Peter Philips Resource

UEE30811 Certificate III
Electrotechnology Electrician

AC Rotating Machines
Philips Tutorial & Practical

Solve Problems in Single Phase & Three Phase Low Voltage Machines.

Student Name____________________ Date__________________

Teacher Name ___________________ Class_________________

Lesson	Duration	Topic.	Practical
1 09	4hours	22.1 Three Phase Induction Motor	Motor Construction & Testing
2 10	4 hours	22.2 Wound Rotor Induction Motor	Motor Characteristics
3 11	4hours	22.3 Induction Motor Load Characteristics	Voltage, Speed Torque
4 12	4 hours	22.4 Motor Protection	Overload operation
5 13	4 hours	TEST	NO PRACTICAL
14 6	4 hours	23.1 Single Phase Induction Motor	1ph Split Phase Motor
7 15	4hours	23.2 Capacitor Motors 23.3Shaded Pole Induction Motors 23.4 Universal Motors	1ph Series Universal
16 8	4 hours	24.1 Alternators	Alternators
17 9	4 Hours	24.2 Synchronous Motors	Synchronous Motors
18 10	4 hours	Final Test	Final Test

To Attain competence a 50% pass mark in Transformers & 50% pass mark in AC Machines is required.

Assessment	Type of Assessment	Duration	Weighting %
1	Transformer Theory Test 1	1 Hour	20%
2	Transformer Theory Test 2	2 Hours	20%
3	Transformer Practical Test 2	45 Min	10%
4	AC Machines Theory Test 1	2 hours	20%
6	AC Machines Theory Test 2	2 Hours	20%
7	AC Machines Practical Test 2	45 min	10%

PLEASE NOTE THE ABOVE IS A GUIDE AND LESSONS MUST BE PLANNED TO SUIT CLASS COMPETENCY AND TERM DURATION

Practical Exercise 1: 3 Ph Motor Construction & Testing

Task:

- To measure the resistance of the phase windings of a three phase induction motor.
- To measure the insulation resistance of the phase windings of a three phase induction motor.
- To correctly connect the motor so that it will run in star and delta.
- To test fault find on a 3 phase induction motor .

Equipment:

1 x six terminal three phase induction motor
24v Betts & 415V motors can be used depending on availability
1 x digital multimeter
1 x insulation resistance tester (megger)
1 x clip on ammeter
1 x hand held tachometer

REMEMBER·
WORK SAFELY AT ALL TIMES
Observe correct isolation procedures

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

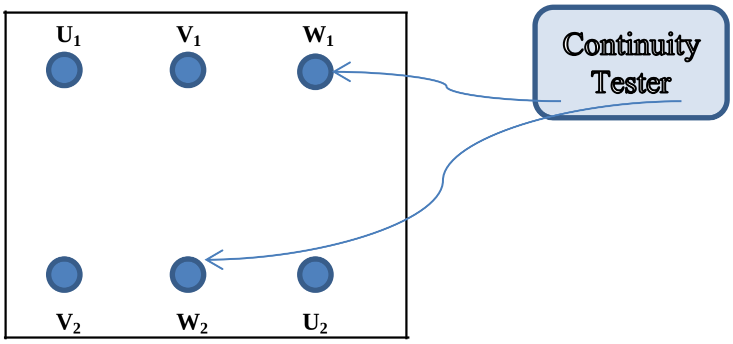
Procedure 1

- Remove all links from the terminal block of the three phase motor.
- Using the digital multimeter measure the resistance of each of the phase windings and record below.

U1 – U2______________

V1 – V2 ______________

W1 – W2 _____________



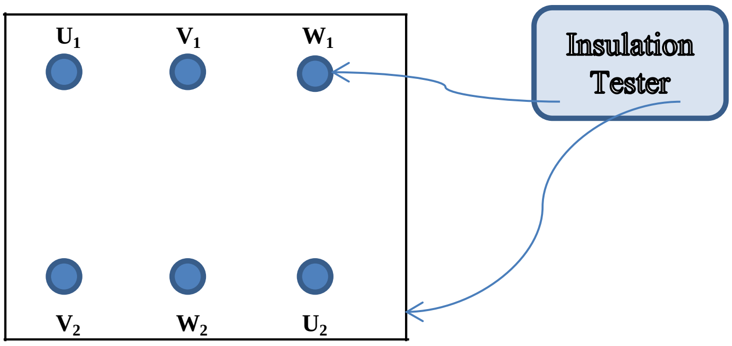
Procedure 2

- Using the IR tester measure the insulation resistance between each phase winding and earth
- Using the IR tester measure the insulation resistance between each individual phase winding.
- .

U – Earth/Frame______________ U – V ___________________

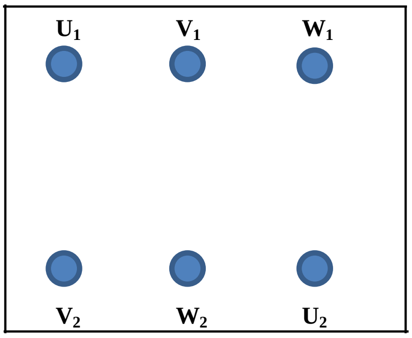
V – Earth/Frame ______________ V – W ___________________

W – Earth/Frame _____________ W – U ___________________

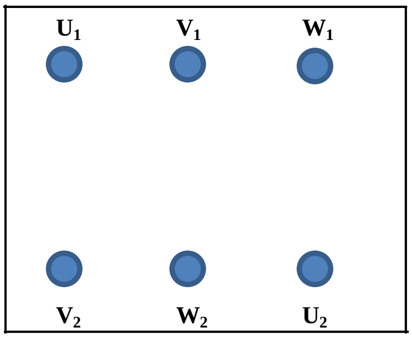


Procedure 3

Draw in the link connections on the diagrams below for Star & Delta connections.



STAR



DELTA

Procedure 4 - Betts motor only or continue onto procedure 5

Connect the Betts motor in **STAR** and measure the line currents and rotor speed and direction of rotation.

Line Current 1________________________ Rotor Speed_________________

Line Current 2________________________ Rotor direction ______________

Line Current 3________________________

Swap any two supply lines & note the direction of rotation ________________________

Connect the Betts motor in **DELTA** and measure the line currents and rotor speed.

Line Current 1________________________ Rotor Speed________________

Line Current 2________________________

Line Current 3________________________

Swap any two supply lines & note the direction of rotation ________________________

Explain why there is a difference in the line currents between star & delta connected motors.

____

____

____

____

Procedure 5 – 415V motor only

Connect the 415V 3ph induction motor in Star or Delta as directed by your teacher.

Close switch 1 and step through the testing procedure to determine if there are any faults within the machine.

Open switch 1 and close switch 2 and repeat the test procedure.

Place your results and comments on the table below

NO Faults	Continuity of lead A-A___________ B-B ___________ C-C ___________	Circuit Resistance from lead A – B ___________ B – C ___________ A – C ___________	Insulation Test A – Earth ______ B – Earth ______ C – Earth ______	Condition of motor GOOD
Switch Closed				
1				
2				
3				
4				
5				
6				

Check your results with the teacher before replacing all equipment in its appropriate place.

