 43 Inside micrometer with extension rods and sleeve

The inside micrometer should be held lightly, fingers close to each end, one end being allowed to travel slightly when sizing. When it is adjusted correctly there should be only a very gentle feel when the micrometer is at right angles to the axis of the work. Consistency and accuracy will improve with experience.

For holes too small to allow sufficient space for the micrometer to be held in the hand, a handle that can be screwed into the head of the micrometer is provided (see Fig. 44).

Care must be taken when inserting extension rods. The micrometer should also be checked with an outside micrometer of known accuracy, at the size at which it is to be used.

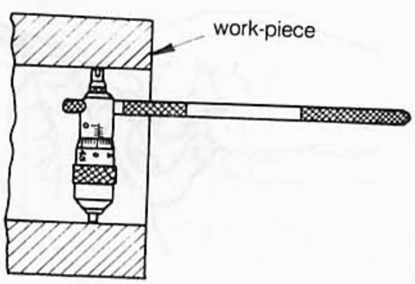



Figure 44 Inside micrometer fitted with a handle

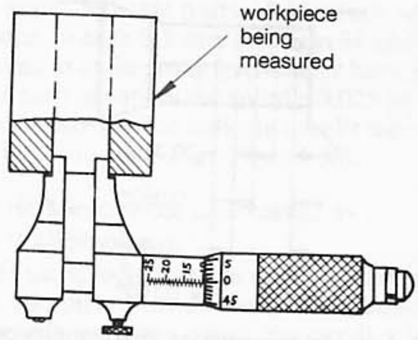



Figure 45 Inside micrometer for small holes

Figure 45 shows a different inside micrometer caliper, which can be used to measure small holes 5 to 25 mm in diameter.

## Micrometer Depth Gauges

This type of micrometer is used to measure the depths of holes, grooves, steps, etc.

The type shown in Figure 46 has 25 mm of movement, but its capacity can be increased by means of interchangeable rods.

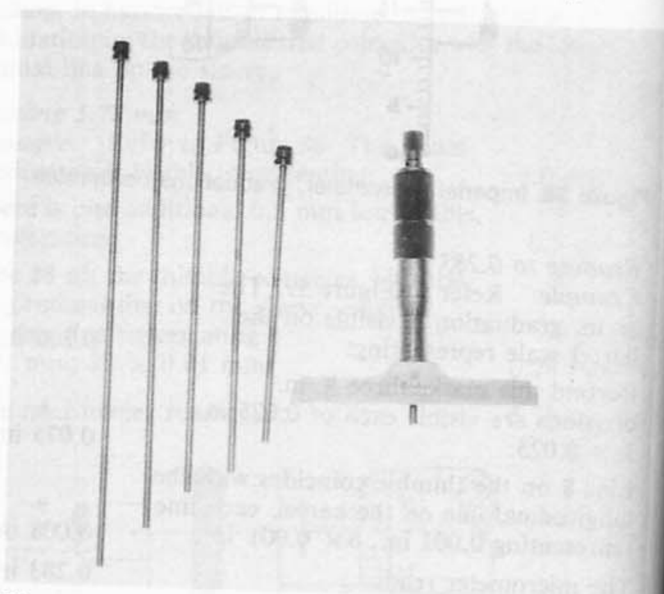


Figure 46 Micrometer depth gauge with extension rods

The zero reading of the depth micrometer should be checked, or the micrometer should be checked using a standard at the required size. The testing should be carried out on an accurately flat surface.

*Note:* Before adjusting for zero error, check whether the rod or micrometer head needs to be adjusted.

## Screw-thread Micrometers

A thread micrometer resembles an ordinary caliper micrometer but has special contacts made to suit the screw thread form to be measured. Figure 47 shows a typical thread micrometer with the spindle pointed to the V-thread form and a corresponding recess in the anvil. The method of applying the contacts is shown in Figure 48.

If correctly adjusted and applied, this type of micro-

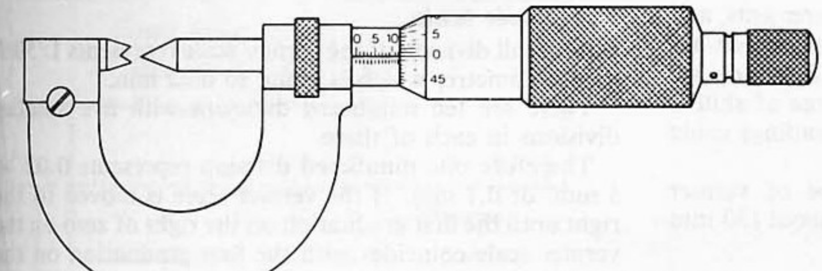



**Figure 47** Screw-thread micrometer

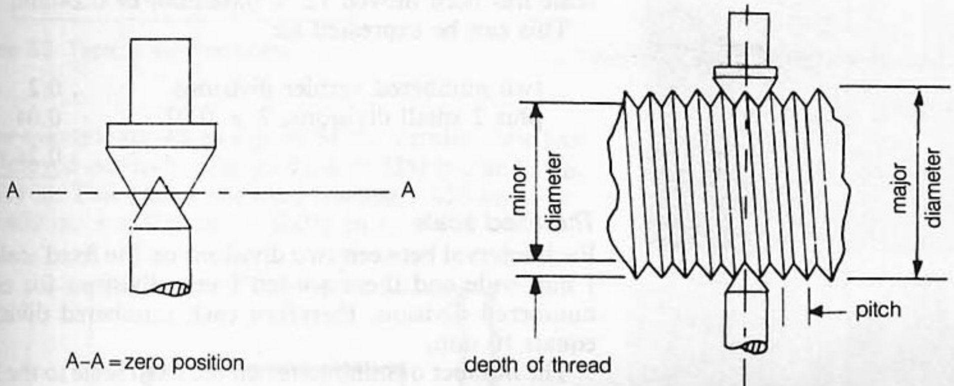



**Figure 48** Methods of applying contacts

meter gives the pitch diameter of the thread being measured.

*Note:* The pervious pages have covered only some of the vast range of micrometer anvil and frame types available.

## Care of a Micrometer

A micrometer is a delicate precision instrument and must be treated accordingly. To obtain satisfactory results and maintain the accuracy of the micrometer, the following points should be observed:

- Before using the micrometer clean the faces of the spindle and the anvil.
- Check the zero reading. If an error exists, either allow for it, or have the micrometer adjusted by the person responsible for this work.
- Be certain that the work is stationary before applying the micrometer, and remember that damage can result from handling a micrometer and other tools at the same time.
- See that the workpiece is clean and dry.
- When in use, the micrometer should be placed where it will not be in grit, cutting fluids, or ordinary lubricating oil.
- Do not handle the micrometer more than necessary, nor allow it to be exposed to heat.
- Do not screw the thimble out beyond the scale on the barrel.
- Do not leave the spindle in contact with the anvil.
- Remember that lubrication of the screw and nut, and any necessary adjustments, should be done only by the person trained and responsible for this work.
- Before being put away, the exterior of the micrometer should be cleaned, and then smeared with a film of the recommended lubricant.
- Micrometers should be stored in such a manner that they are safe from dust, corrosion and damage.

# Verniers

## Principle of a Vernier

The vernier scale is used on measuring instruments such as calipers, height gauges, depth gauges, micrometers, and protractors. Finer measurements than are possible reading the basic scales can be obtained. A tool with a vernier has a fixed or main scale and a moveable vernier scale. Each division on the vernier scale is generally smaller than the corresponding division on the main scale. The difference between two such divisions is the finest measurement that can be obtained using that particular vernier. (Fig. 49.)

The usual difference on a metric vernier is 0.02 mm. On imperial verniers the usual difference is 0.001 in.

## Vernier Calipers

One vernier caliper can replace a number of micrometers, and does not require extension pieces. Further, it is often

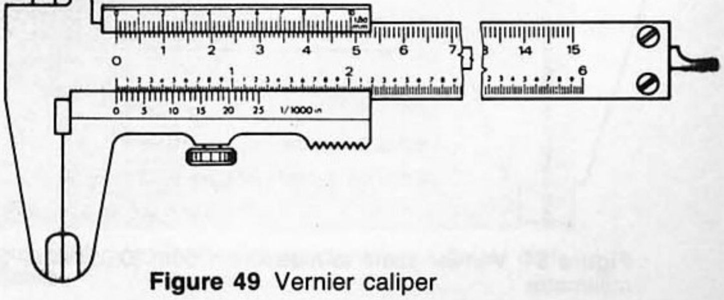



**Figure 49** Vernier caliper

suitable for both external and internal measurements, and can be used in locations such as narrow slots that are inaccessible to micrometers. Micrometers, however, are in many cases preferred, as a greater degree of skill is required to obtain consistently accurate readings using a vernier caliper.

Figure 50 illustrates the common type of vernier caliper. Vernier calipers range in size from about 150 mm to about 1200 mm.

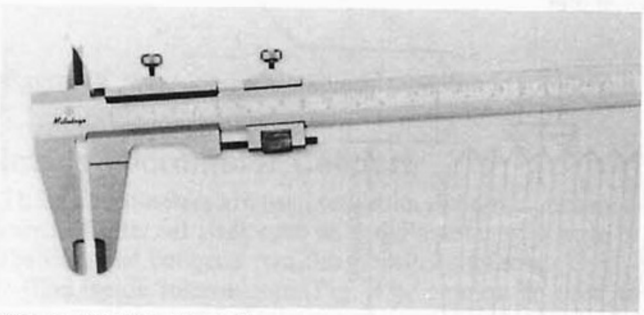


**Figure 50** Vernier caliper

## Using a Vernier Caliper

With the type shown in Figure 50 the procedure is as follows:

1 Move the sliding jaw to the approximate position.
2 Lightly tighten the locking screw on the fine adjustment clamp.
3 Adjust the sliding jaw by means of the knurled fine-adjustment nut until, with the instrument square to the workpiece, the jaws contact the workpiece with a sensitive feel.
4 Lightly tighten the locking screw on the sliding jaw.

In general, the precautions against strain, misuse and faulty storage applying to micrometers are also essential for vernier calipers.

## Reading a Metric Vernier Graduated for Fiftieths of a Millimetre (0.02 mm)

A typical metric vernier scale is shown in Figure 51. The reading is made, using both the vernier and the fixed scale.

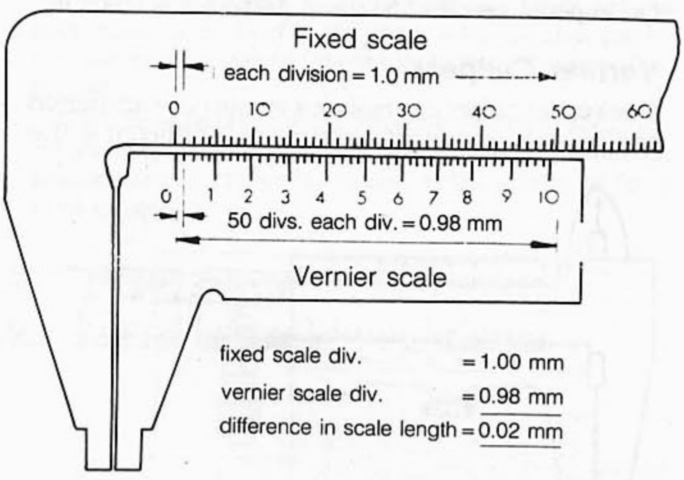



**Figure 51** Vernier scale to measure 1/50th (0.02) of a millimetre

### *The vernier scale*

Each small division of the vernier scale represents 1/50th of a millimetre, which is equal to 0.02 mm.

There are ten numbered divisions with five smaller divisions in each of these.

Therefore one numbered division represents 0.02 × 5 mm, or 0.1 mm. If the vernier scale is moved to the right until the first graduation on the right of zero on the vernier scale coincides with the first graduation on the fixed scale, the vernier scale has been moved 0.02 mm.

If the 12th graduation is made to coincide, the vernier scale has been moved 12 × 0.02 mm, or 0.24mm.

This can be expressed as:

| | |
|---|---|
| two numbered vernier divisions | 0.2 |
| plus 2 small divisions, 2 × 0.02 | 0.04 |
| | 0.24 mm |

### *The fixed scale*

Each interval between two divisions on the fixed scale is 1 mm wide and there are ten 1 mm divisions for each numbered division, therefore each numbered division equals 10 mm.

The number of millimetres on the fixed scale to the left of zero on the vernier scale is read.

### *Reading the vernier*

| | | |
|---|---|---|
| 1 Read the number of millimeters to the left of the vernier scale zero (see Fig. 52): | = | 16.00 mm |
| 2 Read the vernier scale numbers between zero and the graduation (marked *) in line with the fixed scale (2) | = | 0.2 mm |
| 3 Count the additional small divisions to the coinciding lines (3 × 0.02) | = | 0.06 mm |
| 4 Add the figures to determine the reading | = | 16.26 mm |

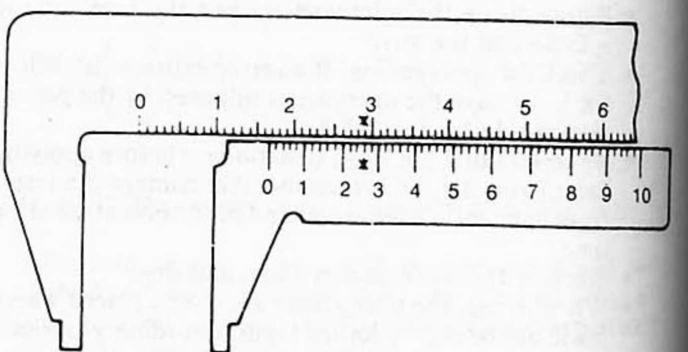



**Figure 52** Reading of 16.26 mm on a vernier caliper

## Reading a Vernier Caliper Graduated for Thousandths of an Inch

A typical imperial vernier scale is shown in Figure 53.

1 First note how many whole inches, tenths and fortieths the zero line on the vernier scale has been moved from the zero line on the fixed scale.
2 Note on the vernier scale the number of divisions from zero to where a graduation mark on the vernier scale coincides with one on the main scale.

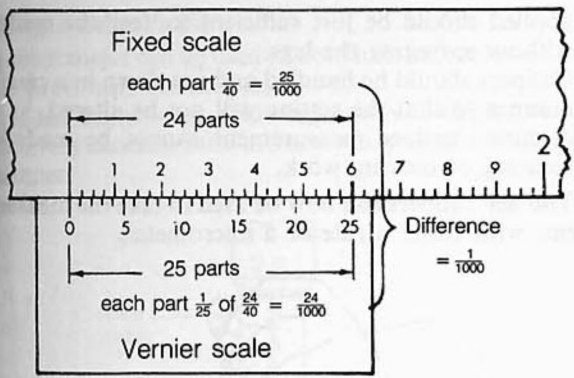



**Figure 53** Typical vernier scale

In the example shown in Figure 54 the vernier scale has been moved one inch, $\frac{4}{10}$ in. (0.4), $\frac{1}{40}$ (0.025) in., and $\frac{11}{1000}$ (0.011) in. This makes the total reading 1.436 in. (1 in. + 0.400 in. + 0.025 in. + 0.011 in.).

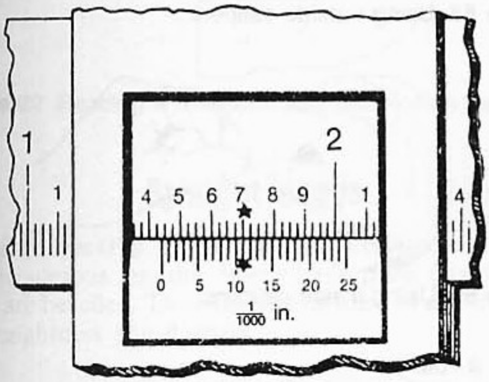



**Figure 54** Reading of 1.436 inch on a vernier caliper

Testing a Vernier Caliper

1 See that the jaw faces are clean.
2 Check the jaw faces for parallelism with a standard 6-8 mm or $\frac{1}{4}$ in. diameter test plug. If this is not available examine the vernier caliper for a variable light gap when the jaws are closed.
3 Close the jaws and check the zero reading.
4 To test the accuracy at various positions, use standard test pieces.

## Vernier Height Gauges

These gauges are used in the tool-room and inspection departments, and for certain workshop applications such as marking out. They enable the setting or checking of distances on components to an accuracy of 0.02 mm from a given datum plane such as a surface plate. Figure 55 illustrates the principle of these instruments. Skilled use of these depends on acquiring the correct feel, for which care and practice are essential.

Substantially more accurate results can be obtained by using a dial gauge attachment in place of a finger, and using the instrument as a comparator. In this way an accuracy of 0.002 mm is possible.

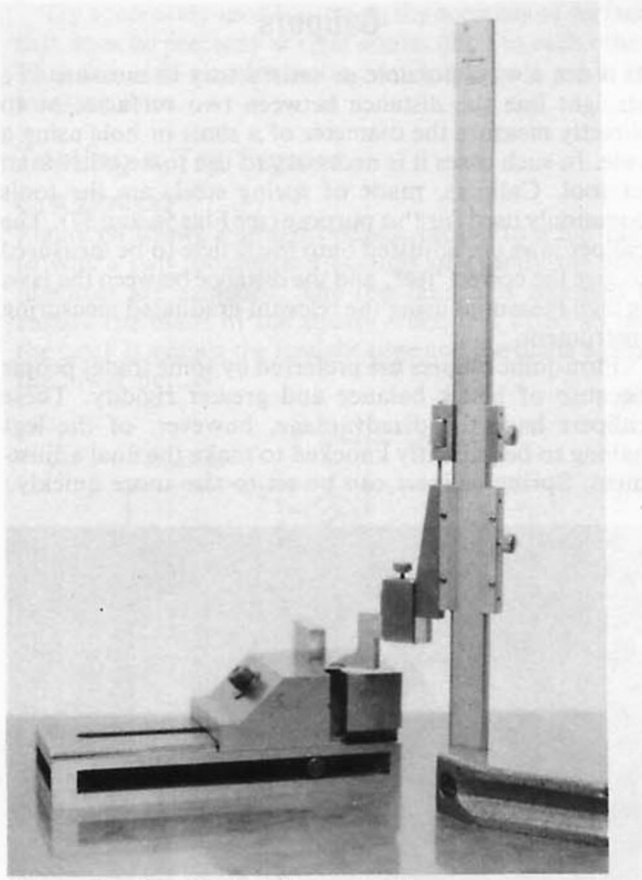


**Figure 55a** Vernier height gauge direct measurement

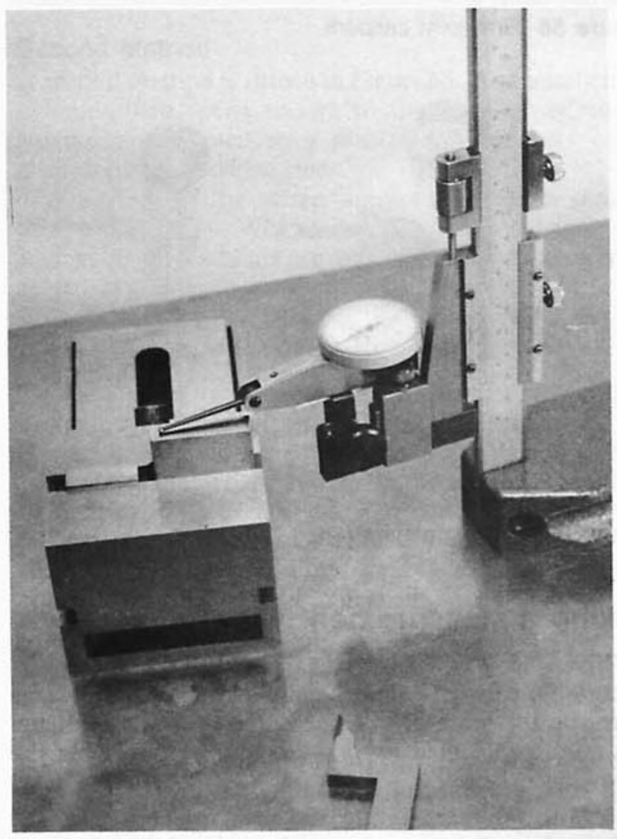


**Figure 55b** Vernier height gauge using a finger dial indicator

## Calipers

It is not always possible or satisfactory to measure in a straight line the distance between two surfaces, or to directly measure the diameter of a shaft or hole using a rule. In such cases it is necessary to use some other kind of tool. Calipers, made of spring steel, are the tools commonly used for this purpose (see Figs 56 and 57). The caliper jaws are adjusted onto the article to be measured to give the correct 'feel', and the distance between the jaws is then measured using the relevant graduated measuring instrument.

Firm-joint calipers are preferred by some trades people because of better balance and greater rigidity. These calipers have the disadvantage, however, of the legs having to be patiently knocked to make the final adjustment. Spring calipers can be set to size more quickly.

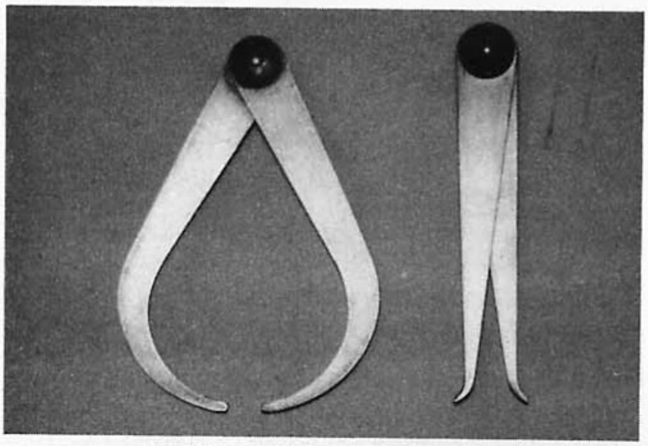


**Figure 56** Firm joint calipers

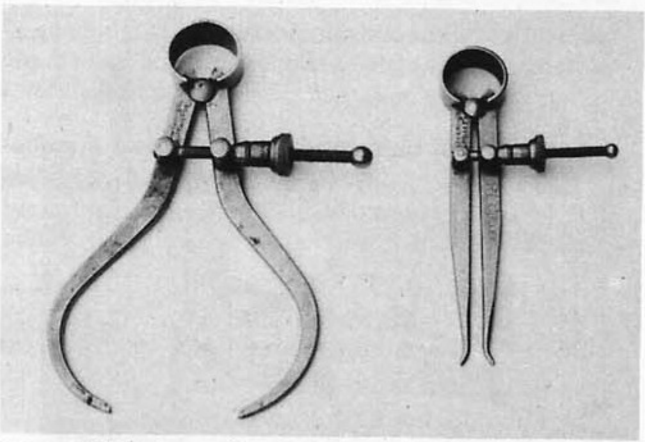


**Figure 57** Spring calipers

## Taking a Measurement with Calipers

### Correct Use of Calipers (Figs 58 to 62)

Accurate measurement with calipers depends to a large extent on the sense of touch. Skill in the use of calipers can only be attained by practice and by observing the following principles:

- Hold the calipers lightly and near the end.
- Keep the calipers square to the axis of the work.
- Never force them over or into the work. The pressure applied should be just sufficient to 'feel' the contact without springing the legs.
- Calipers should be handled and put down in a careful manner so that the setting will not be altered.
- Accurate caliper measurement cannot be made on rotating or moving work.

The 'set' calipers can now be used to take the measurement, with either a rule or a micrometer.

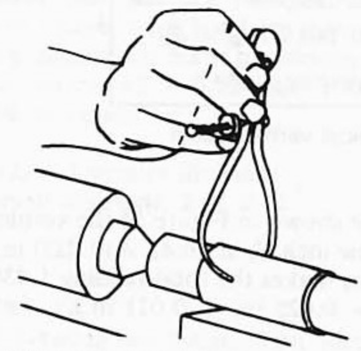


**Figure 58** Using outside calipers

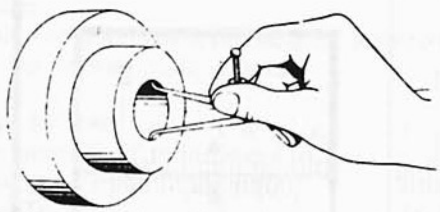


**Figure 59** Using inside calipers

*Using a rule*

Care should be taken to keep the points of the legs parallel to the edge of the rule and the calipers to the centre of the graduation.

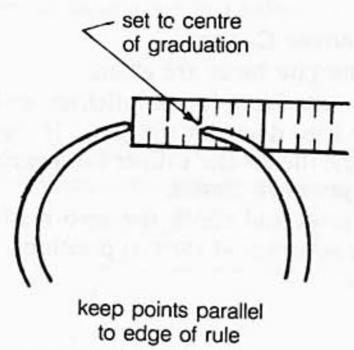



**Figure 60** Setting outside calipers

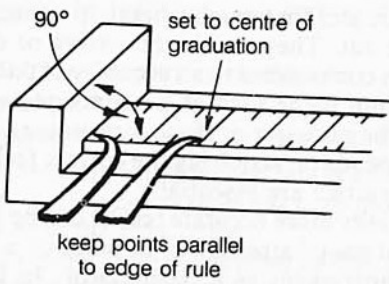



**Figure 61** Setting inside calipers

*Using a micrometer*

A micrometer can be used to obtain an accurate size from the previously set calipers.

If the calipers are held very lightly towards the joint end, very accurate measurements may be obtained in this manner.

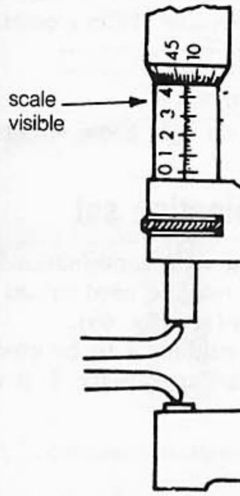



**Figure 62** Reading a measurement from inside calipers

## Straight edges

Straight edges (Fig. 63) are made of steel and are obtainable in various lengths. Some have plain edges, other types are bevelled. The edges are finished to a high degree of straightness and flatness.

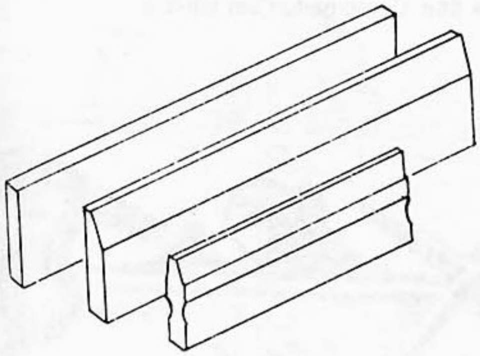


**Figure 63** Types of straight edges

Straight edges are used for testing flat surfaces, to align work being set up, and as a guide for scribing straight lines.

The edge of a square or a steel rule (if maintained in good condition) may often be used as a practical workshop straight edge, but the degree of accuracy is not as high as can be obtained using a proper straight edge.

## Try squares

The engineer's try squares are made of steel, the more expensive types being hardened before being ground. They are made in a large range of sizes, some having bevel-edged blades.

Try squares are used for testing the accuracy of surfaces that must be precisely at right angles (90°) to each other. They are used also for setting work and as a guide for marking lines.

### Testing a Try Square

First Method

Figure 64 shows a straight edge attached to a flat plate to which two toolmaker's buttons of exactly the same diameter are attached. The top button is adjusted to engage the blade of the square when it is fitted so that the stock is against the straight edge and the blade against the lower button.

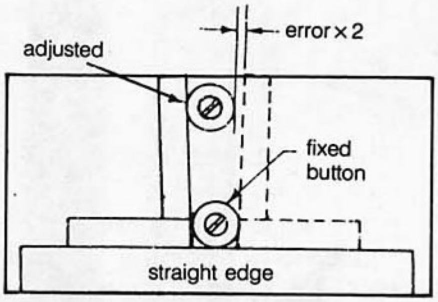



**Figure 64** Testing a square using a straight edge and buttons

By placing the square in the second position, twice the error is indicated. This may be measured with a feeler gauge or, if the error is very small, the tension of blades of equal thickness may be felt when they are placed between the buttons and the blade of the square.

Second Method

A second method is shown in Figure 65. A precisely made cylinder, with ends square to the parallel cylindrical surface and known as a master square, rests on an accurately flat surface plate.

A portion of the master square's surface is smeared with bearing blue. When the square is moved against it, high spots on the blade are indicated by blue being transferred at points of contact.

### Using a Try Square

To test surfaces required to be precisely at right angles, first remove all burrs from the workpiece and ensure that the workpiece and the square are clean. Face the workpiece towards the light and apply the square as indicated in Figures 66 or 67 and 68.

Remember that the stock must be held firmly against the finished surface and that the blade must just lightly contact the surface being checked.

### Care of the Try Square

The try square is a precision tool and should be treated as such if it is to remain accurate. Keep it in a position where it is not likely to fall. When it is in use and when it is stored, ensure that it is not knocked by other tools. Test it regularly for accuracy. Smear the try square with a thin film of lubricant or anti-rust compound when not in use. -

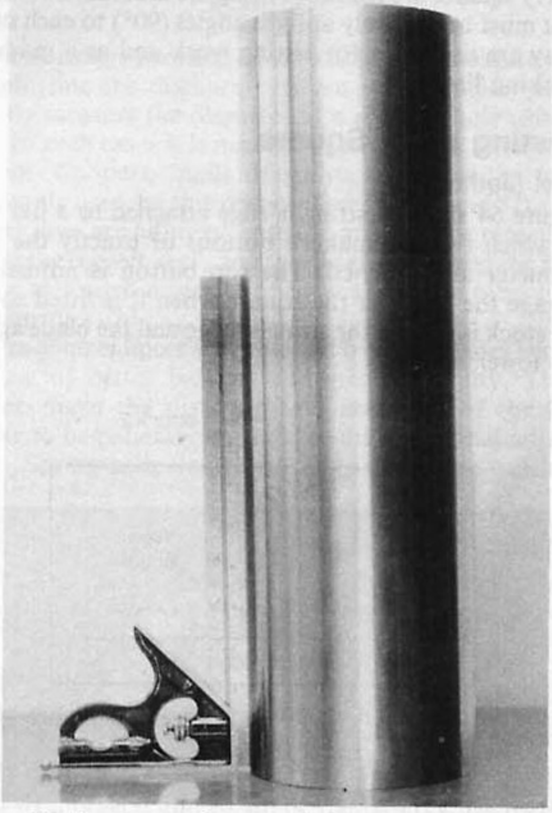


Figure 65 Testing against a cylindrical master square

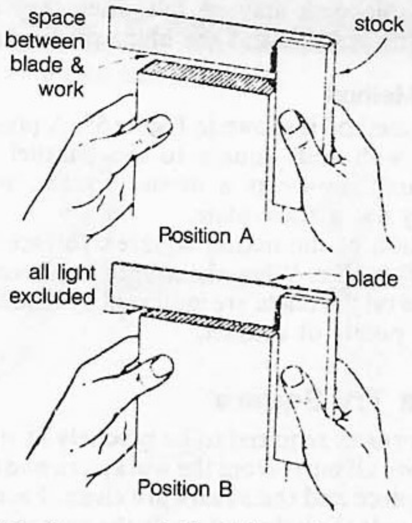



Figure 66 Testing an outside right angle

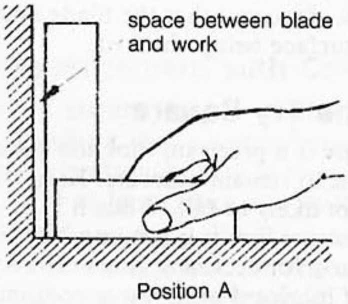



Figure 67 Testing an inside right angle—position A

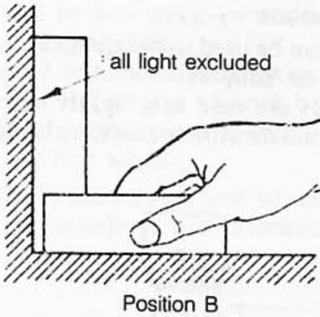



Figure 68 Testing an inside right angle—position B

## Combination set

The square head and rule of a combination set form a most useful tool, which may be used to test and mark both 90° and 45° angles (see Fig. 69).

The adjustable blade enables it to be used in places inaccessible to an ordinary try square. It is useful also as a depth gauge.

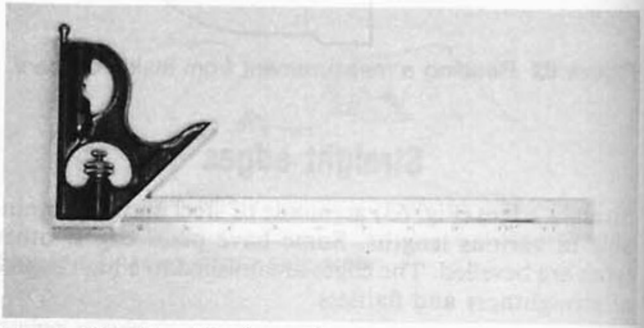


Figure 69a Combination set square

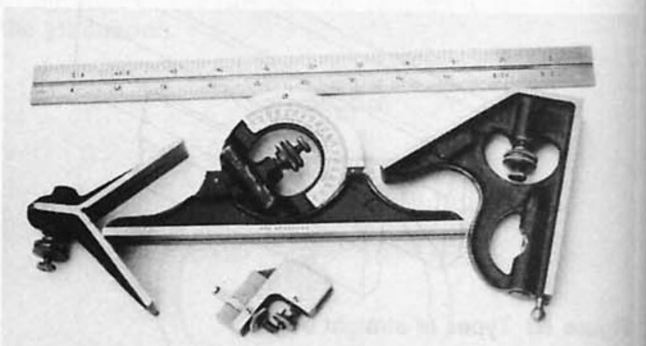


Figure 69b Combination set complete—The attachment in the foreground is used to hold another rule at right angles

The protractor head, graduated to 180°, is used for both marking out and setting work for machining.

The centre square, as it is called, is used for marking the centre line on round work. The rule on which these three heads are used is usually 300 mm or 12 in., longer rules are available and sometimes necessary. The square and protractor heads contain a small level vial which is very useful for setting some types of work.

## Toolmakers square

The toolmakers square (Fig. 70) is a miniature of the combination square, the rule being only 100 mm long; a plain small blade with the ends at 45° and 30° is also included. Another type of toolmakers square has several small blades of various lengths and widths and provision for 10° adjustment either side of 90°.

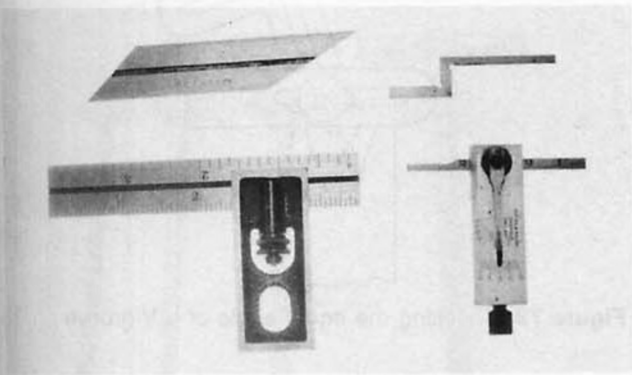


**Figure 70** Toolmakers square—two types

## Protractors

A protractor is used for marking and testing angles and for setting work. Protractors are made in several forms; examples of ordinary protractors are shown in Figures 71 and 72. These are graduated to read from 0 to 180 degrees.

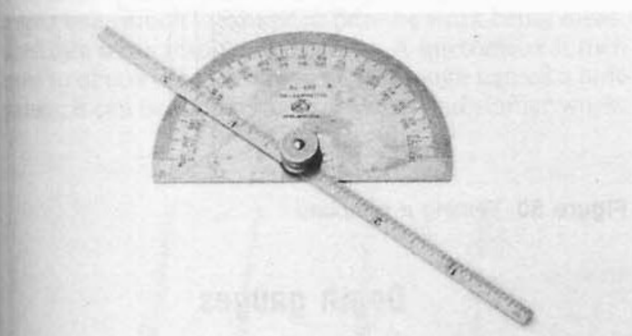


**Figure 71** Ordinary protractor

**Figure 72** Protractor part of the combination set

### Vernier Protractors

For more accurate work, vernier protractors are available.

The vernier bevel protractor (Fig. 73) is used for accuracies of less than one degree. The vernier enables graduations of $\frac{1}{12}$ (0.083) of a degree to be read, that is, 5 minutes of arc. The bevelled edge on the vernier scale brings the graduations close to the main scale, thus reducing parallax errors (errors caused by not having the line of sight perpendicular to the scale face).

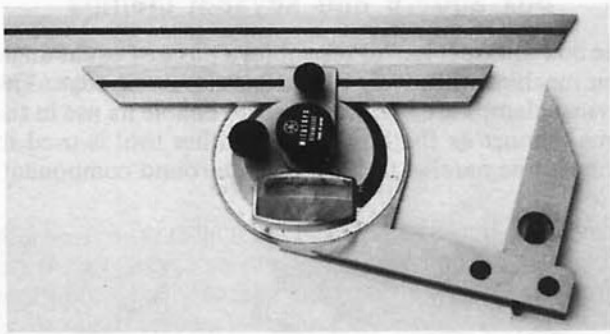


**Figure 73** Vernier bevel protractor

### Principle of the Vernier Protractor

The main scale is graduated in degrees.

The vernier scale is graduated so that 12 divisions on the vernier occupy the same space as 23° on the main scale. Each division on the vernier is equal therefore to $\frac{1}{12}$ of 23° or $1\frac{11}{12}$°.

Two divisions on the main scale equal 2°. The difference between two divisions on the main scale and one division on the vernier is $2° - 1\frac{11}{12}°$, which equals $\frac{1}{12}$° or 5 minutes.

The vernier protractor allows readings to be made in clockwise and anticlockwise directions.