____________________**END**____________________

Tutorial 1 Multiple Choice

1. To reverse the direction of rotation of a squirrel cage motor you would:
   a) disconnect and reverse the slip ring connections
   b) replace the squirrel cage rotor with a wound rotor
   c) interchange any two supply lead connections
   d) change the delta connected stator winding to a star connection

2. The rotor winding of a wound rotor induction motor is usually connected in:
   a) delta
   b) star
   c) series
   d) parallel

3. The stator core is laminated to:
   a) improve starting torque
   b) provide silent running
   c) reduce hysteresis loss
   d) reduce eddy current loss

4. Rotor bars are usually made from:
   a) steel or copper
   b) steel or aluminium
   c) carbon or copper
   d) copper or aluminium

5. To improve starting torque and to reduce operation noise rotor bars are:
   a) skewed with respect to the stator slots
   b) cast aluminium
   c) star connected
   d) the same number as the stator slots

6. The air gap between the rotor and the stator core is typically;
   a) 0.05mm
   b) 0.5mm
   c) 5.0mm
   d) 50mm

7. Slip speed is the difference between:
   a) standstill and rotor speed
   b) rotor speed and stalling speed
   c) synchronous speed and rotor speed
   d) synchronous speed and standstill speed

Tutorial 1 Short Answer

1. List the components of a 3ph induction motor?

____
____
____
____
____
____
____
____

2. What other name is The Rotating Magnetic Field (RMF) produced by the stator winding is also known as?

____

3. What determines the direction in which a three phase magnetic field will rotate around the stator?

____

4. What is the relationship between the direction of rotation of the RMF and the rotor?

____
____

5. What is developed **in the rotor** of an induction motor by the interaction of the rotor and stator fields which allows mechanical work to be done?

____

6. On a 3ph induction motor how many pairs of poles are there, and at what angle are they displaced?

____

7. What determines the speed of rotation of the RMF produced by a three phase induction motor? (Look for the formula to help you).

____

8. Briefly explain why the rotor speed of an induction motor is always less than the speed of the stator RMF.

____
____

9. What rule can be used to determine the direction of rotation of a 3ph induction motor?

____

10. In a 50Hz, 3ph squirrel cage induction motor, what is the rotor frequency when the machine has a locked rotor?

____

11. In a 50Hz, 3ph squirrel cage induction motor, what is the rotor frequency when the machine is running at half speed?

____

12. In a 3ph squirrel cage induction motor which has a three stud terminal block, is it possible to change its configuration from star to delta.

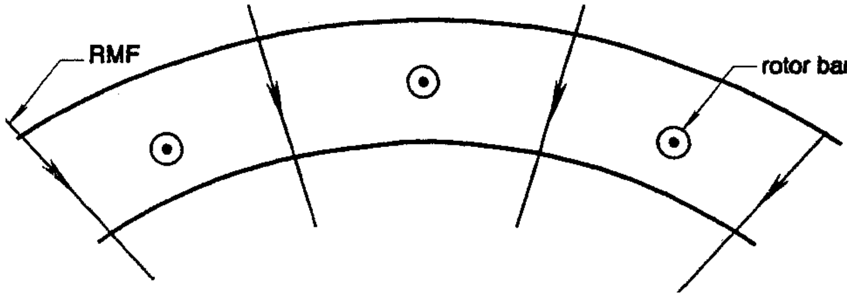
____

13. In terms of U,V,W. State the winding connections to ensure a delta configuration.

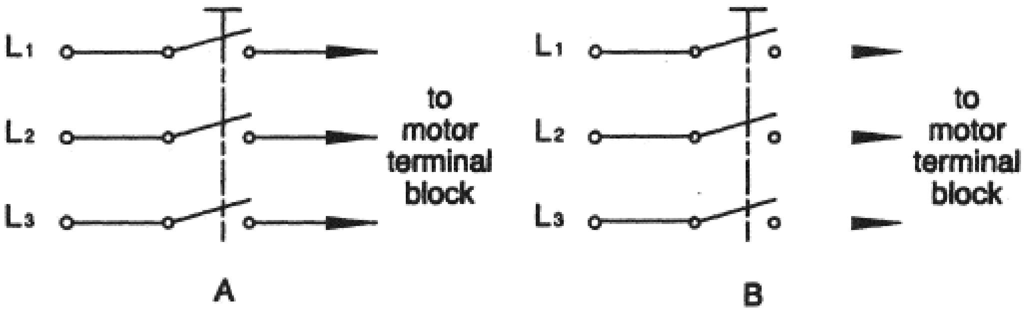
U1______________________________
V1______________________________
W1______________________________

Tutorial 1 Drawings & Diagrams

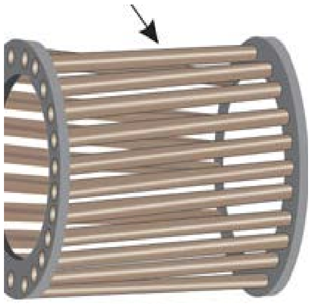
1. The diagram below shows the RMF and the induced rotor conductor current. On the diagram, show in which direction the RMF is rotating to induce the current shown and draw in the resultant flux around the rotor bars.



2. The figure below represents an isolation switch of a three phase motor. Show the changes needed to reverse the direction of rotation.



3. What materials can the rotor bars be made from?



4. Name the item in figure 1.

Figure 1

Tutorial 1 Calculation

1. Calculate the synchronous speed of an eight pole, 50Hz induction motor.

2. Show the effect of operating a motor designed to operate on 50Hz if it is connected to a 60Hz supply

3. If the synchronous speed of a 50Hz induction motor is 1500 rpm, calculate the number of stator poles.

4. A 3ph motor synchronous speed is 2800rpm and the slip speed is 2575rpm. Calculate the rotor speed

5. Using the correct formula calculate the percentage slip of a 3ph squirrel cage motor which has an RMF of 8000rpm and a rotor speed of 7835rpm.

6. A 60Hz 3ph motor has a percentage slip of 4%. Calculate the rotor frequency.

7. A three phase 8 pole induction motor on load runs at 720 RPM when operating from a 50Hz supply. Calculate the motors
   a. Synchronous speed
   b. Slip speed
   c. Percentage slip
   d. Rotor frequency

Practical 2 Effects of reduced voltage on Speed & Torque.

Task: To monitor the operations of:

- correctly connected delta squirrel cage motor with rotor resistance
- a delta connected motors speed with added rotor resistance
- a delta connected motors torque with added rotor resistance
- a delta connected motors currents with added rotor resistance

Equipment:

- 1 x BETTS 6 terminal three phase motor
- 1 x Betts Plate
- 1 x rubber coupling
- 1 x flywheel
- 1 x clip on ammeter
- 1 x hand held tachometer
- 1 x digital multimeter
- 1 x Motor resistor banks set.

Remember: Work safely at all times!

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

Ensure all lose clothing; hood laces and jewellery does not come into contact with Rotating Machines.

Procedure: Couple the motor & flywheel together onto the Betts plate.

1. Connect the Stator in Delta and the Rotor in Star.
2. Connect the supply to 41.5V 3ph supply and measure the following values**.**

Line current (Max at start)__________________ (Min at Rated speed)_______________

Rotor Current (Max at start)_________________ (Min at Rated Speed)________________

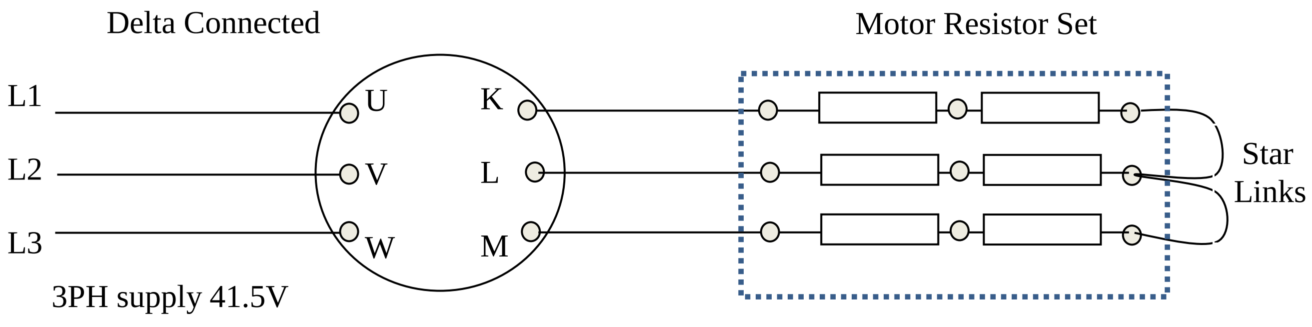
Rotor Speed__________________________________

Question 1 Why is the current high at the start and reduces value at rated speed?