### Reading a Vernier Protractor

1 Note the number of whole degrees from zero on the main scale to zero on the vernier.

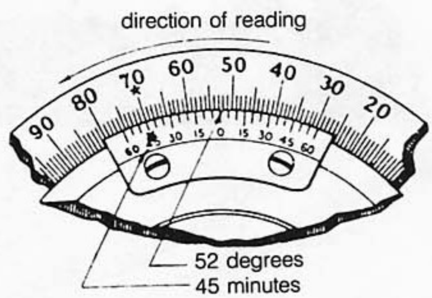



**Figure 74** Vernier protractor reading of 52° 45′

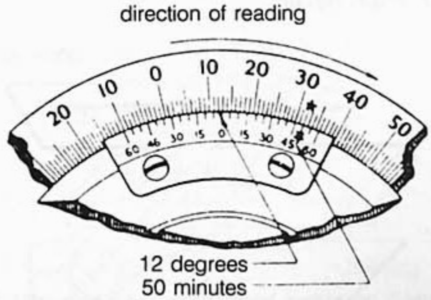



**Figure 75** Vernier protractor reading of 12° 50′

2 Count the number of divisions on the vernier scale from zero to where a graduation mark on the vernier coincides with another on the main scale. This indicates the number of $\frac{1}{12}°$ or 5 minutes. (Figs. 74 and 75 show examples of readings.)

## Box square and keyseat clamps

The box square (Fig. 76) resembles a piece of equal-angle iron machined all over, with a bevel on one edge. The keyseat clamps are used on a rule to enable its use in the same manner as the box square. Either tool is used to scribe a line parallel to the axis on a round component.

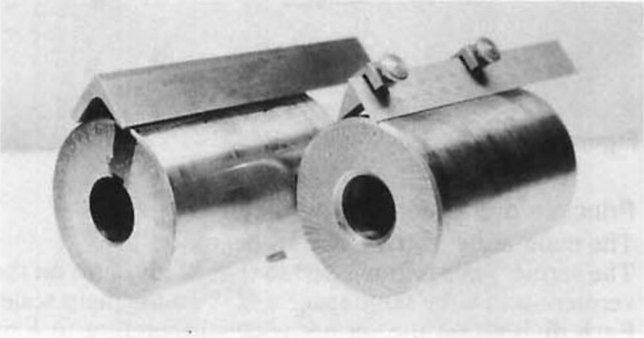


**Figure 76** Box square and keyseat clamps shown on work

## Bevel gauges

Bevel gauges are used for marking out and testing angles, and for transferring angles from one piece of work to another. As they are not graduated, they have to be set using a protractor. Figures 77 and 78 illustrate common types of bevel gauge.

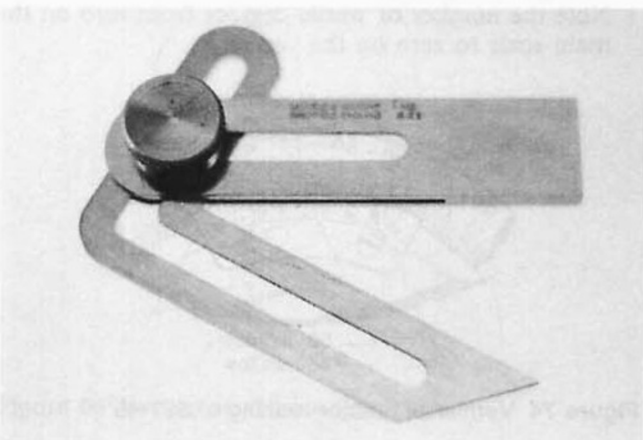


**Figure 77** Plain bevel

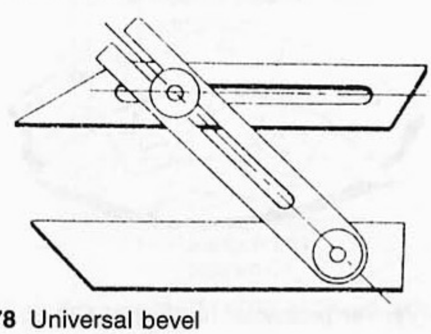


**Figure 78** Universal bevel

## Using a Bevel Gauge

The procedure is illustrated in Figures 79 and 80.

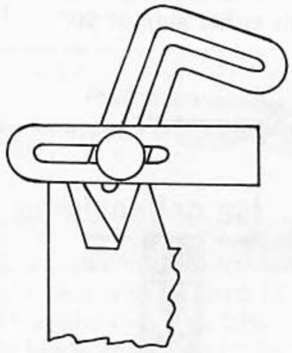


**Figure 79** Checking the equal angle of a V-groove

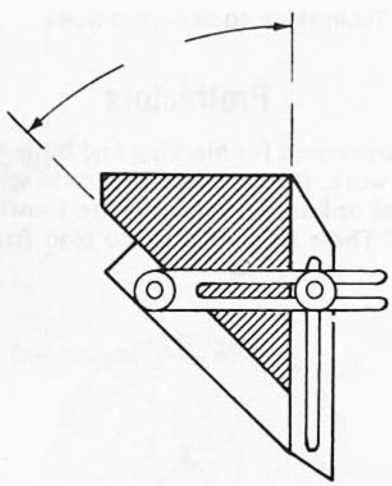


**Figure 80** Testing a template

## Depth gauges

These consist of a simple plate, carrying a narrow rule that can be clamped to it (Fig. 81). They are used to measure depths of shoulder positions and similar work. Some have provision for a 2 mm diameter rod to be interchanged with the rule for entering smaller spaces.

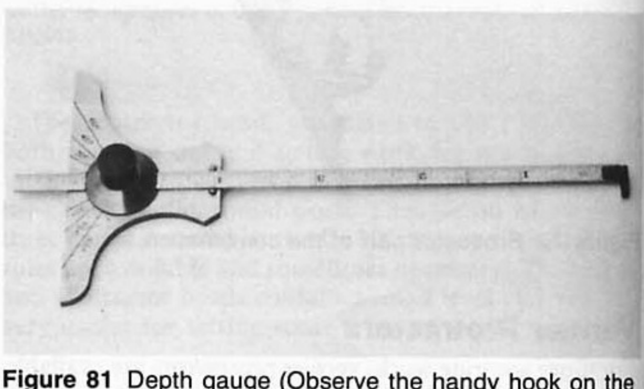


**Figure 81** Depth gauge (Observe the handy hook on the rule)

## Telescoping gauges

In these gauges (Fig. 82) the measuring anvils with spherical ends telescope into the body and at right angles to the handle. In taking a measurement, the anvils are allowed to expand into the work to be measured and locked by the screw through the handle; a micrometer is then used to obtain a measurement over the set anvils.

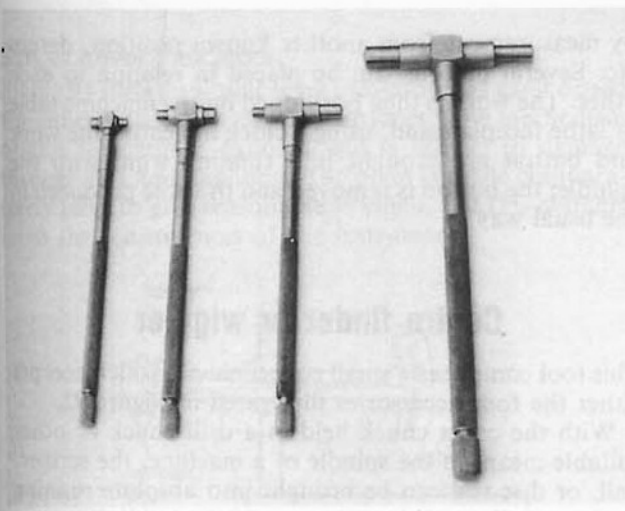


**Figure 82** Set of telescoping gauges

## Small hole gauges

The measuring end of these gauges (Fig. 83) resembles a split ball, which is expanded into the work being measured by a screw through the handle. A micrometer is then used to obtain the measurement. Although named a hole gauge, it can be used to measure slots and similar work.

**Figure 83** Set of small hole gauges

## Screw pitch gauges

These gauges have 20 to 30 blades depending on the type (Fig. 84). They are housed like feeler and radius gauges and are used to ascertain and check screw pitches.

They are commonly made in three types for imperial, metric, and BA pitches.

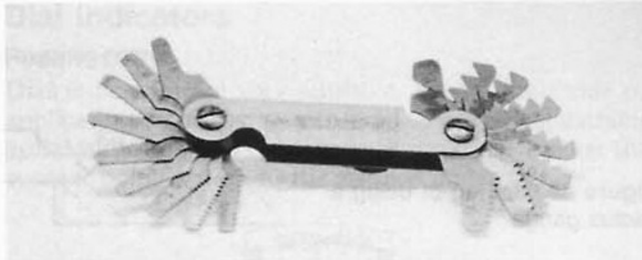


**Figure 84** Screw pitch gauge

## Centre gauges

A centre gauge (Fig. 85) is a small plate gauge for checking the angle of a screw-cutting tool and for setting the tool square to the axis of the work in the lathe. The 60° is also used to check the angle of machine centres.

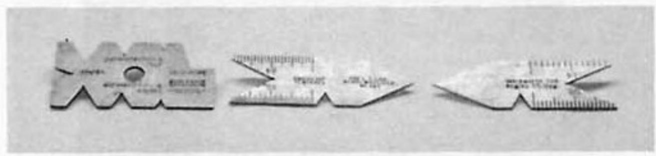


**Figure 85** Typical centre gauges

## Feeler gauges

Feeler or thickness gauges (see Fig. 86) are used to measure small spaces, for example the kind that are necessary to give clearance when one part is being fitted to another, or when setting up work or adjusting tools in machines (see Fig. 87).

A useful range of metric blades is from 0.03 to 0.5 mm.

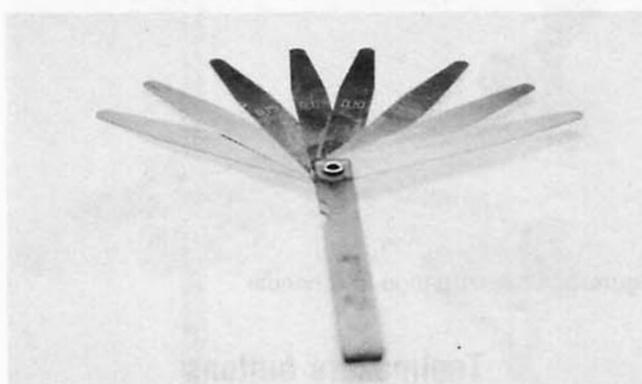


**Figure 86** Set of feeler gauges

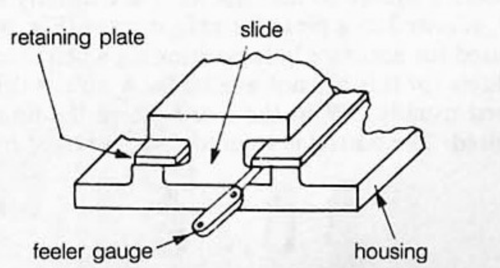



**Figure 87** Checking the clearance between parts of a machine slide

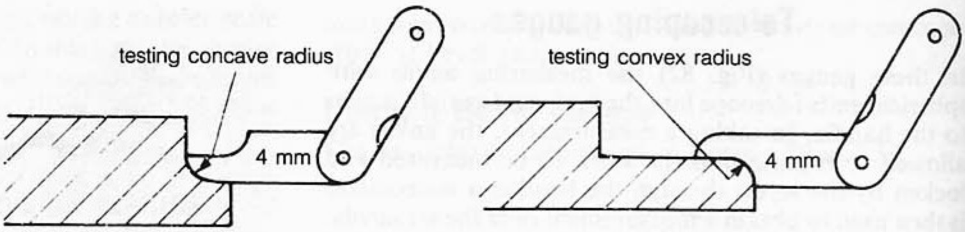



**Figure 88** Method of using a radius gauge

## Radius gauges

These gauge sets are made with blades having convex and concave arcs of the same radius on each blade. (See Fig. 88.) The blades are usually grouped in sets, each set containing a range of sizes. They are housed in a holder in a similar manner to feeler gauge blades. Another style is the individual gauges with five radii on each blade (Fig. 89 and 90.)

**Figure 89** Radius gauges, loose blade type, in a wallet

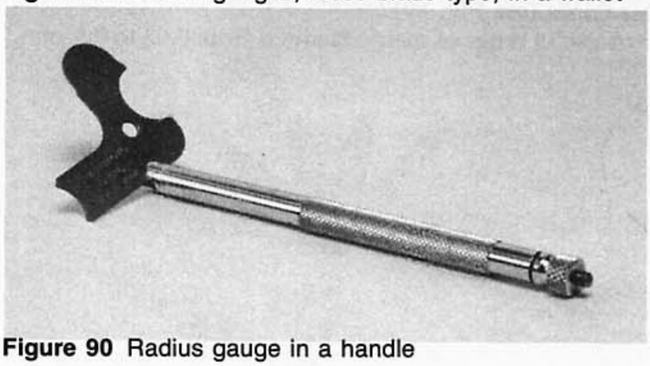


**Figure 90** Radius gauge in a handle

## Toolmakers buttons

These are accurately ground cylinders with one end absolutely square to the axis; they are usually in sets of four, screwed to a plate for safe storage (Fig. 91). They are used for accurate hole positioning when machines or facilities for this are not available. A hole is drilled and tapped usually $\frac{1}{8}$ W in the work where the final hole is required. The button is secured with its screw in position by measurement from another known position, datum etc. Several buttons can be placed in relation to each other. The work is then positioned on the machine table or lathe faceplate and, using a clock indicator, the work and button are brought into running truth with the spindle; the button is removed and the hole produced in the usual way.

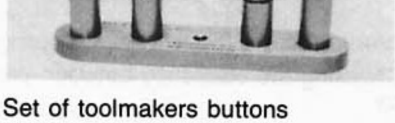


**Figure 91** Set of toolmakers buttons

## Centre finder or wiggler

This tool comprises a small collect chuck, which accepts either the four accessories illustrated in Figure 92.

With the collet chuck held in a drill chuck or other suitable means in the spindle of a machine, the scriber, ball, or disc rod can be brought into absolute running truth regardless of the accuracy of the holding means. The ball or disc can be used to pick up an edge or shoulder and the scriber a centre line. The fourth unit is used to mount a small indicator (not illustrated).

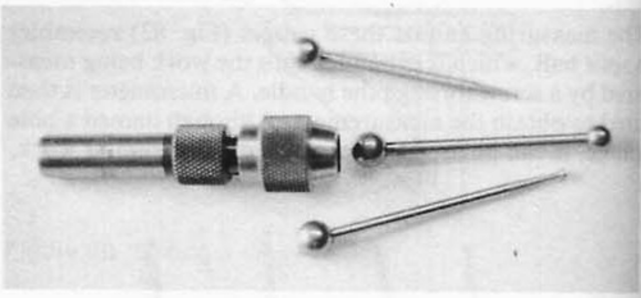


**Figure 92** Centre finder or wiggler

## Indicators

Indicators are testing and measuring instruments usually made to read to an accuracy of 0.02 mm. By using an indicator it is possible to set out or to test work to very close tolerances because it shows both the position and the amount of error.

### Lever Indicators

#### Principle

There are several types of lever indicator, all of which operate on the principle shown in Figure 93. A small movement of the contact point A produces a far greater movement of the pointer C because of the position of the fulcrum B. For example, if the distance BC is 30 times greater than AB, a 0.02 mm movement of A, which is not a visible amount, will cause C to move 0.60 mm, which is quite visible.

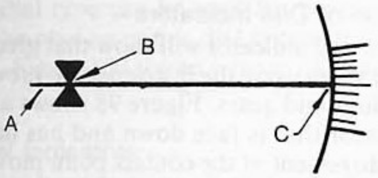



**Figure 93** Principle of lever indicators

### Simple Lever Indicators

Figure 94 shows a simple lever indicator that can be used for either internal or external surfaces. The mechanism of this indicator is exposed and is subject to damage through dirt and handling. The pivot is made comparatively large to give reasonable strength, but this detracts from the sensitiveness of the instrument.

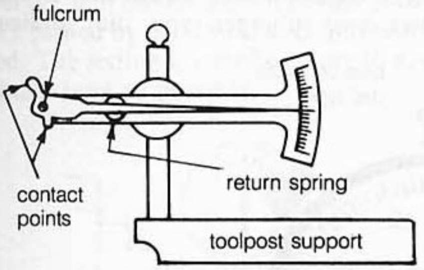



**Figure 94** Simple lever indicator

### Compound Lever Indicators

A compound lever indicator is shown in Figure 95. The compound lever allows a large deflection of the pointer, but requires more moving parts than the simple lever type. The exposed positions of these parts make it difficult to keep the instrument in good order.

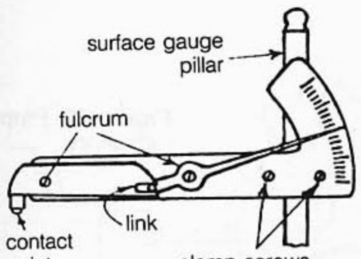



**Figure 95** Compound lever indicator

Figure 96 shows another type of compound lever indicator. The mechanism of this instrument is very sensitive and is enclosed in a metal tube, which gives protection from dust and handling.

### Uses of Lever Indicators

Lever indicators are most useful for accurately setting work on a lathe faceplate or in a chuck. They are supported on a special rest, which fits in the tool post of the machine, as shown in Figure 94, or on the pillar of a surface gauge as shown in Figure 95. These indicators are also useful for accurately setting work, or work-holding devices such as vices on shaping, planing, slotting and other machines.

## Dial Indicators

### Features

Dial indicators are very sensitive, have a multitude of applications, and are easy to read. Figure 97 illustrates a dial indicator and the magnetic stand used to set the contact point square to the surface under test.

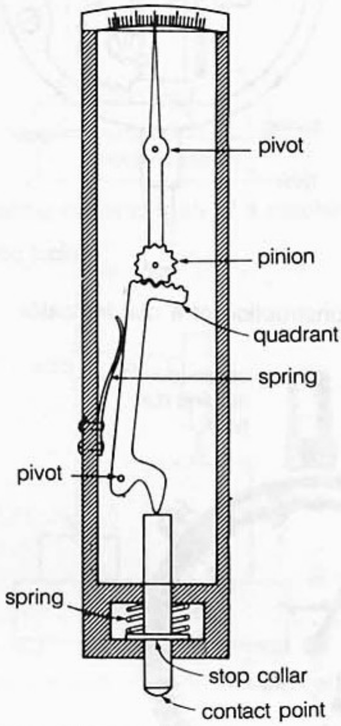



**Figure 96** Enclosed lever indicator

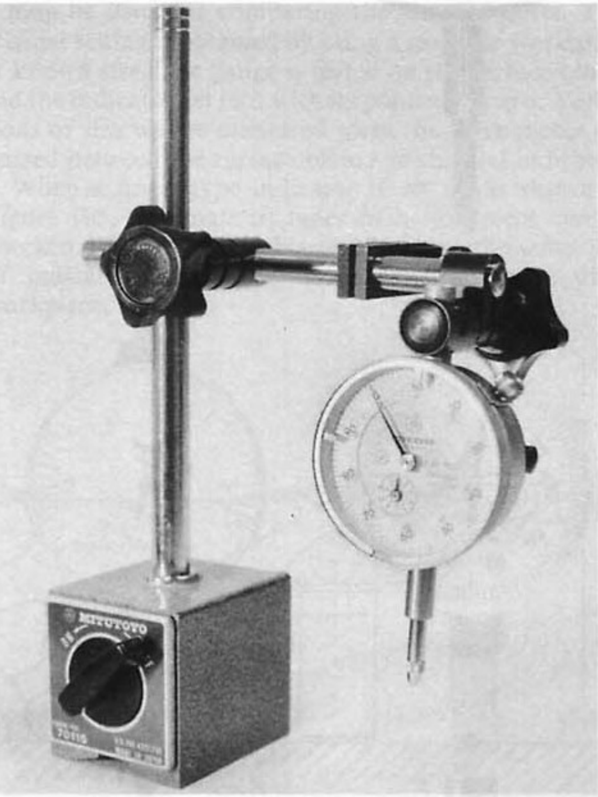



**Figure 97** Dial indicator and magnetic stand

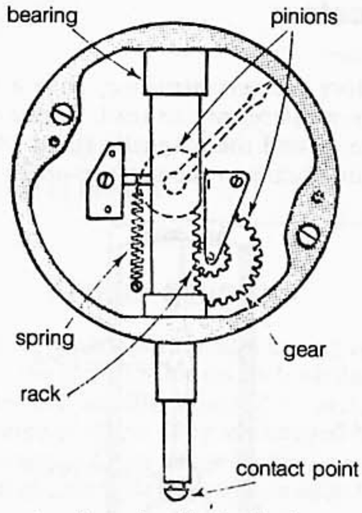



**Figure 98** Construction of a dial indicator

### Construction of Dial Indicators

A study of a dial indicator will show that great care must be exercised when using the instrument to prevent damage to the bearings and gears. Figure 98 shows a view inside a dial indicator that is face down and has had the back removed. Movement of the contact point moves the rack, which turns a small pinion. A large gear is fixed to the same shaft as the small pinion and meshes with another small pinion (shown dotted) in the centre front of the indicator. The pointer is attached to the central pinion shaft. A very light return spring keeps the contact point against the work.