____

____

3. Connect the secondary resistors to the rotor (in series) and measure the following values.



Line Current______________ Rotor Current_____________ Rotor Speed ______________

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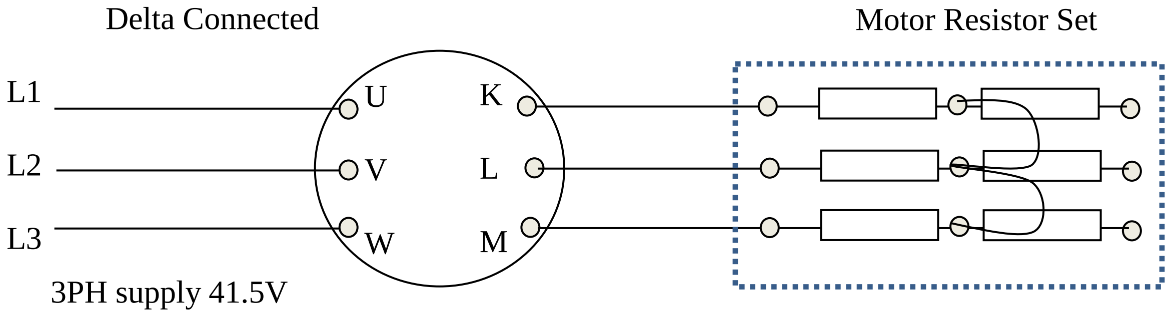
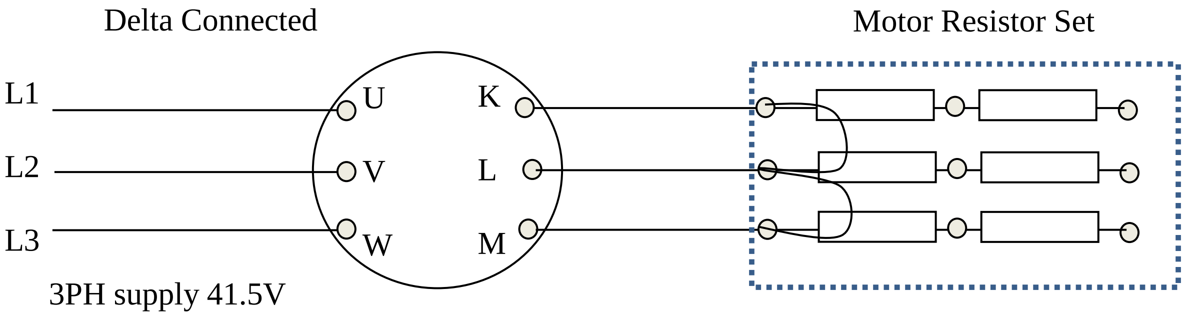
4. Remove or short out half the resistors and measure the following.

Line current ____________ Rotor Current ___________ Rotor Speed______________



5. Remove or short out all resistors and measure the following values.

Line current ____________ Rotor Current ___________ Rotor Speed______________



Question 3 Explain any benefits from using resistance starting on a wound rotor.

____

____

____

Disconnect Equipment and return to its appropriate place.

Tutorial 2 Multiple Choice (Wound Rotor & Special Purpose Induction)

1. The rotor winding of a wound rotor induction motor is usually connected in:
   a) delta
   b) star
   c) series
   d) parallel

2. How many slip rings would you expect to find on the shaft of a squirrel cage rotor?
   a) four
   b) three
   c) two
   d) none

3. Interchanging any two slip ring connections of a wound rotor would:
   a) reverse the rotation of the motor
   b) prevent the motor from operating
   c) cause the motor to overload
   d) have no effect on the motor operation

4. Torque developed by a 3ph induction motor is at a maximum:
   a) when the rotor is at standstill
   b) at rated speed
   c) at synchronous speed
   d) when rotor resistance equals rotor reactance

5. Rotor currents in an induction motor operating at rated speed are
   a) Low frequency
   b) High frequency
   c) Supply frequency
   d) Stator frequency

6. When resistance is added to the rotor circuit of a slip ring induction motor driving a constant load, the speed will:
   a) Remain the same and supply more torque
   b) Remain the same and draw more current
   c) Be reduced
   d) Be increased

7. The rotor field of a three phase induction motor is due to
   a) DC excitation
   b) Electromagnetic induction
   c) Rotor reactance
   d) Rotor resistance

8. Breakdown, Maximum and stalling torque all occur at the same time within the machine. What occurs in the rotor to cause this effect.
   a) Rotor frequency is at maximum
   b) Mechanical load is to heavy
   c) Stator is connected in Delta
   d) Rotor reactance = Rotor resistance

9. What is an advantage if adding resistors as a speed control method?
   a) Increased stator current
   b) Increased voltage in the rotor
   c) Increased torque
   d) Increased rotor currents

10. Torque of an induction motor varies in relation to slip:
    a) for all values of slip
    b) for high values of slip
    c) for low values of slip
    d) for medium values of slip

11. The results obtained from a locked rotor test would be:
    a) maximum torque and current
    b) full load torque and current·
    c) starting torque and current
    d) no-load torque and current

Tutorial 2 Short Answer

1. What type of three phase induction motor would allow resistance to be added to the rotor?

2. What disruptive effect is removed by connecting the stator in delta on a three phase wound rotor?

3. What effect will changing a star connected stator into a delta connected stator have on the direction of rotation of the motor?

4. Where would you use witness marks?

5. As the slip of a motor decreases, what happens to the rotor speed?

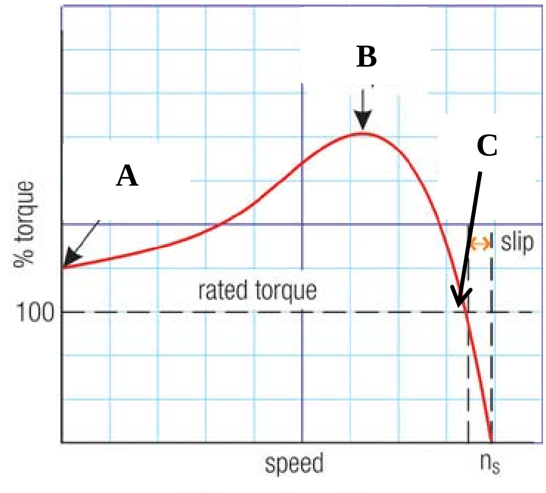
6. What would be the torque developed if the rotor speed was equal to synchronous speed?

7. When does maximum torque occur for three phase induction motors?

8. What would happen if the load torque became greater than the rotor torque developed by the motor?

Tutorial 2 Graphs & Diagrams

1. Name the points marked on the diagram opposite:

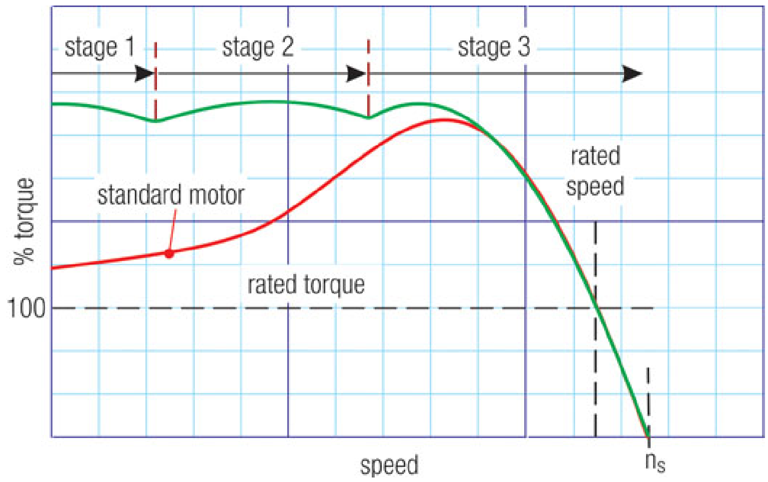


A. ______________________________

B. ______________________________

C. ______________________________

2. Answer the questions in relation to the graph shown below.



a. At zero rotor speed why is the torque at maximum (stage 1.)

____

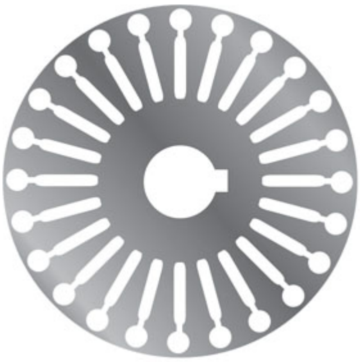
b. As the rotor speed increases, what happens to the value of inductive reactance?

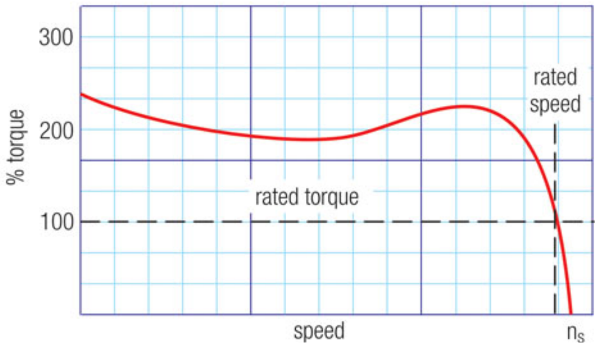
____

c. As the torque dips at stage 1 & 2, what happens to cause the torque to increase again

____

3. What type of special rotor is shown below? ______________________





4. Would the rotor above suit a machine which requires a constant or variable torque.

____

5. Sketch a graph representing the relationship between Rotor resistance, Rotor reactance and rotor speed.

Tutorial 2 Calculations (revision)

1. Determine the synchronous speed of a 48 pole 60Hz three phase motor.

2. Determine the number of poles per phase if the RMF rotates at 1500rpm when the supply frequency is 25Hz.

3. A 50Hz induction motor has rotor currents with a frequency of 2Hz. Determine the slip % that this motor operates with.

4. A three phase 4 pole induction motor on load runs at 1725 RPM when operating from a 60Hz supply. Calculate the motors
    a. Synchronous speed
    b. Slip speed
    c. Percentage slip
    d. Rotor frequency

Practical 3: Three phase induction motor characteristics

Task: To monitor the operations of:

- correctly connected star and delta squirrel cage motors
- a star connected motor which is single phasing
- a delta connected motor which is single phasing
- a star connected motor which has a phase reversal
- a delta connected motor which has a phase reversal

Equipment:

- 1 x BETTS 6 terminal three phase motor
- 1 x Betts Plate
- 1 x rubber coupling
- 1 x flywheel
- 1 x clip on ammeter
- 1 x hand held tachometer
- 1 x digital multimeter

Remember: Work safely at all times!

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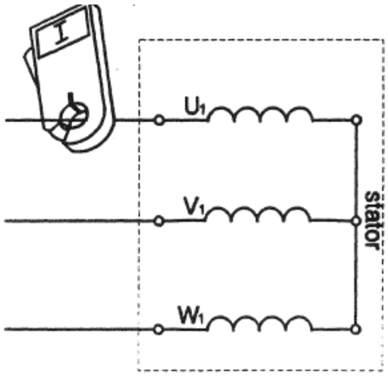
Always select the correct test equipment
Be careful when working near rotating machines

Ensure all lose clothing; hood laces and jewellery does not come into contact with Rotating Machines.

Procedure: Couple the motor & flywheel together onto the Betts plate

1. Connect the motor in STAR as shown below and measure shaft speed & line currents:



Star connection

I_{L1} = ________ A,

I_{L2} = ________ A,

I_{L3} = ________ A,

N = ________ rpm.

2. Open circuit 'one line' (disconnect L1 from supply) and start the motor measure each line current and shaft speed.

I_{L1} = ________ A,

I_{L2} = ________ A,

I_{L3} = ________ A,

N = ________ rpm.

3. Reconnect the open line. Reverse one phase winding and start the motor. Measure each line current and shaft speed.

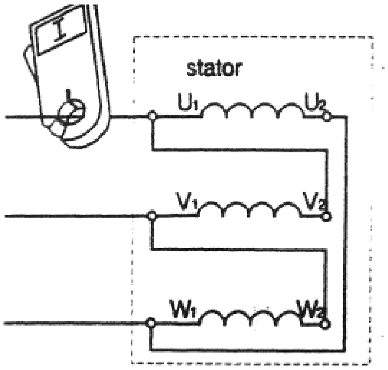
I_{L1} = ________ A,

I_{L2} = ________ A,

I_{L3} = ________ A,

N = ________ rpm.

4. Connect the motor in DELTA as shown below and measure shaft speed & line currents



Delta connection

I_{L1} = ________ A,

I_{L2} = ________ A,

I_{L3} = ________ A,

N = ________ rpm.

5. Open circuit one line and start the motor. Measure each line current and shaft speed.

I_{L1} = ________ A,

I_{L2} = ________ A,

I_{L3} = ________ A,

N = ________ rpm.

6. Stop the motor and reconnect the line supply and reverse one phase winding and start the motor. Measure each line current and shaft speed.

I_{L1} = ________ A,

I_{L2} = ________ A,

I_{L3} = ________ A,

N = ________ rpm.

Disconnect all equipment and return it to its correct place.

Observations

1. When connected in star with an open line, did the motor:
    a. Rotate without assistance? ______________________________
    b. Reach its rated speed? _________________________________

2. Explain the effects when the star connected motor had its phase winding reversed.
____
____
____

3. When running normally did the Star or Delta connected motor draw more power. Prove your answer. (Calculate).

4. When connected in Delta with an open line, did the motor:
    a. Rotate without assistance? ______________________________
    b. Reach its rated speed? _________________________________

5. Explain the effects when the Delta connected motor had its phase winding reversed.
____
____
____

Tutorial 3 Multiple Choice

1. Induction motor power factor:
   a) is constant
   b) increases with load increases
   c) decreases with load increases
   d) increases with load decreases

2. The frequency in the rotor currents:
   a) Increase with speed increased speed
   b) Increase with increased slip
   c) Decrease with increased slip
   d) Decreases with load increases

3. The output power of a three phase induction motor is determines using speed and:
   a) Torque
   b) Current
   c) Poles
   d) Flux

4. The power factor of an unloaded motor is :
   a) High
   b) Low
   c) Leading
   d) Unity

5. Losses in a three phase induction motor are due to:
   a) Iron Losses
   b) Copper Losses
   c) Windage
   d) All of the above

6. The efficiency of a three phase induction motor improves when:
   a) The power factor reduces
   b) When the motor is unloaded
   c) The output power increases
   d) The input power reduces

7. Failure of one phase supplying a three phase motor will:
   a) Have no noticeable effect on the motor
   b) Cause the motor to overheat
   c) Stop the motor turning
   d) Reduce the current drawn by the motor