The gears act as a compound lever arrangement, and a small movement of the contact point is magnified to an observable movement of the pointer.

### Types of Dial Indicator

A variety of indicators are used in the workshop. Figure 99 shows two plunger-type dial indicators. The

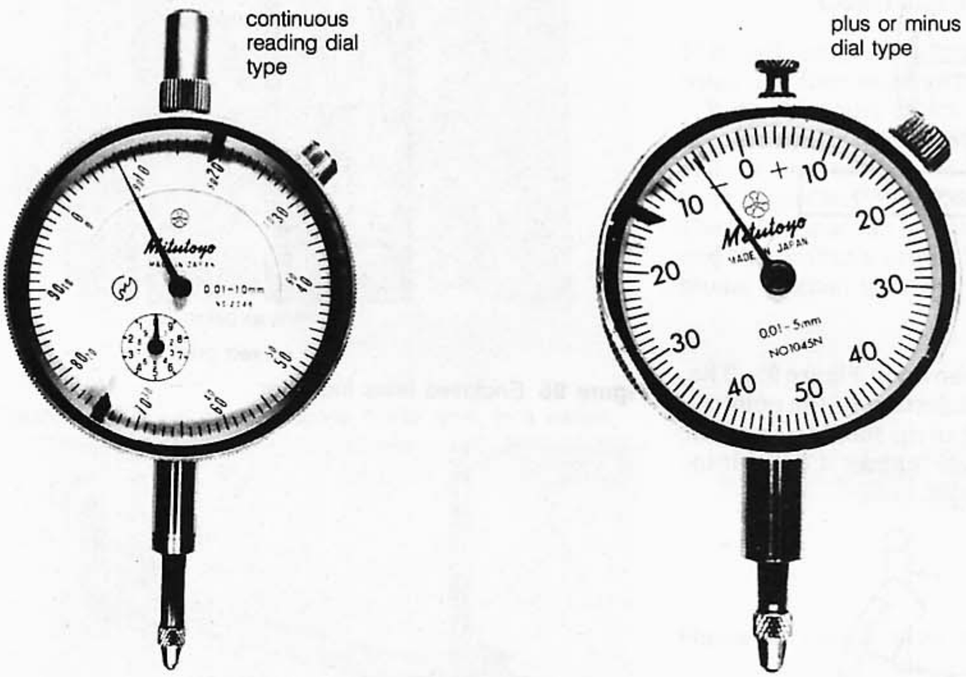



**Figure 99** Plunger-type dial indicators

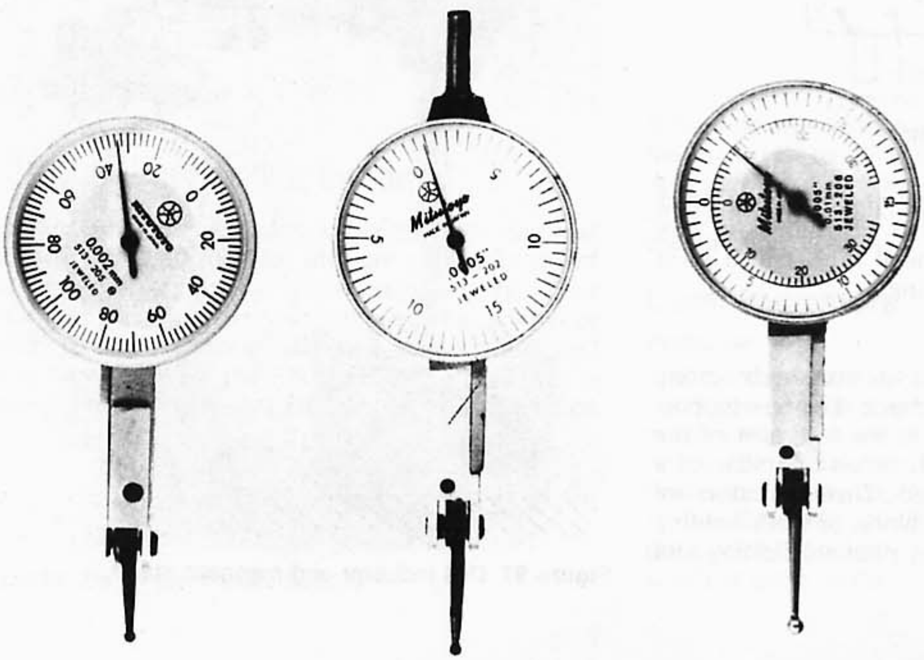


**Figure 100** A range of finger-type dial indicators

continuous-dial type can be used for measuring movement, and the plus-or-minus dial type can be used as a comparator. Figure 100 shows a range of finger-type dial indicators.

## Uses of Dial Indicators

Dial indicators have many applications in the workshop, some being:

- to set work accurately in a machine;
- to test the accuracy of machine slides, and play adjustments, etc.
- to use, in conjunction with other equipment, such as gauges and surface plates, as a simple comparator.

Figure 101 shows a dial indicator used for testing work that is held in a lathe chuck. The indicator is supported from either the lathe bed or the toolpost and carefully brought into contact with the work until the pointer has moved about 0.5 mm on the scale. The dial is set to zero and the work turned by hand so that the error of setting can be noted. The setting is tested as close to and as far from the chuck jaws as possible.

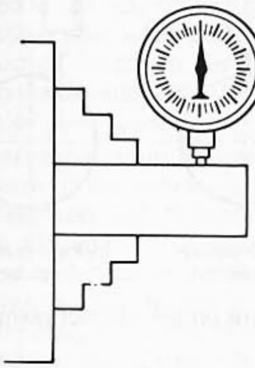


**Figure 101** Testing chuck work

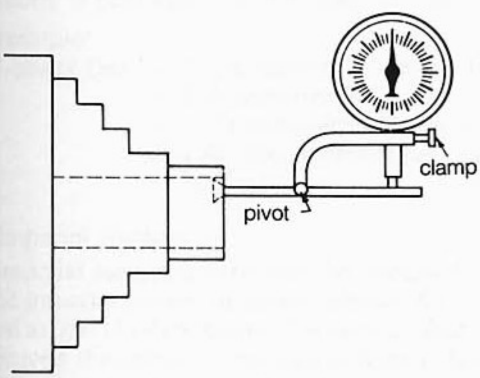



**Figure 102** Using an internal attachment

Figure 102 shows a dial indicator fitted with an attachment that permits internal or otherwise inaccessible places to be checked. This attachment is a 1:1 ratio lever, the end of which will enter small spaces such as a cylinder bore.

A typical set-up for testing the bearings of a machine is shown in Figure 103 which depicts a dial indicator being used to test a drilling machine spindle for true running.

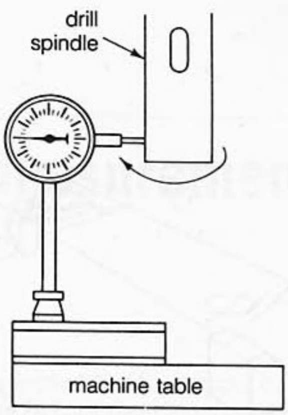



**Figure 103** Testing running truth of a machine spindle

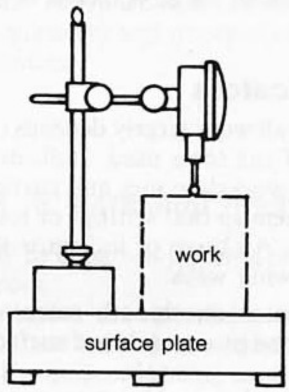



**Figure 104** Testing size of work Dial indicator set up as a comparator

When a dial indicator is set up as shown in Figure 104, it may be used for comparing the sizes of parts. The original setting is obtained by using a gauge or workpiece of known size. The gauge is rested on the surface plate, and the indicator set to it with its pointer on zero. Variations of size will be measured when the work pieces are passed between the surface plate and the dial indicator.

When a finger-type indicator is set up as shown in Figure 105, the angle of taper of a workpiece can be checked using a sine bar. Figure 106 shows the same type of indicator being used to check straightness of a workpiece.

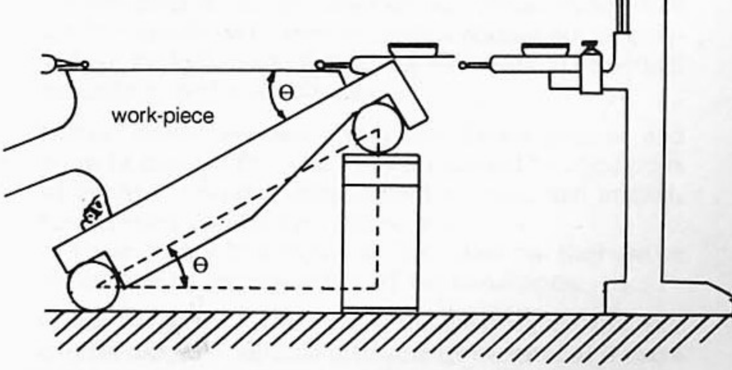



**Figure 105** Checking the angle of taper of a workpiece

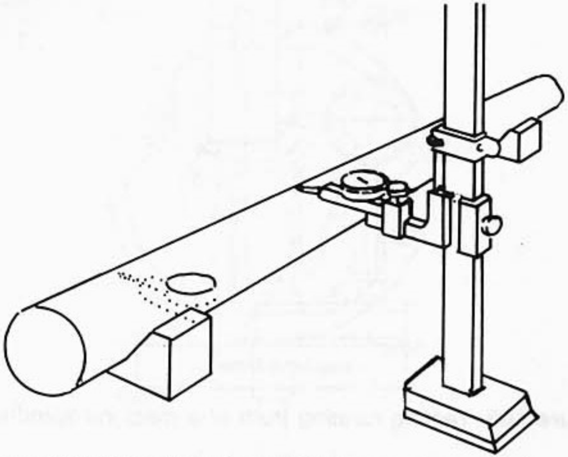


Figure 106 Checking the straightness of a workpiece

## Care of Indicators

The accuracy of all work largely depends on the efficiency and accuracy of the tools used. Indicators are delicate instruments for workshop use, and particular care must be taken with them so that settings or tests can be made with confidence. All types of indicator should be cared for in the following ways:

- Use the indicator on smooth machined faces only. Rough machined or unmachined surfaces will damage the indicator.
- Do not operate the machine by power until the final check is desired; even then the speed must be very slow, because rapid movement of the pointer sets up vibrations that may damage the mechanism.
- Do not allow the contact point to run off the end of the work. Sudden large movements of the contact point may cause it to be damaged by jarring.
- Serious damage will be done if the range of movement of the contact point is exceeded.
- Do not oil the contact spindle of dial indicators as oil will cause the gears to stick and the bearings to have excessive friction.
- Make sure that all equipment used to support indicators is rigid.
- Keep indicators where they will be protected from dirt and damp, both during use and in storage.
- Keep an indicator carefully separated from its attachment so that damage cannot occur if they bump together. Use a box with recesses for each part.
- Make sure that the pressure placed on the contact point is as direct as possible (see Fig. 107). If the contact point is not square to the test surface an incorrect reading will be obtained.

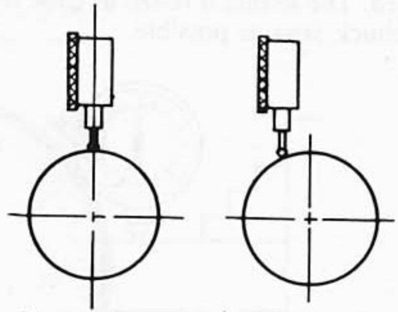


Figure 107 Pressure on the contact point

# 20

# Introduction to precision measurement

## Systems of measurement

The reliability of any measurement depends on the relationship it bears with some known standard.

There are two systems of measurement in present use, namely the metric system and the British or Imperial system.

### The Metric System

The metric system is used by over 80% of the world's population, and in the near future this system will almost certainly be universally adopted.

The standard of length in the metric system is the metre, which is the distance travelled by light in a vacuum during a time of $\frac{1}{299\,792\,458}$ sec.

The metric system of units adopted by most countries is a modern form of the metric system and is known as the *Systeme International d'Unités*, which is generally abbreviated to SI units.

The standard of length in the SI system remains the metre. However, as this length is too large for most precision engineering purposes, the millimetre has been adopted as the basic unit of length for precision engineering measurement.

One of the major advantages of the metric system is that it is a decimal system, and conversion from one unit to another is performed in multiples of ten.

For example:

1 metre (m) = 10 decimetres (1 dm = $10^{-1}$m)
= 100 centimetres (1 cm = $10^{-2}$m)
= 1000 millimetres (1mm = $10^{-3}$m)
= 1000 000 micrometres (1$\mu$m = $10^{-6}$m)

### The Imperial System

The imperial standard yard was the standard of length for the imperial system of measurement. As this is now defined as 0.9114 of the metre, it is obvious that the metre is effectively the universal standard of length. But the inch is still used in some countries as the basic unit of length for precision engineering measurement.

The main disadvantage of the imperial system is that there is no uniformity of conversion factor within the system. This necessitates the use of fractions when converting from one unit to another.

For example:

12 inches (in.) = 1 foot (ft)
3 feet (ft) = 1 yard (yd)
22 yards (yd) = 1 chain (ch.)
1000 000 incro-inches = 1 inch.

Australia has adopted the SI system of units, but some years will elapse before the change-over is complete. In the meantime, both systems will be in use, but conversion from one system to the other should be avoided where possible. Metric measurements should be made with metric equipment and imperial measurements with imperial equipment.

## Errors in workshop measurement

All errors may be classified as being either systematic or accidental errors.

Systematic errors are avoidable errors that occur because of incorrect techniques or through non-allowance for errors in the equipment being used. Typical examples resulting in this type of error are:

- use of direct rather than comparative measuring techniques;
- allowance not being made for zero and calibrating errors in equipment;
- allowance not being made for measurements taken at other than standard temperature.

Accidental errors are those occurring randomly and are therefore difficult to control. Generally they may be considered as human or conditional errors.

All machining and measuring operations are subject to error, either machine, human, or instrumental. It is essential to critically examine each operation so that sources of error can be determined and the error either eliminated or minimized.

**Machine errors** These can arise from imperfect guide ways, such as worn lathe beds, loose bearings, loose gibs, or even warping or misalignment of machine parts. Normal machine maintenance should obviate these errors but the possibility of their occurence should not be overlooked. Periodic inspection of machines should be normal procedure, perhaps annually.

**Human errors** Human errors are always present and occur in random fashion. They are caused by conditions of lighting, operator fatigue both physical and mental, temperature conditions, and so on.

These cannot be completely eliminated but they can be minimized by improvement of the conditions.

**Instrument errors** This type is the most significant, and careful usage of suitable instruments is essential if these errors are to be avoided.

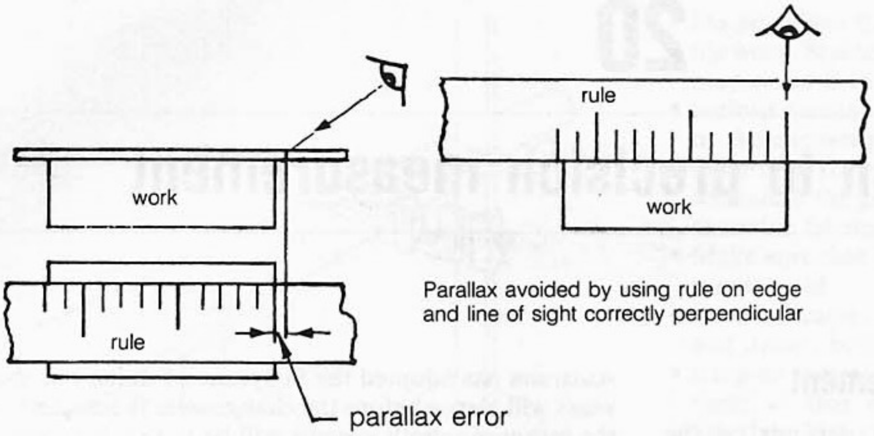



**Figure 1** Parallax error

## Common Sources of Error

### Rules

Both parallax and graduation errors can occur in rules.

Graduation errors are most unlikely if rules from reputable manufacturers are used. However, a pattern-maker's contraction rule could be used inadvertently.

Parallax errors are very common and occur when the line of sight is not perpendicular (normal) to the surface of the rule. The error increases in proportion to the thickness of the rule being used. Figure 1 shows how the error occurs and how it can be avoided.

### Verniers

As with rules the possibility of graduation errors can be ignored if instruments from reputable manufacturers are used. Two other errors are common and are caused by the measuring faces and the slide.

#### *Wear on measuring faces*

Figure 2 shows the points at which wear occurs on the measuring faces of the jaws of a vernier caliper. It is clear that checking the zero error of the instrument cannot compensate for errors due to this wear. The only solution is to periodically check the measuring faces with a straight edge, precision roller and gauge blocks, and grind and lap faces when necessary.

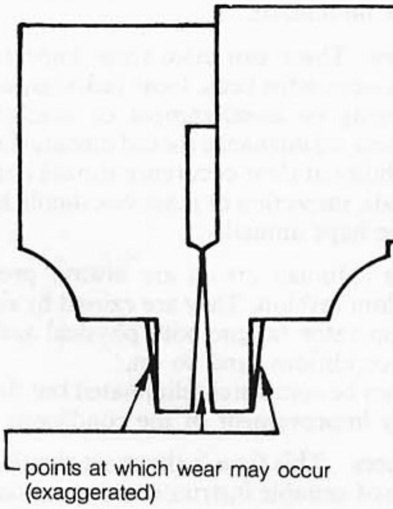



**Figure 2** Wear on measuring faces

#### *Bent beam*

The beam can cause considerable error if it is bent longitudinally across its thickness or its width. If bent across its thickness, the ensuing error is constant for a given jaw position and is usually quite small, as shown in Figure 3.

In the construction of vernier calipers an important principle is violated. This is the Abbe Principle or Principle of Alignment, which states that the line of the scale should coincide with the line of measurement.

If the beam is bent across its width, then, as Figure 4 shows, the error caused is directly proportional to the distance from the measuring scale to the point of contact of the measuring faces on the part being measured.

These errors can be detected by testing between the jaws for parallelism and accuracy using a precision roller and the same size gauge block.

### Micrometers

#### *Zero error*

The main error likely in micrometers is zero error, which is easily checked by cleaning the measuring faces, bringing them together and noting the reading. If a micrometer is periodically tested for pitch error and accuracy of measuring faces by some authority, then zero error is the only other significant error. However, as an extra safeguard, the micrometer should be checked against a standard of a similar size and shape as the workpiece; for example, if flat work is being measured, the micrometer should be checked against a suitable gauge block, whereas for cylindrical work the micrometer should be checked against a suitable precision roller. In this way, the error caused by variations in measuring pressure can be avoided.

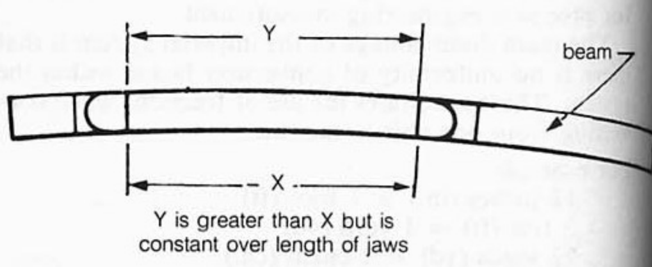



**Figure 3** Beam bent longitudinally

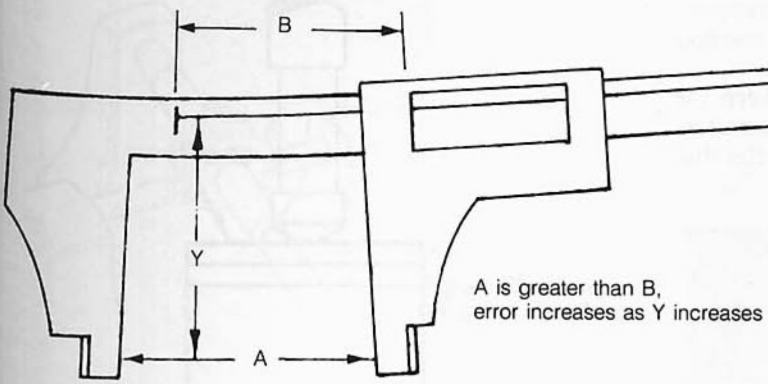



**Figure 4** Beam bent across width

*Errors due to heat*

All metals expand when heated and contract when cooled. This is a very real problem in workshop measurement and both the workpiece and the measuring equipment should be kept at the same temperature during measurement. As an example of the error that could occur through heat, consider the grinding of a 50 mm diameter on a steel bar in a cylindrical grinding machine when using a copious flow of coolant. The temperature of the coolant, and therefore that of the workpiece, could be 15°C at a time when the workshop temperature, and therefore that of the micrometer being used to measure the diameter, was 30°C.

When the workpiece is taken from the machine it will expand as its temperature rises to that of the workshop. Therefore, if the workpiece is measured before it reaches this temperature, the reading will be in error by eleven millionths of a millimetre for every millimetre of diameter for every degree Celsius difference in temperature between the coolant and the micrometer. In the above example, the error would be $-0.000\,011 \times 50 \times (30-15)$, i.e. $-0.008$ mm.

Consider a micrometer at shop temperature of 20°C and a steel workpiece just removed from a lathe after a turning operation in which it has become too hot to hold, for instance, 50°C. The error in this case would be $0.000\,011 \times 50 \times 30$, i.e. 0.0165 mm per 50 mm of diameter. Obviously, both workpiece and measuring equipment should be kept at the same temperature.

When the workpiece is not steel, however, an error in measurement will occur if the temperature is not standard, i.e. 20°C. This error is caused by the differing coefficients of linear expansion of different materials. For example, brass has a coefficient of 20 parts per million per degree Celsius and aluminium a coefficient of 23 parts per million. Therefore, even if the temperatures of a workpiece and a micrometer are the same, for example 35°C, then an error must occur when the temperature of both is 20°C. The micrometer will shrink 11 parts for every 23 parts that aluminium shrinks per unit length per degree Celsius.

In these cases, a calculation will always be necessary. For example, an aluminium cylinder was found to be exactly 100 mm in diameter when its temperature was 35°C. What was its true size at standard temperature?

$$
\begin{aligned}
\text{True size} &= \text{Reading} - \text{aluminium shrinkage} + \text{micrometer shrinkage} \\
&= 100.00 - (100 \times 23 \times 10^{-6} \times 15) + (100 \times 11 \times 10^{-6} \times 15) \\
&= 100.000 - (0.0345 + 0.0165) \\
&= 99.95 \text{ mm}
\end{aligned}
$$

This error was caused by the difference in shrinkages of the steel measuring equipment and the aluminium component.

It is appreciated that the errors indicated in this discussion are very small and within normal machining tolerances. The machinist must realize that these errors may reduce the tolerance within which he is expected to work unless he takes necessary precautions.

## Comparative measurement

Comparative measurement uses instruments that may be set to a known size. The size of the workpiece is compared with the known size by placing it between the measuring faces; the amount above or below the known size will be indicated.

It is common practice to use micrometers and similar instruments to obtain sizes by direct measurement. However, this may allow instrumental errors caused by 'feel' to make the measurement incorrect. To obviate these errors when precise measurements are required, it is recommended that the measuring instrument be used as a comparator. To do this, a standard is necessary, which should be either the exact size required, or as close as possible to the exact size, and with the same geometric shape as the workpiece. For instance, the first of a batch of components to be ground to a very closely toleranced diameter could be accurately checked in the inspection department and labelled with its actual size. Each successive component to be checked would then be compared with this by using a micrometer to establish any small difference in size between the component and the standard.

### Use of a Dial Gauge

An even better method than using the micrometer is to set up a dial gauge as a comparator, using a standard, as with the micrometer method. An accurate surface is necessary to take the place of the work table of a complete comparator. Figures 5, 6 and 7 show how this method could be applied.

Whichever method is used it is essential to keep the difference between standard and workpiece as small as possible so that errors of graduation, e.g. of the dial gauge, have little effect on the result.

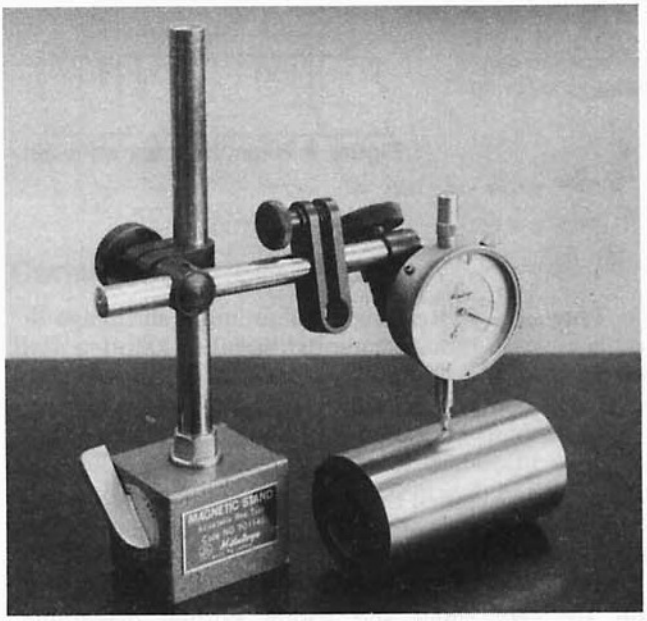


**Figure 5** Dial gauge used as a comparator

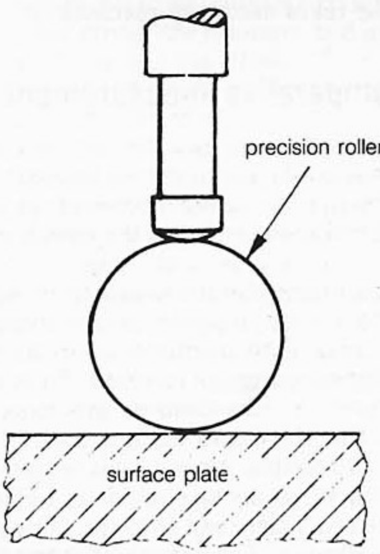



**Figure 6** Precision roller used as a standard

## Use of a Floating Carriage Micrometer

This type of micrometer was designed for the express purpose of measuring the minor and effective diameters of screw threads of V-form.

It operates on the principle of comparative measurement in that a standard of known size and approximately the same diameter as the screw thread is first mounted between the adjustable centres and a series of readings taken on the large micrometer drum. To facilitate these readings, an adjustable fiducial indicator is used to

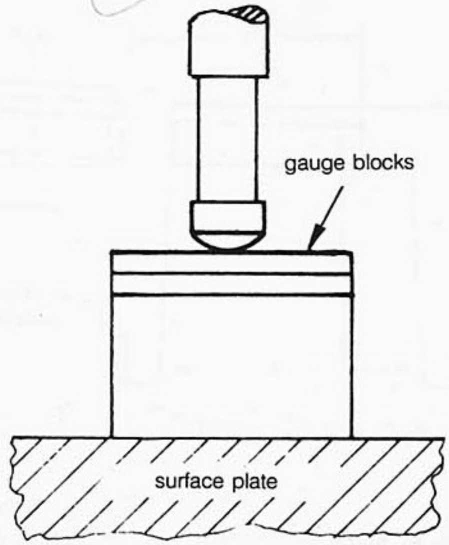



**Figure 7** Gauge blocks used as a standard

indicate when the correct pressure has been applied by the micrometer spindle. As the carriage is free to float normal to the direction of measurement, the spindle pressure is transmitted to the contact face of the fiducial indicator.

Having established a reading on the standard, this is removed and replaced by the screw thread to be measured. Precision prisms are used when checking the minor diameter, and precision cylinders when checking the effective diameter. These are supported in opposite sides of a thread groove and another set of readings is taken. As the size of the prisms or cylinders and the standard are accurately known, then it is possible to accurately ascertain the minor or effective diameter of the screw thread to an accuracy of 0.001 mm or 1 $\mu$m.

Because of the possibility of concentricity errors, which would result in inaccurate contact of the measuring faces of the spindle and the fiducial indicator, it is not recom-

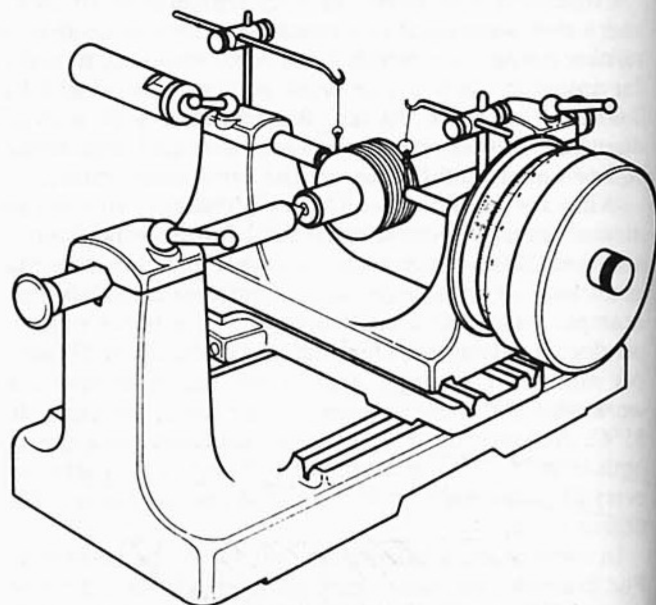


**Figure 8a** Floating carriage micrometer

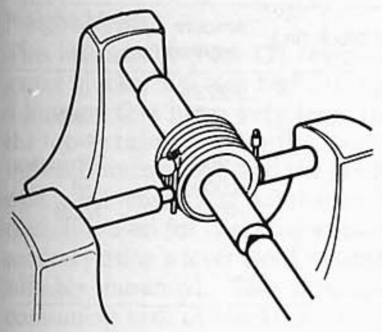


**Figure 8b** Using precision cylinders

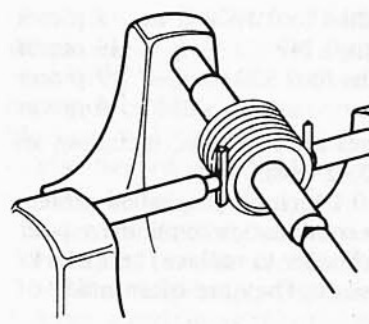


**Figure 8c** Using precision prisms

mended that these instruments be used for measuring plain cylinders supported between centres. Figure 8a shows a screw thread mounted in a floating carriage micrometer; Figure 8b shows precision cylinders being used to check the effective diameter, and Figure 8c shows precision prisms being used to check the minor diameter.

## The use of gauge blocks

Gauge blocks were invented about 1900 by C. E. Johansson, a Swedish engineer. They are made of high-grade steel and are hardened throughout (minimum hardness 800 HV). They have a cross-section 30 or 35 mm by 9 mm and the end faces of each gauge are ground and then lapped to a very high degree of flatnes, parallelism and separation (length) (see Fig. 9).

The flatness of the faces is such that when they are brought together, after first being carefully cleaned, they will adhere (i.e. wringing).

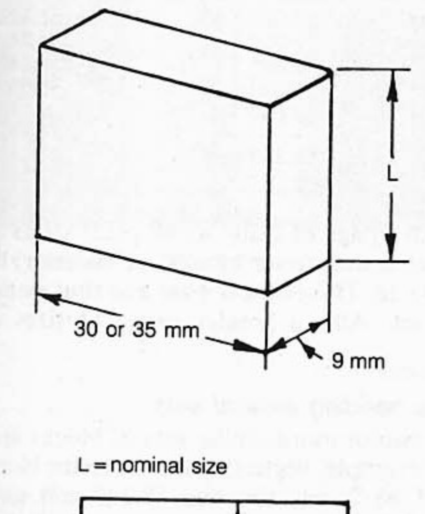



**Figure 9** Gauge blocks

Gauge blocks should be handled carefully to prevent burring, scratching, bruising, or even rusting. They should be carefully cleaned with Shellite to remove most of the protective petroleum jelly and then dipped in petroleum ether and allowed to dry naturally on a slip tray (Fig. 10).

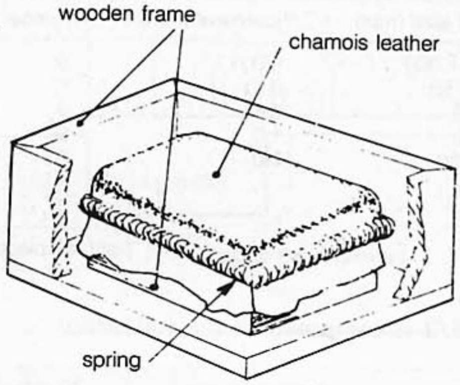



**Figure 10** Slip tray

When cleaned, blocks should be 'wrung' together by placing the wringing faces against each other at right angles and then pressing firmly while rotating the blocks a quarter turn to bring them into line.

This process involves application of the *wringing principle*. When two flat, lapped, mechanically clean surfaces are placed in contact with a sliding movement they will adhere strongly together with a force much greater than can be accounted for by atmospheric pressure alone; it remains even in a vacuum. It is generally accepted that there is a molecular adhesion between the surfaces and the liquid film between them. This film, which may be moisture from the fingers, or the residual film left after cleaning, is about 0.005 $\mu$m thick when a firm tight wring is obtained.

Blocks must not be left wrung together for long periods, say several days, otherwise they may become so strongly attached that the surfaces will be damaged when they are separated. The surface molecules interlock to produce a cold weld at the points of contact of the metal.

After using gauge blocks they should be carefully cleaned as before and coated with white, acid-free, petroleum jelly before being returned to their box.

## Composition of Gauge Sets

### English Sets

A typical set of gauge blocks E.81 (English 81 pieces) consists of the following:

- 0.1001 by ten-thousandths to 0.1009 — 9 pieces
- 0.101 by thousandths to 0.149 — 49 pieces
- 0.050 by five-hundredths to 0.950 — 19 pieces
- 1, 2, 3 and 4 inches — 4 pieces

Other smaller combinations are available, including an extra-thin series around 0.02 inch.

Many sets contain two 0.1 inch blocks, called protectors, used on each end of a combination to minimize wear on the other blocks. It is cheaper to replace these blocks than some of the larger sizes. They are often made of tungsten carbide.

### Metric Sets

Metric gauge block sets are available with either a 1 mm or a 2 mm base size. For example, set M41/1 is metric, with 41 pieces and 1 mm base; set M88/2 is metric, with 88 pieces and 2 mm base.

Set M41/1 is composed of the following:

| Range of size (mm) | Increment (mm) | Number of pieces |
|---|---|---|
| 1.001–1.009 | 0.001 | 9 |
| 1.01–1.09 | 0.01 | 9 |
| 1.1–1.9 | 0.1 | 9 |
| 1.0–9.0 | 1.0 | 9 |
| 10, 20, 30 | 10.0 | 3 |
| 60 | — | 1 |
| 100 | — | 1 |
| | Total | 41 pieces |

Set M88/2 is composed of the following:

| Size (mm) | Increment (mm) | Number of pieces |
|---|---|---|
| 2.0005 | — | 1 |
| 2.001–2.009 | 0.001 | 9 |
| 2.01–2.49 | 0.01 | 49 |
| 0.5–9.5 | 0.5 | 19 |
| 10–100 | 10.0 | 10 |
| | Total | 88 pieces |

Two protector slips, 2.0 mm long, are also supplied with each set.

## How to Use Gauge Blocks

Gauge blocks may be used to build up any length, within the range of the set, by using combinations of blocks. The smaller the number of blocks used in any combination, the less the chance of error. Also, if care is taken to always use the minimum number of blocks, then the effective life of the set will be extended.

### Selecting the Right Combination for a Given Size

*English measurement (using E81 set)*

The recommended method is to first select the protector blocks if applicable, and then work from right to left, eliminating the smallest units of the size first.

*Note:* Protector blocks can only be effectively used when the required size is above 12 mm (approximately 0.5 in.).

*Example:* Size required is 2.3731 in.

| Series from which block is selected | Size of block (in.) | Amount still required (in.) | |
|---|---|---|---|
| 1 Protector block | 0.1000 | 2.2731 | |
| 2 Protector block | 0.1000 | 2.1731 | Each |
| 3 Ten thousandth | 0.1001 | 2.0730 | step |
| 4 Thousandth | 0.1230 | 1.9500 | eliminates |
| 5 Hundredth | 0.9500 | 1.0000 | last |
| 6 Unit | 1.000 | Nil | figure |
| Total | 2.3731 in. | | |

For any required size up to 5 in. only four blocks, plus protector slips, are necessary.