8. If two line voltages equal the value of phase voltage in a 3ph star connected motor, then:
   a) A fuse has ruptured
   b) The frequency has reduced
   c) Its connected in delta
   d) One phase winding is reversed

9. After carrying out an insulation test between each of the stator windings and earth, the motor would pass if all test result were:
   a) less than 5Ω
   b) between 5Ω and 10kΩ
   c) between 10kΩ and 1 MΩ
   d) greater than 1MΩ

10. Rotor torque varies *proportionally* to the:
    a) supply voltage squared
    b) rotor speed
    c) supply current
    d) supply frequency

Tutorial 3 Short Answer

1. List three possible losses that you would find in a rotating machine.

   ____
   ____
   ____

2. Complete the statement;

   Power in = Power out __________________________

3. Which has a higher value:
   1. Power In or Power Out

4. What does HEM stand for:

   ____

5. State the typical efficiency of an HEM motor.

   ____

6. What is the efficiency of a motor operating under ‘no load’

   ____

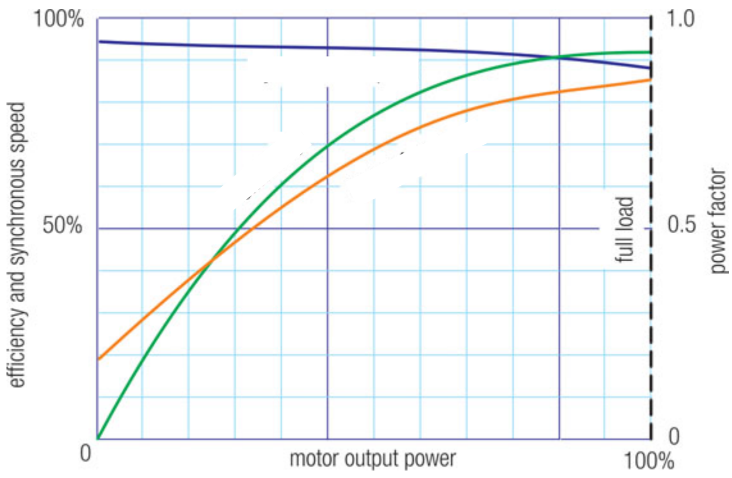
7. List some effects on a motor from the following faults:
   1. Short circuit in a winding____________________________
   2. Reversed winding ________________________________
   3. Ruptured fuse __________________________________
   4. Worn bearings _________________________________

8. State the fault when a star connected motor has two line voltages equal to the phase voltage.

   ____

Tutorial 3 Drawings & Diagrams

1. Label the curves in the graph below identifying rotor speed, efficiency & power factor.

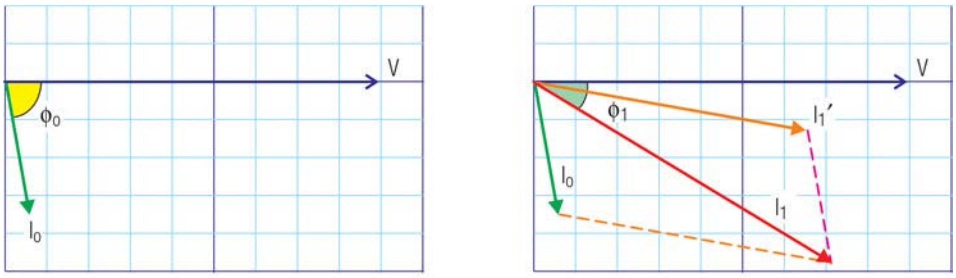


2. Answer the following questions relating to the motor phasor diagrams shown below.

   a. Which motor has the better power factor

   b. Which motor is operating under ‘no load’

   c. Which motor would have the higher efficiency

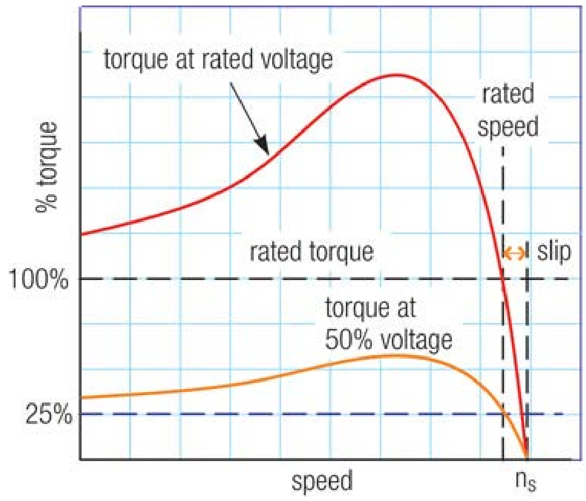


Motor A	Motor B

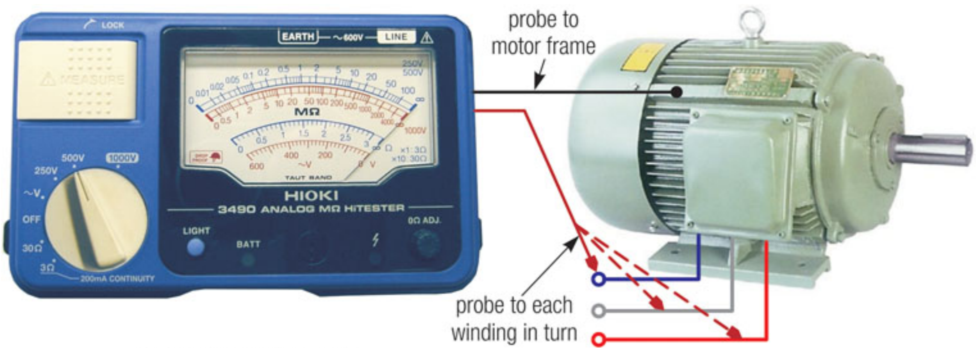
3. Study the graph below and answer the following questions.

   a. What percentage has the torque dropped by, when the voltage has been reduced by 50%

   b. If the rated torque was 17Nm determine the new torque at 50% reduced voltage.



4. What test is being carried out on the motor shown below?



Tutorial 3 Calculations

1. The mechanical load delivered by a 3Ph motor is 6.2kW with losses of 1.3kW. Determine the efficiency of the motor.

2. A 3ph 400V motor on full load draws 9amps with a p.f. of 0.9, calculate the input power.

3. The motor in question 2 has losses of 700W, determine its efficiency?

4. A 3ph 50Hz motor draws 3kW, has losses of 0.3kW and rotates at 1485rpm. Calculate the rated torque.

5. A 400V motor which develops 19Nm rated torque is operated at a reduced voltage of 220V. Determine the new torque developed.

6. If a motor delivers 30Nm starting torque, calculate the new torque when the voltage is reduced by 50%

Practical 4 Thermal Overload Connection & Operation

Aim: To examine the operation of a thermal overload device when used in circuit control.

Objectives: Connect up a thermal overload.

Determine its operation in terms disconnecting supply to the contactor coil.

Understanding the correct value of the overload setting.

Determine Start-up & Run currents

Equipment:

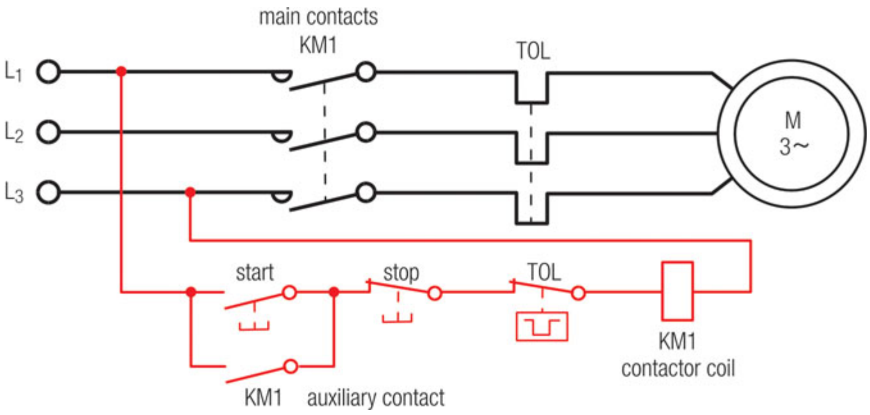
- 3ph 41.5V Betts motor
- Thermal Overload Unit
- Contactor
- Start Stop Station
- N/O Auxiliary contact
- Fuse panel
- Connection leads
- Clip on ammeter
- Multimeter

Remember: Work safely at all times!

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

Ensure all lose clothing; hood laces and jewellery does not come into contact with Rotating Machines.

1. Construct the circuit below. Connect the motor in Delta **(Don't use protection fuses in supply lines)**



2. Press the start push button and check your motor circuit latches and runs continuously.

3. Press the stop push button to check your motor circuit de-energises and the motor slows to a stop.

4. Set you overloads to the minimum setting & 'Hold' the motor shaft (locked Rotor) and press the start. Measure the maximum current with the clip on ammeter.

5. Release the motor and measure the full load running current.

6. With the information above, select the correct current setting on the thermal overloads.

7. Hold the motor shaft again and start the motor, time how long the TOL takes to trip. Reset the overload and repeat.

8. Place you results in the table below

Maximum Start Current	
Run Current	
Overload Setting for normal operation	
Trip Time 1st attempt	
Trip Time 2nd attempt	
Trip Time 3rd attempt	

Observations

1. What value should a thermal overload be set to?

2. Explain why there was a time difference between each thermal overload trip.

3. Explain what caused the contactor to de-energize when the TOL tripped.

4. How many normally closed contacts, open on the TOL when it trips.

5. Give an example of what could cause a locked rotor.

6. Does a TOL give protection for short circuits faults?

7. What type of thermal overload was used in the above practical?

   Magnetic, Thermal or Differential.

8. What type of time characteristic does the thermal overload have?

________________END_________________

Tutorial 4 Multiple Choice

1. Thermistor (Over Temperture) protection is used to:

   (a) detect .and indicate abnormal motor temperature
   (b) detect and indicate abnormal circuit temperature
   (c) detect abnormal motor temperature and disconnect the motor
   (d) detect abnormal motor temperature and operate control circuit

2. The inverse time characteristic of thermal overloads means that the overload will react:

   (a) faster to a larger fault current than to a small fault current
   (b) to any fault current regardless of the currents value
   (c) slower to a larger fault current than to a small fault current
   (d) faster to a smaller fault current than to a larger fault current

3. In-line over temperature sensing units are connected:

   (a) in two of the motor supply lines
   (b) in series with the motor winding circuit
   (c) in series with the motor control circuit
   (d) in the control circuit

4. The relationship between operating time and current of a thermal protection device is known as the:

   (a) time to current ratio
   (b) inverse time characteristic
   (c) proportional time characteristic
   (d) tripping time

5. The setting on a thermal overload is adjusted to:

   (a) the full load current of the motor
   (b) *150%* of the motor full load current
   (c) 200% of the motor full load current
   (d) anywhere within the adjustment range

6. If the setting on a thermal overload is set to the maximum possible adjustment, the overload will:

(a) operate correctly
(b) not provide effective protection
(c) only protect on low currents
(d) protect for short circuits as well

7. A three phase induction motor is started DOL and locks up at start. The expected protection operation would be:

(a) rapid tripping of the motor overload protection
(b) instantaneous tripping of the short circuit protection
(c) instantaneous tripping of the motor overload protection
(d) slow tripping of the motor overload protection

8. A common cause of a motor overload is:

(a) adjacent conductors touching
(b) one conductor touching the motor frame
(c) the motor load partially seized
(d) operating in high ambient temperatures

9. The contact associated with a thermal overload is:

(a) normally open and is connected in series with the control circuit
(b) normally closed and is connected in series with the control circuit
(c) normally open and in parallel with the motor contactor coil
(d) normally closed and in parallel with the motor contactor coil

10. If the setting on a thermal overload is set to the minimum possible adjustment, the overload will:

(a) operate correctly
(b) not provide effective protection
(c) only protect on low currents
(d) allow for longer starting periods on heavy load

11. A problem associated with repetitive starting is:
    (a) increased operator control for all applications
    (b) motor power factor is altered
    (c) controls have to be ventilated
    (d) control accessories have a shorter life span

12. Instantaneous magnetic overload relays must have their rated trip current:
    (a) equal to the starting current of the motor
    (b) slightly exceeding the starting current of the motor
    (c) slightly exceeding the full load current of the motor
    (d) equal to the full load current of the motor

Tutorial 4 Short Answers

1. In accordance with AS/NZS3000 all motors over 370W must be provided with what?

2. To prevent fluctuations in the supply authority systems motor starting currents must be limited. State the maximum starting current allowed in a domestic situation for

    a. Single phase motor___________________
    b. 3ph phase motor ___________________

3. What document would you reference to confirm the starting currents allowed in NSW

4. Name the two types of overload Relays

5. Are thermistors placed in the motor *power* or *control* circuit?

6. What are three advantages of HRC fuses

7. What additional benefit does a differential overload provide?

8. Describe the effects on the control circuit and the motor if the supply voltage is low

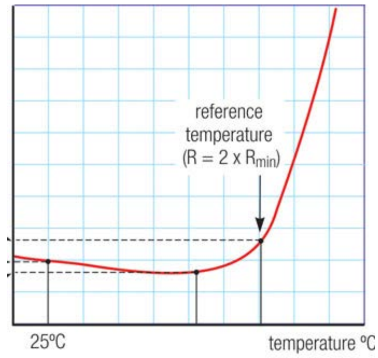
9. State two reasons why you would install under voltage relay protection

10. List three problems associated with repetitive starting

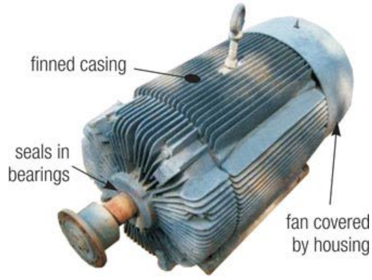
11. What level of protection does IP68 provide?

Tutorial 4 Diagrams

1. Identify the graph below. Explain what it represents and state its temperature coefficient category.

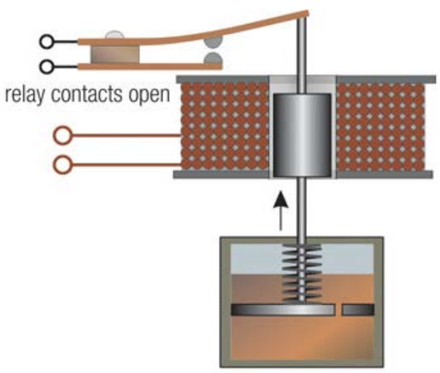


2. Identify the motor enclosure opposite.



3. Identify the fuses category below and state and specific labels which state its suitability for motor protection.

4. Identify the overload device opposite.



_________________END___________________

Practical Exercise 5A: 1Ph Motor (Betts) Construction & Testing

Task:

- To measure the resistance of the phase windings of a split phase, single phase induction motor.
- To measure the insulation resistance of the phase windings of a single phase induction motor.
- To correctly connect the motor so that it will run in forward & reverse directions.