*Metric measurement (using M41/1 set)*

*Example:* Size required is 58.343 mm

| Series from which block is selected | Size of block (mm) | Amount still required (mm) | |
|---|---|---|---|
| 1 Protector block | 2.000 | 56.343 | |
| 2 Protector block | 2.000 | 54.343 | |
| 3 Thousandth | 1.003 | 53.340 | |
| 4 Hundredth | 1.040 | 52.300 | Each |
| 5 Tenth | 1.300 | 51.000 | step |
| 6 Unit | 1.000 | 50.000 | eliminates |
| 7 Unit | 20.000 | 30.000 | last |
| 8 Unit | 30.000 | Nil | figure |
| Total | 58.343 mm | | |

*Metric measurement (using M 88/2 set)*

*Example:* Size required is 58.343 mm

| Series from which block is selected | Size of block (mm) | Amount still required (mm) |
|---|---|---|
| 1 Protector block | 2.000 | 56.343 |
| 2 Protector block | 2.000 | 54.343 |
| 3 Thousandth | 2.003 | 52.340 |
| 4 Hundredth | 2.340 | 50.000 |
| 5 Unit | 50.000 | Nil |
| Total | 58.343 mm | |

The main advantage of using an 88 piece set as against a 41 piece set is that fewer blocks are necessary to give the required size. This reduces wear and thus extends the life of the set. Also a greater range of sizes can be obtained.

*Applications needing several sets*

In practice, two or more similar sets of blocks are often needed. For example, neglecting the protector blocks and using an M 88/2 set, the size 58.343 mm could be obtained as follows:

| Combination 1 | Combination 2 | Combination 3 |
|---|---|---|
| 2.003 | 2.009 | 2.008 |
| 2.340 | 2.004 | 2.005 |
| 4.000 | 2.330 | 2.170 |
| 50.000 | 20.000 | 10.000 |
| | 30.000 | 40.000 |
| 58.343 mm | 58.343 mm | 58.343 mm |

### Height Master

This instrument (Fig. 11) resembles a stack of 20 mm gauge blocks, 300 mm high, staggered on each other in a housing that has a very large micrometer thimble on the top to raise or lower the stack 20 mm. The pitch of the micrometer screw and the graduations of the thimble enable movements of 0.001 mm to be easily made and read. It is used for checking work or machine movement accuracy using a lever clock indicator or electronic probe suitably mounted. The instrument saves the time-consuming task of stacking gauge blocks for the same result. The Imperial instrument has a 1 in. travel.

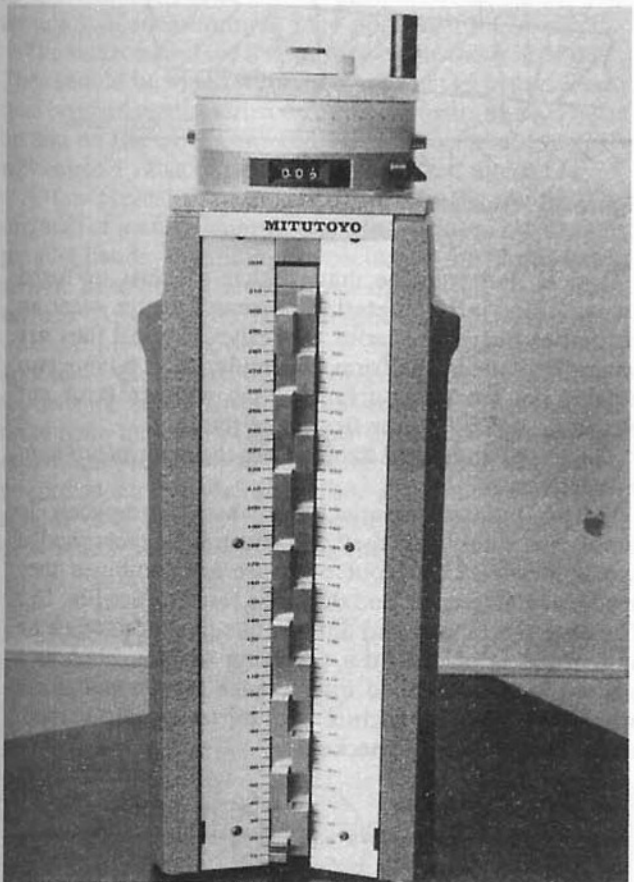



**Figure 11** Vertical heightmaster

### Using Gauge Blocks to Check Gap Width

When checking the size of a gap, or similar feature, the method of 'halving the difference' is the most efficient means of building up the correct combination of gauge blocks.

The method is applied as follows:

1 Using a rule, a range of sizes, including the size required, is determined as accurately as possible. For example, for the sketch shown in Figure 12, it is obvious that the gap width is between 14 and 15 mm.
2 After ascertaining that the gap is in fact between 14 and 15 mm, by trying the appropriate gauge block packs the next combination tried would be 14.5 mm, the size mid-way between 14 and 15 mm.
3 Assuming that the 14.5 mm combination entered the gap, the next size to be built up would be 14.75 mm.

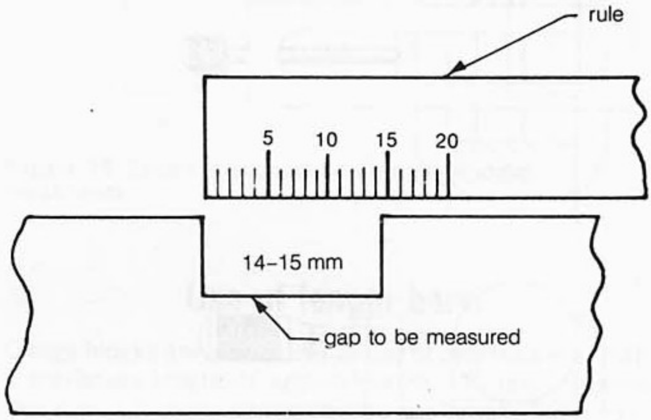



**Figure 12** Measuring a gap

4 Should this combination not enter the gap the next size tried would be $\frac{14.75 + 14.5}{2}$, i.e. 14.625 mm
5 The difference between the smallest 'not go in' pack and the largest 'go in' pack is halved until the correct size is obtained.

This method eliminates much of the guess work and invariably results in quicker determination of size.

## Accuracy of Gauge Blocks

There are four grades of accuracy of gauge blocks. Those grades are listed in A.S. 1457–1973.

Table 1 Tolerances for gauge blocks

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Range of nominal sizes (mm) | | Tolerances (μm) | | | | | | | | | | | |
| | | Grade 00 | | | Grade 0 | | | Grade 1 | | | Grade 2 | | |
| Above | Up to and including | Gauge length ± | Parallelism | Flatness | Gauge length ± | Parallelism | Flatness | Gauge length ± | Parallelism | Flatness | Gauge length ± | Parallelism | Flatness |
| — | 10 | 0.06 | 0.06 | 0.05 | 0.12 | 0.10 | 0.10 | 0.20 | 0.16 | 0.15 | 0.45 | 0.30 | 0.25 |
| 10 | 25 | 0.08 | 0.06 | 0.05 | 0.14 | 0.10 | 0.10 | 0.30 | 0.16 | 0.15 | 0.60 | 0.30 | 0.25 |
| 25 | 50 | 0.10 | 0.06 | 0.05 | 0.20 | 0.10 | 0.10 | 0.40 | 0.18 | 0.15 | 0.80 | 0.30 | 0.25 |
| 50 | 75 | 0.12 | 0.06 | 0.05 | 0.25 | 0.12 | 0.10 | 0.50 | 0.18 | 0.15 | 1.00 | 0.35 | 0.25 |
| 75 | 100 | 0.14 | 0.06 | 0.05 | 0.30 | 0.12 | 0.10 | 0.60 | 0.20 | 0.15 | 1.20 | 0.35 | 0.25 |

There is no real advantage in using reference blocks 00, as the sizes of the calibration grade (0) are accurately known and the accuracies of the flatness and parallelism are close to those of reference blocks. The inspection grade (Grade 1) blocks are suitable as standards for the highest class of gauge inspection. The workshop (or Grade 2) blocks are quite adequate for everyday work, even in a works' metrology room, but they should be regularly tested for flatness and size against a master set.

## Gauge Block Accessories

Various forms of holders and accessories are available for use with gauge blocks and are shown in Figures 13 and 14. All of these have lapped faces where contact with block faces is made.

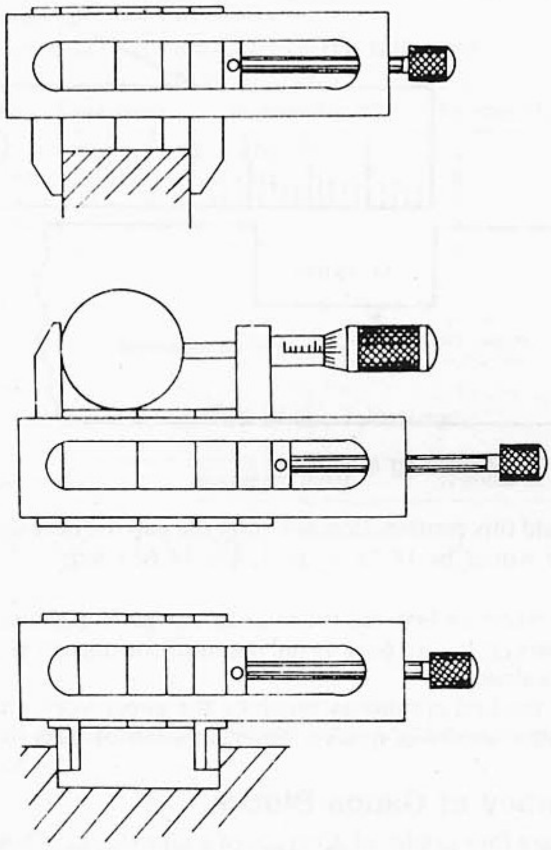


**Figure 13** Examples of built-up gauges

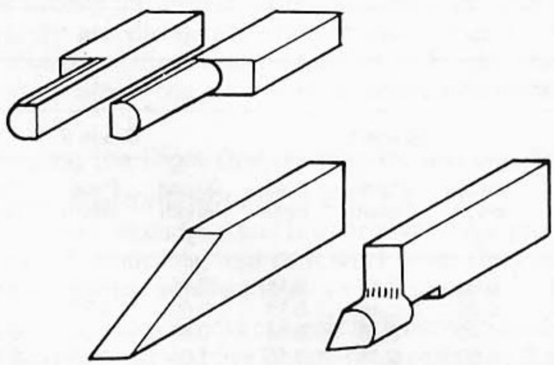


**Figure 14** Block gauge accessories

## Using an Optical Flat to test Flatness of Gauge Blocks

Over a period of time gauge blocks become worn, and they may be difficult to wring together. As the wringing property of gauge blocks depends on the quality of flatness of the gauging surfaces these should be checked periodically. The method of testing the flatness of gauge blocks is by means of light interference, using an optical flat as a reference plane (Fig. 15).

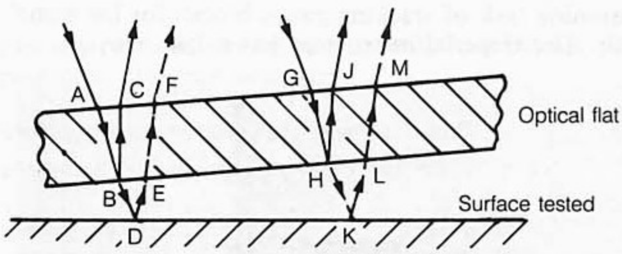



**Figure 15** Principle of the optical flat

Optical flats may be made either of glass or fused quartz. The latter material possesses better wearing properties but is the more expensive. Optical flats are generally made in the form of circular discs having two parallel flat working surfaces, each with an error not exceeding 0.000 05 mm from true flatness.

The use of an optical flat involves the *principle of light interference.*

If two monochromatic light waves, completely in phase, are combined, they will cause brightness, and if two light waves 180° out of phase are combined they produce interference, and darkness results. (See Fig. 16.) The alternate bright and dark bands produced when an optical flat is placed on a reflecting surface, such as a gauge block, are called interference fringes and these provide an accurate picture, similar to a contour map, of the surface being checked.

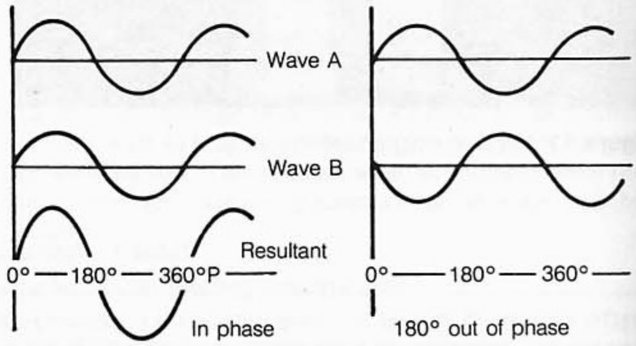



**Figure 16** Cause of interference bands

The optical flat shown in Figure 15 is inclined slightly to a flat reflecting surface, which is being examined for flatness. A ray of light entering the optical flat at A is partly reflected at B to emerge at C, and partly transmitted to be reflected at D along the path DEF. The emerging rays at C and F have slightly different directions but they can be brought together by an optical system such as the eye. The difference between the lengths of the paths taken by the two rays is $BD + DE$ and if this distance is an even number of half-wavelengths, the rays are in phase and a bright band is seen. At another position, G, the path difference $HK + KL$ may be an odd number of half-wavelengths, causing the rays from J and M to interfere, thus producing darkness.

Between consecutive dark bands the path difference alters by a whole wavelength and therefore the separation between the flat and the surface changes by a wavelength. Knowing the wavelength of the light used, the inaccuracies in the surface can be measured. The change in separation per band is usually taken as 0.3 μm (μm = micro = 0.000 001), and it is possible to estimate to approximately $\frac{1}{10}$ of the distance between bands. The accuracy of measurement may approach 0.02 μm.

The surfaces and the flat must be clean and free of dust. They should be wiped with a solvent such as benzine, and then brushed gently with a camel hair brush. The flat must be laid on the work, not slid across the surface, as this will cause a false pattern of interference bands.

A few typical patterns are shown in Figure 17. The surfaces at a and b are flat and are indicated by straight parallel bands, the different spacing of the bands being caused by different inclinations of the flat to the test surface. At c, the surface is spherical. To determine whether it is convex or concave, light finger pressure is applied at the centre of the rings. If the bands move towards the centre the surface is concave. If they move away from the centre the surface is convex. The surface at d is curved more in one direction than the other. e represents a cylindrical surface and f indicates either a ridge or a valley. Light pressure of the fingers will determine which of the two is the case.

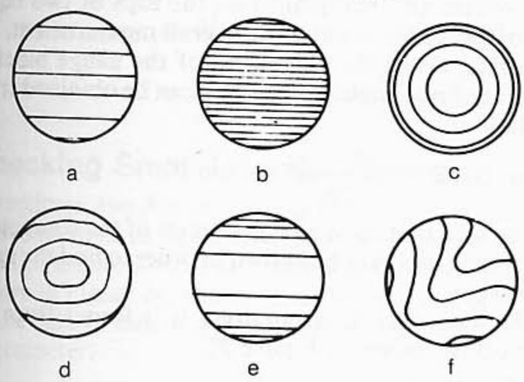



**Figure 17** Typical interference patterns

When checking gauge blocks, errors in transverse and longitudinal flatness are determined from the shape of the fringe on the gauge. Thus Figure 18a shows an error in transverse flatness of approximately one-third of a fringe spacing, that is, approximately 0.1 μm or 0.000 0001 m, if the half-wavelength of the light used is taken as 0.6 μm or $6 \times 10^{-7}$m. Figure 18b shows a gauge with a longitudinal error of approximately one fringe space or 0.000 0003 m.


**Figure 18** Errors in transverse and longitudinal flatness

Errors in transverse and longitudinal parallelism are determined from the fringes on the gauge relative to those on the platen. Figure 19a shows a gauge with an error in transverse parallelism of approximately one-half of a fringe spacing and Figure 19b shows a longitudinal error in parallelism of approximately one-third of a fringe spacing.

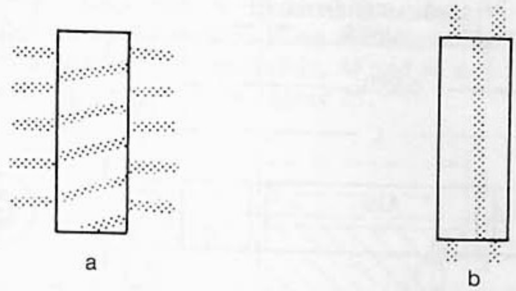



**Figure 19** Errors in transverse and longitudinal parallelism

## Use of length bars

Gauge blocks are convenient to use in combination, with a maximum length of approximately 150 mm. Beyond this size it is more convenient to use length bars.

### Sizes

Length bars are made in sizes from 25 mm to 1200 mm and are approximately 22 mm in diameter. They are made from high-quality tool steel, hardened and stabilized to a rigid specification. The body of each bar is finish-ground and the end faces are lapped to provide wringing properties. The hardness number of the end faces is specified as 'not less than 800 diamond pyramid hardness number' (approximately 62 Rockwell C).

The relevant Standard lays down the maximum permissible errors of accuracy related to length, straightness, flatness and parallelism of end faces, and diameter, according to their grade in BS 1790–1961.

### Grades

There are four grades, as follows:

- *Reference grade length bars*, which are intended as reference standards. They have plane faces and are made to extremely close tolerances and are supplied with an NPL calibration certificate, which indicates any deviation from nominal length or flatness and parallelism of the end faces.
- *Calibration grade length bars*, which have the same degree of perfection in their working features as the reference bars but have somewhat wider tolerances, which permits them to be made more economically. These also should only be used in conjunction with a calibration certificate.
- *Inspection grade length bars*, which have internally threaded ends and can be used in combination. They are intended for use in inspection and toolrooms.

- *Workshop grade length bars*, which also have internally threaded ends and can be used with slip gauges, comparators, and other accessories for the measurement of gauges and fixtures, and in general workshop applications.

Figure 20 shows essential features of the various grades.

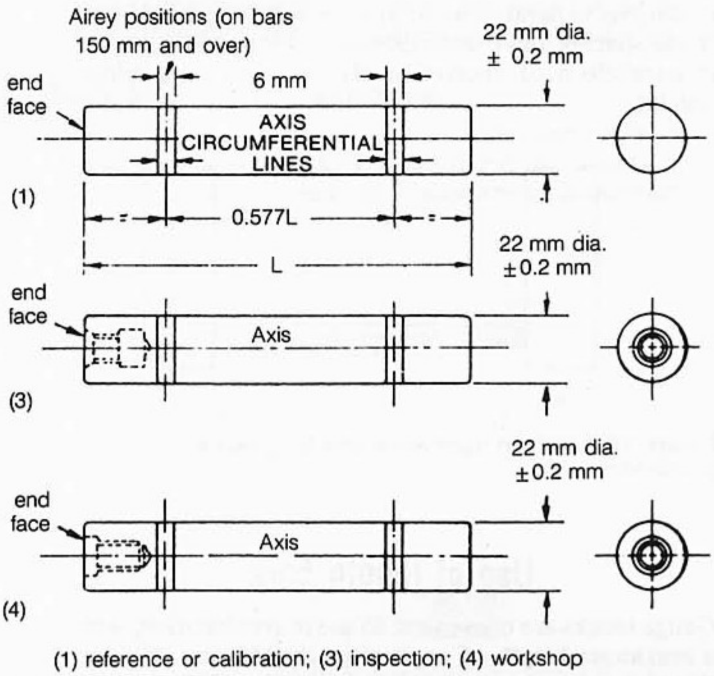



**Figure 20** Grade of length bars (1) reference or calibration; (3) inspection; (4) workshop

### Use of Studs

When a number of Inspection or Workshop length bars are to be used in combination, short loose-fitting studs are used to join each bar. A loose-fitting stud is essential to ensure that the lapped end faces make correct contact and wring together.

### Airey Points

Length bars 150 mm or over have two circumferential lines inscribed around the bar to indicate the position of support when they are used in the horizontal position. The positions at which the lines are inscribed are known as the 'Airey points' and are equivalent to a distance of $0.5773L$, where $L$ is the length of the bar. When a length bar is supported at the Airey points the two ends of the bar axis are collinear. It follows that the two end faces will be parallel to each other in this condition.

### Storage of Length Bars

After use, length bars should be cleaned in a similar manner to gauge blocks and given a light coating of acid-free petroleum jelly. They should be stored in a dry, wooden, felt-lined box, incorporating some means of supporting each bar at its Airey points. Ideally, they should then be stored in a standards room at controlled temperature.

## Use of balls, rollers and discs in precision measurement

Precision balls and rollers are used, in conjunction with gauge blocks, for the absolute measurement of tapers and angles. They are also applied to the measurement of parallel bores such as plain ring gauges.

### Checking External Tapers

Figure 21 illustrates the measurement of a component such as a taper plug gauge, for both angle and size, by means of gauge blocks, precision rollers and an outside micrometer.

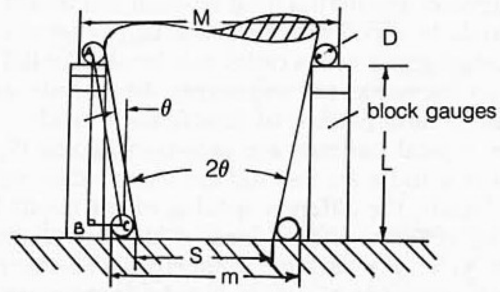



**Figure 21** Measuring with block gauges

The component is placed on a horizontal surface plate on which is a pair of equal precision rollers in contact with the tapered surface, as shown in Figure 21. The overall measurement, $m$, is obtained with a micrometer, care being taken that the measuring pressure is not excessive.

The rollers are then placed on the tops of two equal packs of gauge blocks and the overall measurement, $M$, is obtained. Since the height, $L$, of the gauge block is known, the semi-angle of the taper can be obtained from the relation:

$$\tan \text{BAC} = \frac{M - m}{2L} = \tan \theta$$

It can be seen that the actual diameters of the component or the rollers need not be known in order to find the angle of the taper.

If the diameter, $S$, is required, it is found from the relationships shown in Figure 22.

From Figure 22:

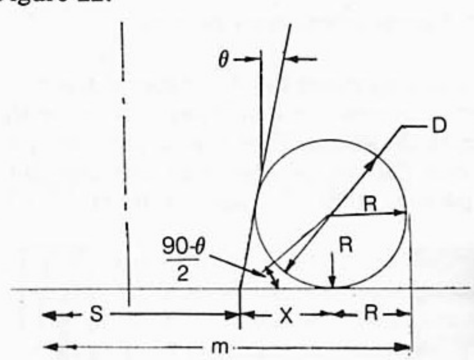



**Figure 22** Relationships for diameter S

$$S = m - 2x - 2R$$

Now $x = R \text{ cotan } \dfrac{90 - \theta}{2}$

$$\text{Therefore } S = m - 2R \cot \frac{90 - \theta}{2} - 2R$$

$$= m - 2R \left(\cot \frac{90 - \theta}{2} + 1\right)$$

$$\text{Therefore } S = m - D \left(\cot \frac{90 - \theta}{2} + 1\right)$$

## Checking Internal Tapers

When the component to be checked has an internal taper, precision balls and gauge blocks are applied as follows.

If the diameter of the taper is large enough, gauge blocks in increasing sizes are placed between the balls until the largest possible sizes are obtained without force, with the arrangements as shown in Figure 23.

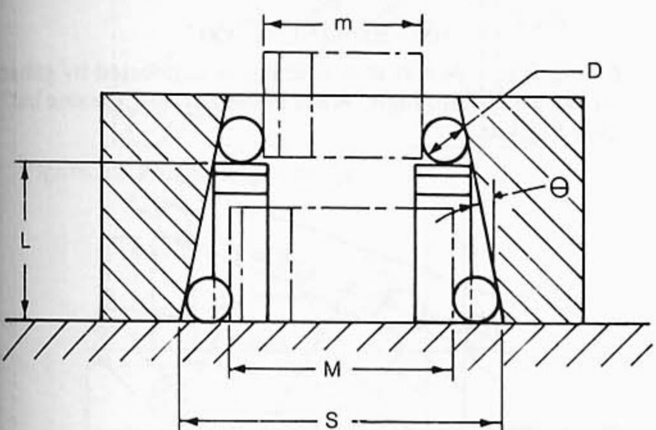



**Figure 23** Measuring internal tapers

$$\text{Then } \tan \theta = \frac{M - m}{2L}$$

$$\text{and } S = M + D \left(\cot \frac{90 - \theta}{2} + 1\right)$$

## Checking Small Internal Tapers

Sometimes, the diameter of the taper is too small for the above method to be applied. In this case, two precision balls of different sizes are placed in the bore in turn, as shown in Figure 24, and the relative heights from the tops of the balls to the surface plate are measured with a height micrometer.

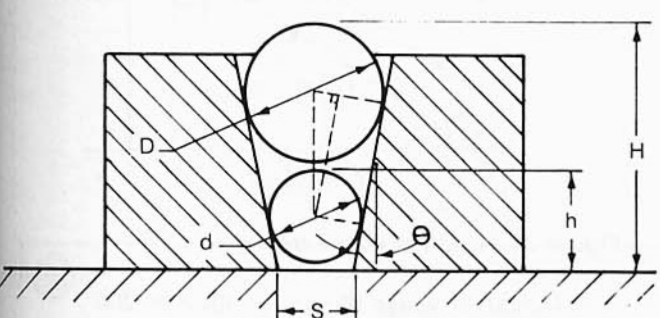



**Figure 24** Use of precision balls to measure small internal tapers

To check the angle  In this case:

$$\sin \theta = \frac{D - d}{2\left(H - \frac{D}{2} - h + \frac{d}{2}\right)}$$

$$\text{i.e. } \sin \theta = \frac{D - d}{2(H - h) - (D - d)}$$

To check the diameter or width, $S$:

$$S = (d(\operatorname{cosec} \theta + 1) - 2h) \tan \theta$$

To check the height  When $S$ is the size to be obtained by machining, the height, $h$, can be found by transposition of the formula for $S$:

$$\text{i.e. } h = \frac{d(\operatorname{cosec} \theta + 1) - S \cot \theta}{2}$$

## Checking Dovetail Slides

Dovetail slides can be checked for angle, size and parallelism by the method given for external tapers. To check an external dovetail slide, $M$ and $m$ are obtained with a micrometer, as in Figure 25.

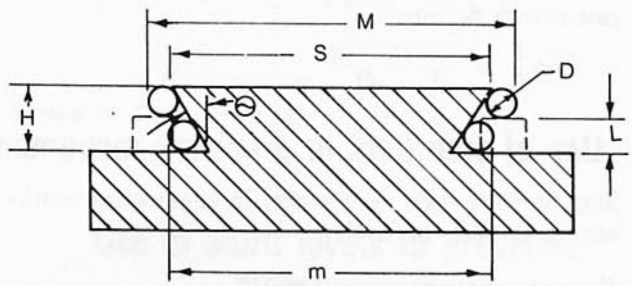



**Figure 25** Checking external dovetail slides

To check the angle  Use the formula:

$$\tan \theta = \frac{M - m}{2L}$$

To check the width  Use the formula:

$$S = m - D\left(\cot \frac{90 - \theta}{2} + 1\right) + 2H \tan \theta$$

For an *internal dovetail*, $M$ and $m$ are obtained by using block gauges (See Fig. 26), and the calculations are then as follows:

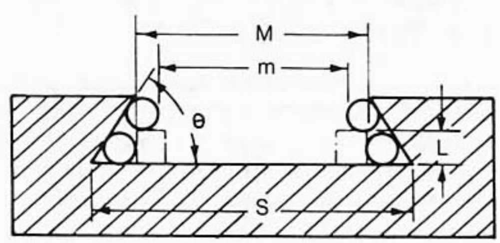



**Figure 26** Checking internal dovetail slides

To check the angle:

$$\tan \theta = \frac{M - m}{2L}$$

To check the width:

$$S = M + D\left(\cot \frac{90 - \theta}{2} + 1\right)$$

## Checking Taper Angles

Taper angles can be accurately set or measured by using standard discs as shown in Figure 27.

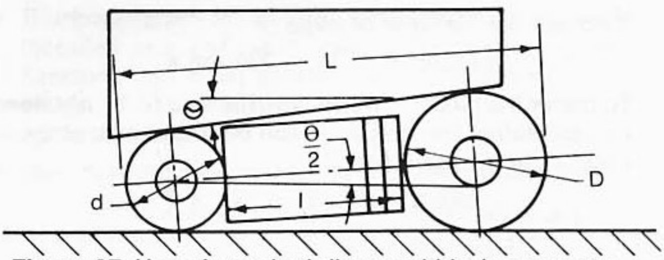



**Figure 27** Use of standard discs and block gauges to set an angle

Where gauge blocks are used between the discs the angle is found from the relation:

$$\sin\frac{\theta}{2} = \frac{D - d}{2l + D + d}$$

Where a micrometer is used, as in measuring $L$, the calculation becomes:

$$\sin\frac{\theta}{2} = \frac{D - d}{2L - D - d}$$

## Use of sine bars in precision movement

Sine bars are used very widely in engineering works to measure angles precisely.

### Construction

A sine bar consists of a rectangular section bar made from suitable gauge steel with two equal-diameter cylinders attached so that the line joining the centres of the cylinders is exactly parallel to the edges of the bar. The centre distance between the cylinders is arranged to be either 100, 200, 250 or 300 mm for workshop-types of sine bars. The most usual centre distance is 100 mm. Three types of sine bar are illustrated in Figure 28.

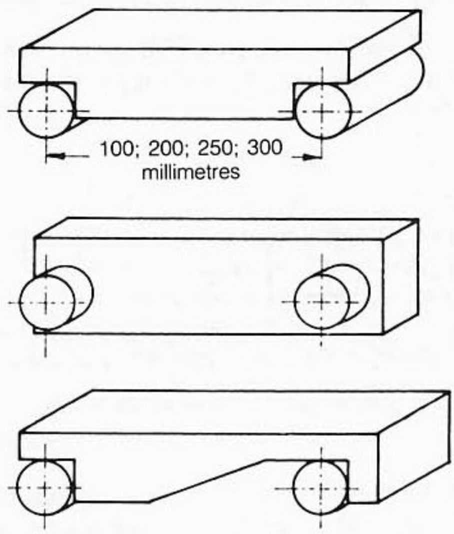



**Figure 28** Sine bars

### Principle and Application

The sine bar is based on the principle that the centre distance between the cylinders is employed as the hypotenuse of a right angle, ABC (see Fig. 29).

The height $BC$ enables the value of the angle to be calculated from its sine, using the following relationship:

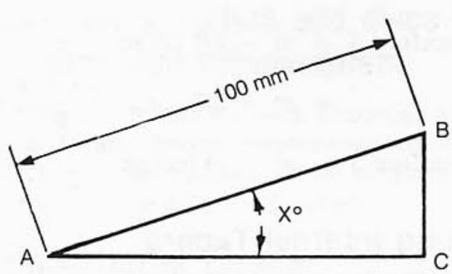



**Figure 29** Relationship of angle to sides of the triangle

$$\sin\theta = \frac{BC}{AB}$$

Since $AB$ is a fixed centre distance, then

$$\sin\theta = \frac{BC}{100,\ 200,\ 250,\ \text{or}\ 300}$$

*Example 1:* A 100 mm sine bar is supported by gauge blocks 20.79 mm high. What is the angle of the sine bar? (See Fig. 30.)

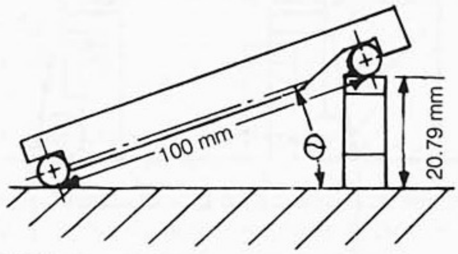



**Figure 30** Angle of sine bar

$$\begin{aligned}\sin\theta &= \frac{\text{height of gauge blocks}}{100}\\ &= \frac{20.79}{100}\\ \sin 12° &= 0.2079\\ \theta &= 12°0'\end{aligned}$$

*Example 2:* A 200 mm sine bar is to be set up at 27°30′. What is the height of the gauge blocks? (See Fig. 31.)

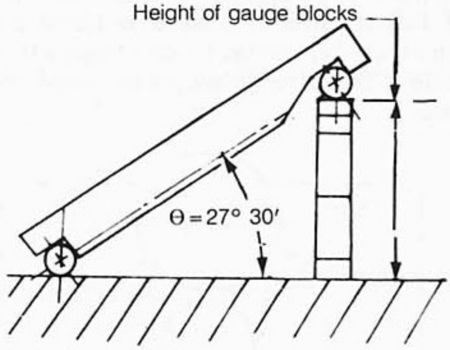



**Figure 31** Height of gauge blocks

$$\begin{aligned}\text{Height of gauge blocks} &= \sin\theta \times 200\\ &= \sin 27°30' \times 200\\ &= 0.4617 \times 200\\ &= 92.34\ \text{mm}\end{aligned}$$

### Accuracy of a Sine Bar

As the accuracy of manufacture of a sine bar should be within 0.002 mm and gauge blocks can be used to obtain the height $BC$ to within 0.002 mm, the angular accuracy obtainable is about 0°0′5″, that is, 5 seconds of arc.

This accuracy decreases as the angle increases, however, so that for angles greater than 45 degrees it is better to use the complement of the angle. The application of a sine bar to set up a simple angle gauge for grinding is illustrated in Figures 32 and 33.

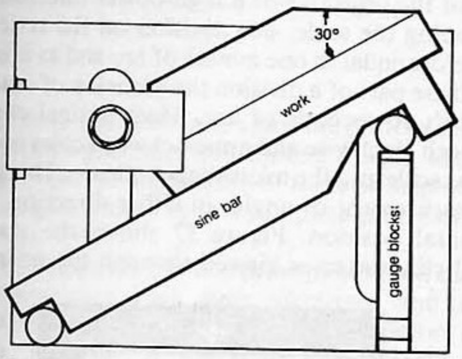



**Figure 32** Simple angle gauge

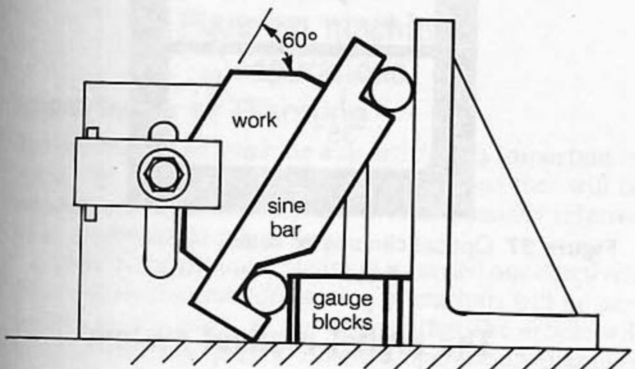



**Figure 33** Using sine bar to set work at 60° angle

## Sine Centres

Sine centres, which developed from the sine bar, facilitate the checking of external taper gauges that have been centred. The principle of use is the same as for sine bars, but it should be noted that for a set-up as shown in Figure 34 the sine of the semi-angle ($\theta$) is equal to $H/L$.

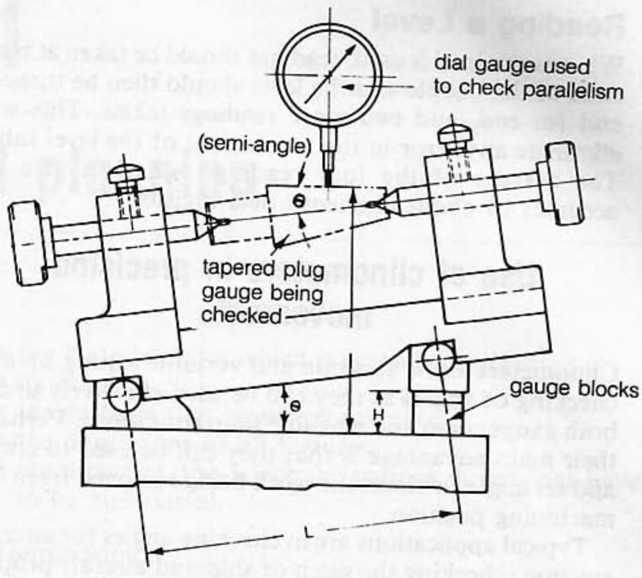



**Figure 34** Sine centre set up

# Use of spirit levels in precision measurement

## Construction and Use

The essential part of an engineer's precision level is a glass tube with a bore accurately ground to a barrel shape, and of a large radius. For general precision work this radius is about 52 m. The tube is almost completely filled with alcohol or similar fluid, and then sealed. The small space remaining in the tube will allow the bubble to move along it for a distance depending on the angle of tilt.

The glass tube is mounted on a suitable flat base, and, in some levels, provision is made for adjustment of the mounting. When the base of the level is horizontal, the ends of the bubble are very close to two main reference lines engraved on the tube. Graduation lines are engraved on the tube on both sides of these reference lines, each graduation representing a very small deviation of the base from horizontal. (Figure 35).

The sensitivity of a level is measured by the amount of tilt of the base represented by one division of the graduations. For most purposes, the sensitivity required is in the order of 0.005 per 100 millimetres per division, i.e. a tilt of 0°0′10″, which is 10″ (seconds) tilt.

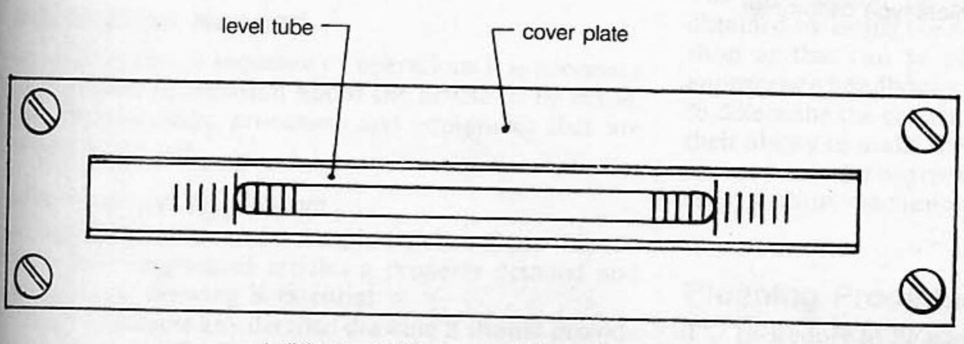



**Figure 35** Typical level tube and cover plate in a precision level

## Reading a Level

Whenever a level is used, readings should be taken at both ends of the bubble and the level should then be turned, end for end, and two more readings taken. This will eliminate any error in the adjustment of the level tube. The average of the four readings will then give an accuracy of about one-tenth of a division.