Equipment:

1 x single phase split phase BETTS induction motor
1 x digital multimeter
1 x insulation resistance tester (megger)
1 x clip on ammeter
1 x hand held tachometer

REMEMBER·
WORK SAFELY AT ALL TIMES
Observe correct isolation procedures

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

Single Phase Motor Connections

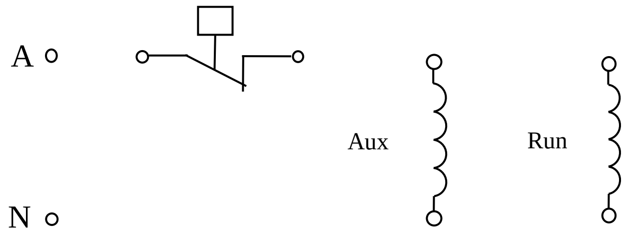
Task. Test, connect, run and reverse a single phase Split Phase Motor

Procedure

1. Measure the resistance of the motor windings.

   a. Run____________________
   b. Start/Aux_______________

2. On the diagram below draw the winding and supply connections required for the correct operation of a split phase motor.



3. Connect the winding and centrifugal switch for correct operation of the motor.

4. Before connecting to the supply:

   a. Calculate the total resistance expected from the motor circuit.

   ____

   b. Measure the total resistance of the motor circuit.

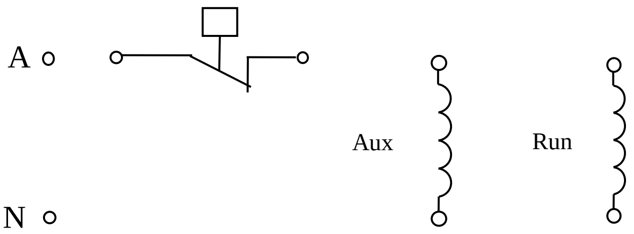
   ____

5. Are they of similar values?

6. Energise the motor and note the direction of rotation.

   Direction of rotation___________________________

7. On the diagram below draw the connection changes required to reverse the motor.

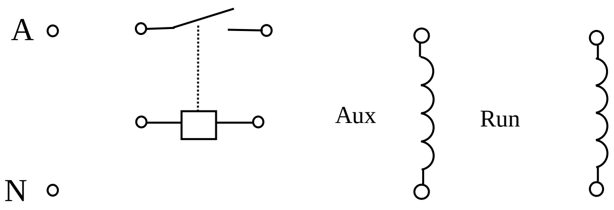


8. Carry out the connection changes required to reverse the motor, energise, and write the direction of rotation.

   Direction of rotation____________________________

9. Demonstrate the reversal to the teacher.

10. Draw the connection for the motor using the current sensing relay.



11. Connect the motor using the current sensing relay and demonstrate its operation to your teacher.

________________________END________________________

Practical Exercise 5B: 1Ph Motor (split phase) Construction & Testing

Task:

- To measure the resistance of the phase windings of a split phase, single phase induction motor.
- To measure the insulation resistance of the phase windings of a single phase induction motor.
- To correctly connect the motor so that it will run in forward & reverse directions.
- To test fault find on a split phase, single phase induction motor.

Equipment:

1 x single phase split phase induction motor
1 x digital multimeter
1 x insulation resistance tester (megger)
1 x clip on ammeter
1 x hand held tachometer

REMEMBER·

WORK SAFELY AT ALL TIMES

Observe correct isolation procedures

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

Procedure 1

- Draw the terminal block & any wires which may be connected.

Procedure 2

- Remove all wires or leads from the terminal block of the 1ph motor.
- Using the digital multimeter measure the resistance of each of the motor windings and record below.

Run ________________ Start/Aux ______________

Procedure 3

- Using the IR tester measure the insulation resistance between each winding and earth
- Using the IR tester measure the insulation resistance between each individual winding.

Run – Earth/Frame__________ Start/Aux – Earth/Frame ___________

Run – Start/Aux _____________

Procedure 4

Calculate the total resistance expected when the run & start windings are connected in parallel.

R_T = ________________________

Procedure 5

Reconnect the motor and measure the total resistance from the supply lead.

Measured R_T = _____________________

Is it similar to your calculated value? _______________

Procedure 5 – 230V Split Phase motor only

Close switch 1 and step through the testing procedure to determine if there are any faults within the machine.

Open switch 1 and close switch 2 and repeat the test procedure.

Place your results and comments on the table below

Fault Switch	Continuity of lead A-A___________ N-N ___________ E-E ___________	Circuit Resistance from lead A – N ___________	Insulation Test A – Earth _______ N – Earth _______	Condition of motor State Fault
Switch Closed				
1				
2				
3				
4				
5				
6				

Demonstrate the rotation of the motor to the teacher then alter the connections required to reverse its direction. Demonstrate rotation reversal to your teacher.

Check your results with the teacher before replacing all equipment in its appropriate place.

____________________END____________________

Tutorial 5- Multiple choice Split Phase Induction Motors

1. The resistance of the insulation between windings and motor core should be:

   A. Greater than 1MΩ
   B. Less than 1MΩ
   C. Greater than 1Ω
   D. Less than 1Ω

2. If the following single phase motors had identical power ratings, which one would produce the lower value of starting torque?

   A. split phase
   B. shaded pole
   C. capacitor start
   D. Universal

3. The single phase motor that has two dissimilar windings displaced 90 electrical degrees is the:

   A. series motor
   B. permanently split capacitor motor
   C. shaded pole motor
   D. capacitor start motor

4. The starting torque of a single phase split phase motor is approx:

   A. 8 x rated torque
   B. 4 x rated torque
   C. Equal to rated torque
   D. 1.5 x rated torque

5. At what rating must unattended split phase motors have over tempature protection:

   A. 240W
   B. 240kW
   C. 240VA
   D. Protection at the discretion of the installer

Tutorial 5 - Short answer

1. Which winding is open circuited by a centrifugal switch at about 75% of synchronous speed of a split phase induction motor?

2. Which winding has the least resistance, the run winding or start winding?

3. Which winding has the least inductance; the run winding or start winding?

4. A split phase induction motor has a two pole run winding. How many poles would the start winding have?

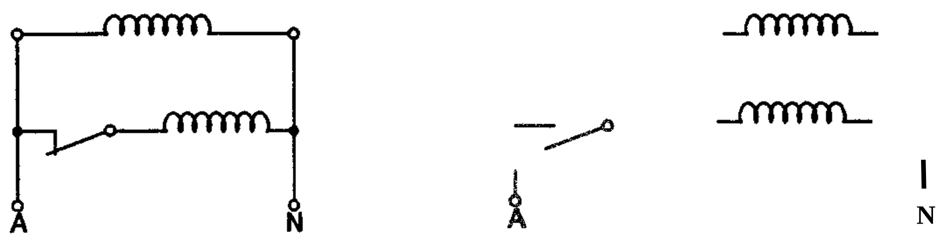
5. Explain how to reverse the direction of rotation of a split phase motor.

6. What is the approximate phase shift between the start and run winding?

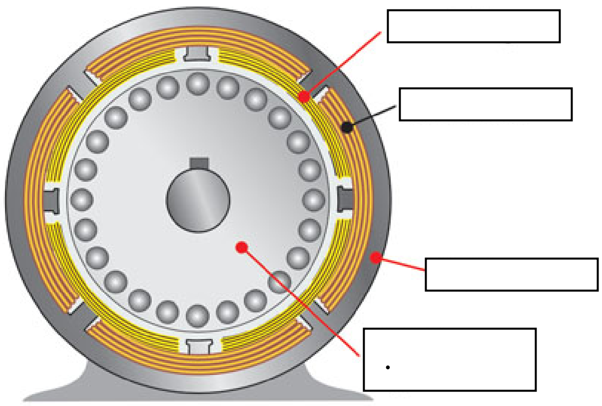
7. A 50Hz two pole induction motor operates on full load with a 10% slip. Calculate the full load rotor speed.