# Use of clinometers in precision movement

Clinometers allow accurate and versatile setting up and checking of angles as they can be used effectively under both gauge room and machine shop conditions. Perhaps their main advantage is that they can be used to check and set angles without the work being removed from the machining position.

Typical applications are in checking angles for aircraft erection, checking the pitch of ship and aircraft propellors, for setting and marking graduations, and for checking angle gauges and angular fixtures.

Clinometers embody a number of measuring principles and may be broadly classified as either mechanical or optical types.

## Mechanical Clinometres

In the mechanical type, a precision level is fitted to a rotating drum, which is directly calibrated in degrees. The drum can be rotated by means of a worm and wormwheel to an accuracy of one minute of arc.

The sensitive spirit level provides the horizontal datum from which all inclinations are measured. Figure 36 shows the principle of a mechanical type of clinometer.

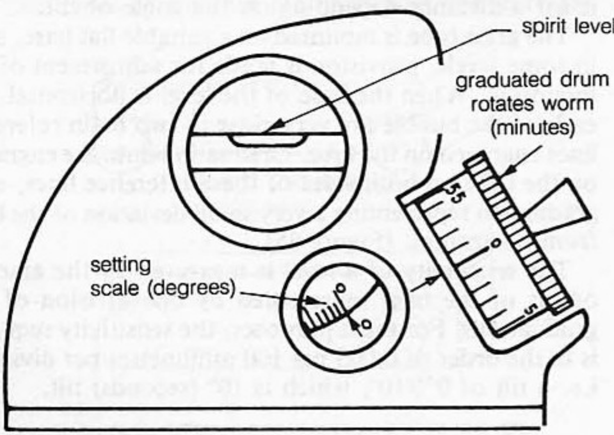



**Figure 36** Principle of mechanical-type clinometer

## Optical Clinometers

These are similar in construction to the mechanical type except for the method of reading the angular setting.

Optical clinometers rely for their accuracy on a circular glass disc, on which is printed a finely divided degree scale. For subdivision, a reticule of 60 divisions, corresponding to one degree on the circle, is placed in the focal plane of the objective of a high-power microscope used for reading the scale; one division on the reticule scale is therefore equal to one minute of arc and as it is possible to estimate part of a division the accuracy of reading may approach 10 seconds of arc. Most optical clinometers have both clockwise and anticlockwise scales on both the circular scale and the microscope reticule. This facilitates the measurement of angles in either direction from the horizontal position. Figure 37 shows the scale of an optical clinometer as viewed through the microscope.

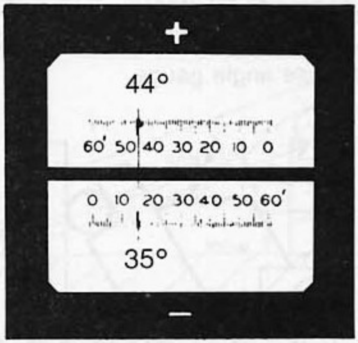



**Figure 37** Optical clinometer scale

# The digital readout system

The system is fitted to many machines to facilitate the accurate movement of machine slides. A precision glass scale enclosed in a dust proof housing is the measuring standard; it is graduated with alternate lines and spaces 20 $\mu$m wide. A light is focused through the glass and through an accurately slotted plate onto photoelectric cells; as the scale moves in relation to them, electrical pulses are produced, which are counted by the readout in + or – values as selected. The readings are to 0.01 mm (0.0005 in.).

The same principle is used on a disc to enable 1 second of rotary movement to be achieved. Other versions and attachments by various manufactures are also available.

# 25

# Drilling machines

## Types of drilling machine

### The Bench Drill

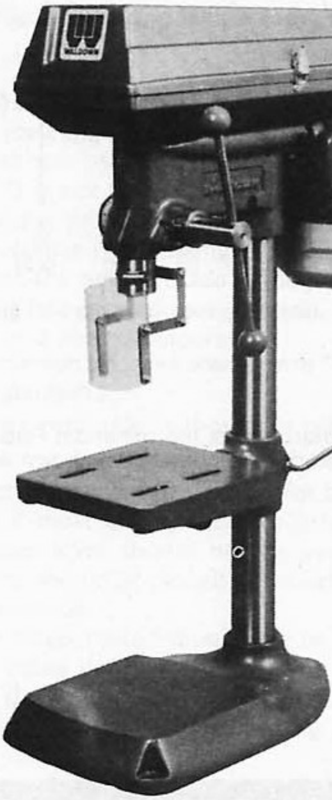



**Figure 1** Bench drill

Bench drills (Fig. 1) are small, very useful machines, which come in a vast range of models and speeds and are fitted with drill chuck or No. 1 or 2 morse taper to accept drills or cutters. A 13 mm diameter is the commonly accepted capacity. Machines with a round table allow work to be clamped, rotating the table and swivelling on the column enables the work to be brought under the drill without being reclamped. Machines with a square table are usually pivoted on to the column swivel, which allows for tilting at an angle or for bringing the surface into the vertical position. Some of these machines may have a taller column for mounting to the floor and are commonly called pedestal drilling machines.

### The Pillar Drill

The pillar drill (Fig. 2) is a much larger version of the pedestal drill, with a geared head and integrated electric

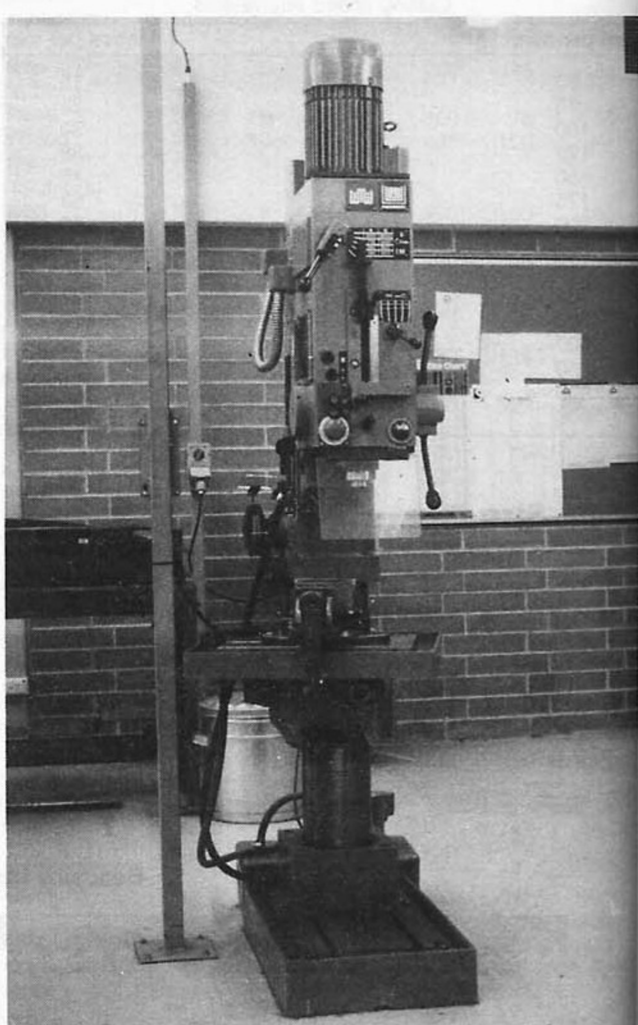


**Figure 2** Pillar drilling machine

motor. The spindle is either No. 3 or 4 morse, and a common speed range can be from 70 to 1700 r.p.m. and a power feed of 0.1 to 0.5 mm/rev of spindle.

The spindle can be reversed by using a gear lever or by reversing the motor. Reversing should be used whenever possible for tapping, as it is a time saver. The use of a releasing tapping chuck for safety against tap breakage is desirable.

### The Radial Drill

The radial drill (Fig. 3) has a large diameter column mounted on a floor table, which forms the base of the machine. A machine slide-way is integral with the arm, which can be raised or lowered and rotated about the

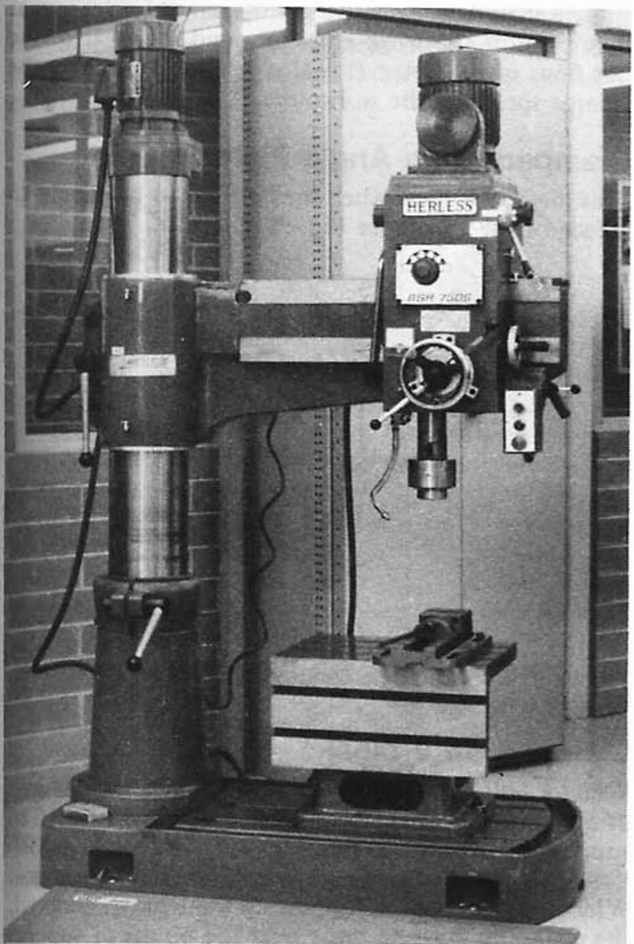



**Figure 3** Radial drill

column, and is at right angles to it. A saddle is manually traversed along the arm and contains the motor, gearbox, speed, feed and reverse selection levers, and hand or power feed to the spindle, which, depending on machine size, can be as large as No. 5 morse taper. A box table is usually used on the base table to enable the majority of jobs to be done at a convenient working height. Some machines also have a table attached to the column and swivelling around it.

Radial drills are constructed in a vast range of sizes with arm lengths from 600 to 4000 mm and appropriate speeds and feeds. The radial drilling machine is the most convenient and easy to use as the spindle can be brought with ease to any position over the work.

## Multi-spindle Drill

Multi-spindle drills (Fig. 4) are used for production work where many holes or faces are produced simultaneously by rotating the tools, using a drill jig to guide them. The spindles, driven by universal joints and a telescoping shaft, are either mounted in a masterplate identical with the jig or on adjustable arms, and are set at the required centres. Some machines built for long-run production have special gear boxes carrying the spindles at fixed centres.

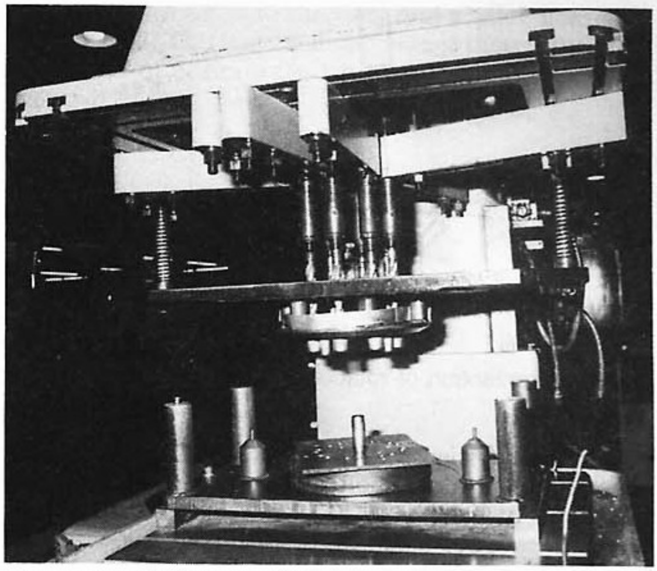


**Figure 4** Multi-spindle drill

### Multi-spindle Heads

Multi-spindle heads (Fig. 5) are constructed for fixed centre multi-hole drilling and are attached to a standard drilling machine.

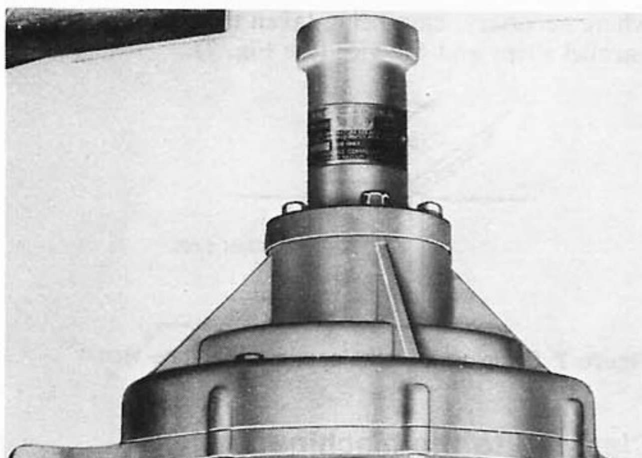


**Figure 5** Multi-spindle head

## Setting up and holding work for drilling

When drilling, the cutting action tends to cause the workpiece to rotate with the drill. As this could cause injury to the operator and damage to the drill and workpiece, steps should be taken to prevent movement.

Sometimes the use of one or more stops to prevent

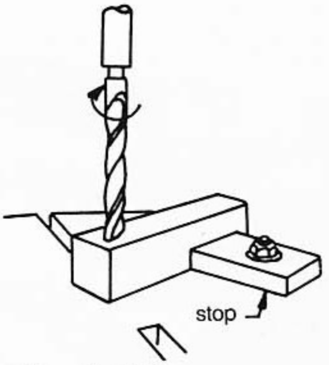



**Figure 6** Prevention of rotation

rotation is sufficient (see Fig. 6). Small holes or large heavy pieces of work are often drilled with the work being held down by hand or by its own weight. In other cases the work must be clamped, as described below.

## Using a Machine Vice

A machine vice is suitable for clamping a large variety of small workpieces and is particularly suited to workpieces that are parallel in width and thickness.

The vice should be bolted to the table of the machine or prevented from rotating by means of a stop.

Parallel strips should be used to support the work where necessary, care being taken to avoid drilling the parallel strips and the vice (see Fig. 7).

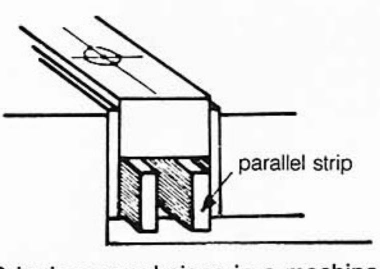



**Figure 7** Gripping a workpiece in a machine vice

## Clamped to the Machine Table

When the hole to be drilled has to be perpendicular to the base of the workpiece, this method is very satisfactory.

If the hole has to be drilled completely through, the workpiece should be supported on parallel strips to avoid drilling the machine table, if no clearance hole is provided in the table (see Fig. 8).

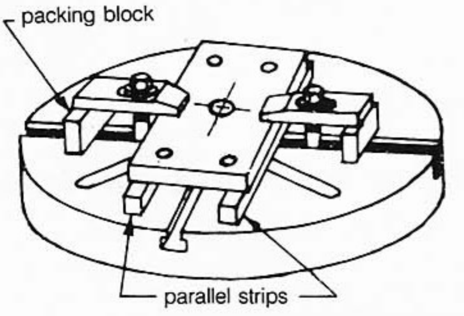



**Figure 8** Workpiece supported on parallel strips and clamped to the table

Care should be taken to place the parallel strips so that they support the work efficiently and are clear of the positions of the holes. It is also essential to prevent the clamps springing the workpiece.

## Clamped to an Angle Plate

This method is ideal when the hole has to be parallel to a face of the work (see Fig. 9).

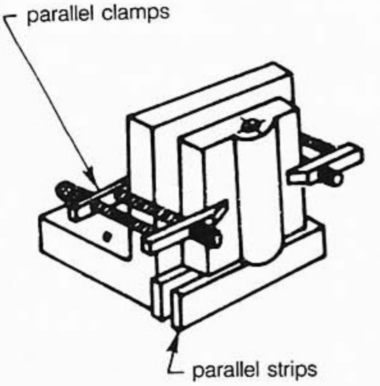



**Figure 9** Workpiece clamped an angle plate

## Clamped on V-blocks

When a hole is to be drilled at right angles to the axis of a cylindrical workpiece, V-blocks should be used to support the workpiece (see Fig. 10). The marked position of the hole should be set centrally on the vertical axis. Whichever method of supporting the work is adopted, the clamping must be done over the points of support and care must be taken to avoid drilling the machine table, parallel strips, V-blocks, machine vice, etc.

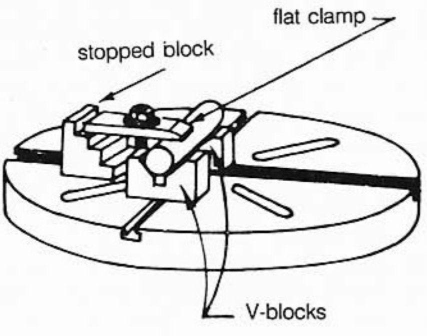



**Figure 10** Workpiece clamped to V-blocks

# Drilling a hole to marking out

When starting to drill a hole, the drill often has a tendency to move from the required position. This problem can usually be prevented by first 'spotting' the position using a smaller drill.

If the drill does move from the required position (Fig. 11a) the displacement may be corrected by chipping a groove using a round-nosed chisel on the side opposite to the direction in which the drill has run (Fig. 11b). The drill tends to cut more freely where the workpiece has been grooved and this 'draws' the drill back to its original position. The above procedure may have to be repeated several times before the drill is centred.

The correction should be made when about one-half of the point of the drill has entered the work, as it obviously cannot be done once the body of the drill has entered the hole.

Another method is to carefully drill a 'pilot' hole with a centre drill. This has the disadvantage that, if the pilot hole is out of position the larger drill cannot be drawn over.

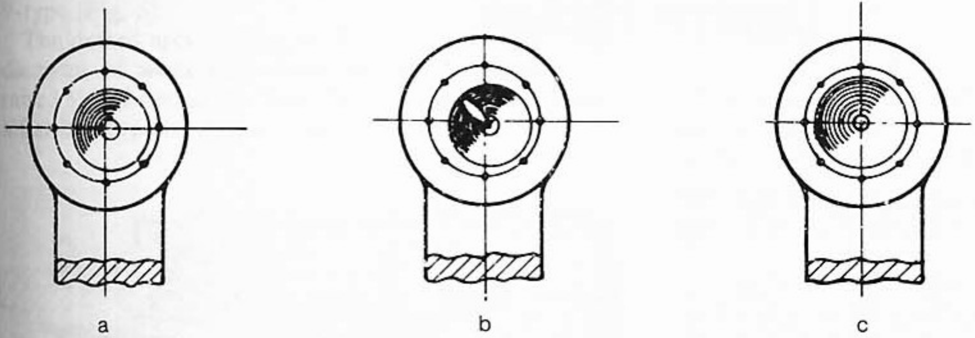



**Figure 11** Drawing a drill back to position