Tutorial 5 - Diagrams

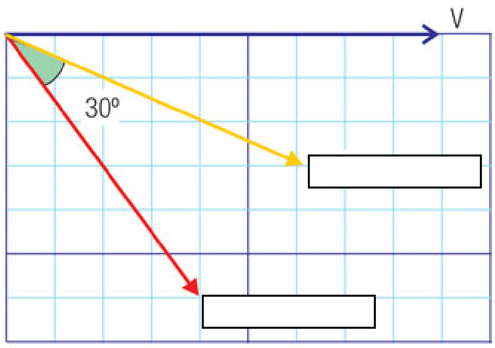
1. On the diagram below show the connection changes needed to reverse the direction of rotation of the motor shown.



2. Label the components of the motor and phasor diagram shown below.

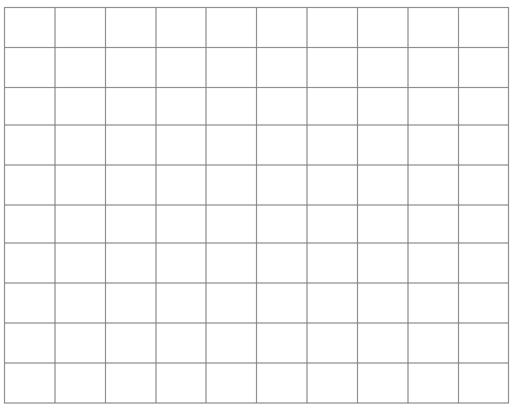


(a) start and run windings in a 4-pole motor



(b) phasor diagram of start and run currents

3. Sketch a typical split phase, single phase torque graph. Clearly label and identify;
    a. Y-axis
    b. X-axis
    c. Starting torque
    d. Maximum torques
    e. Switch operation
    f. Rated torque



Practical Exercise 6: 1Ph Motor (Series Universal)

Task:

- To measure the resistance of the phase windings of a series universal, single phase motor.

- To measure the insulation resistance of the phase windings of a series universal, single phase motor.
-
- To correctly connect the motor so that it will run in forward & reverse directions.

- To test fault find on a split phase, series universal, single phase motor.

Equipment:

1 x series universal motor
1 x digital multimeter
1 x insulation resistance tester (megger)

REMEMBER·
WORK SAFELY AT ALL TIMES
Observe correct isolation procedures

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

Procedure 1

- Draw the terminal block & any wires which may be connected.

Procedure 2

- Remove all wires or leads from the terminal block of the 1ph motor.
- Using the digital multimeter measure the resistance of each of the motor windings and armature and record below.

Field windings 1. _______ 2.________ Armature _____________

Procedure 3

- Using the IR tester measure the insulation resistance between each winding, armature and earth
- Using the IR tester measure the insulation resistance between each individual winding.

Field winding 1 - earth_________ Field winding 2 - earth __________

Armature - earth _______ Field winding 1 - Field winding 2 ________

Procedure 4

Calculate the total resistance, when the windings and armature are connected in series.

R_T = ______________________

Procedure 5

Reconnect the motor and measure the total resistance from the supply lead.

Measured R_T = ___________________

Is it similar to your calculated value? ______________

Procedure 5 – 230V Series Universal motor only

Close switch 1 and step through the testing procedure to determine if there are any faults within the machine.

Open switch 1 and close switch 2 and repeat the test procedure.

Place your results and comments on the table below

Fault Switch	Continuity of lead A-A__________ N-N __________ E-E __________	Circuit Resistance from lead A – N __________	Insulation Test A – Earth ______ N – Earth ______	Condition of motor State Fault
Switch Closed				
1				
2				
3				
4				
5				
6				

Demonstrate the rotation of the motor to the teacher then alter the connections required to reverse its direction. Demonstrate rotation reversal to your teacher.

Check your results with the teacher before replacing all equipment in its appropriate place.

__________________**END**__________________

Tutorial 6A - Multiple choice. Single phase induction motors

1. The single phase motor which is most suitable for a ceiling fan is the:
    a) Capacitor start capacitor run
    b) PSC motor
    c) Split phase motor
    d) Capacitor start motor

2. The single phase motor which is most suitable for an air conditioning compressor motor (where quietness in running is a major concern) is the:
    a) split phase motor
    b) PSC motor
    c) Capacitor start motor
    d) capacitor start capacitor run

3. The single phase motor which is most suitable for use in a domestic refrigerator is the:
    a) shaded pole motor
    b) PSC motor
    c) split phase motor
    d) capacitor-start

Tutorial 6A - Short Answer Single phase induction motors

1. Which type of capacitor motor does not require a start circuit switch mechanism?

2. What will be the likely outcome if the centrifugal switch fails to open as a capacitor start motor accelerates?

3. What is the effect on a split phase motor if the centrifugal switch contacts fail to close when the motor stops?

4. Explain why a capacitor start motor can develop a greater starting torque than a split phase motor.

Tutorial 6A Diagrams Single phase induction motors

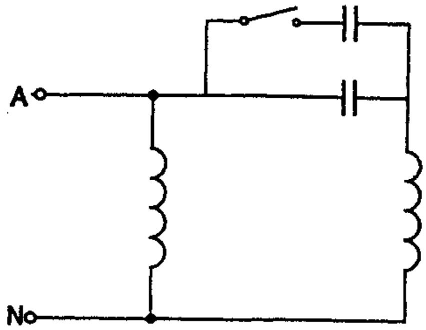
1. For each of the following circuit drawings state the type of motor shown and the most common application

Type of motor

____

Application

____

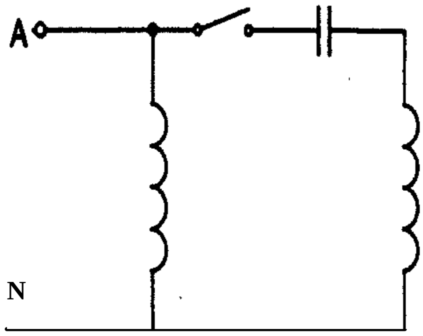


Type of motor

____

Application

____

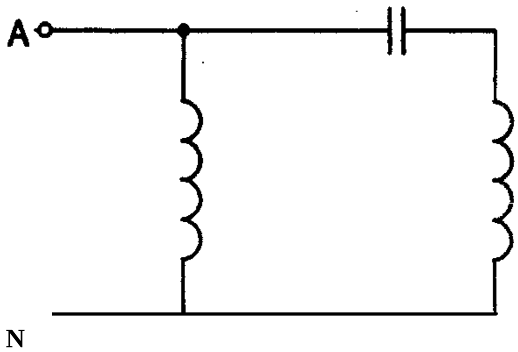


Type of motor

____

Application

____



Tutorial 6B Multiple choice Single phase motors

1. The single phase motor which is most suitable for a cooling fan motor in a projector is the:
    a) Capacitor start capacitor run
    b) PSC Motor
    c) Shaded Pole motor
    d) Capacitor start motor

2. The single phase motor which provides the largest output for size is the:
    a) shaded pole motor
    b) series universal motor
    c) cap start/cap run motor
    a) PSC motor

3. The series universal motor has similar operating characteristics to that of the
    a) DC shunt motor
    b) DC compound motor
    c) DC series motor
    d) AC repulsion motor

4. The field core of a series universal motor is laminated to reduce
    a) hysteresis losses
    b) copper losses
    c) eddy current losses
    d) magnetisation losses

5. The function of the commutator of a series universal motor is to
    a) balance the armature
    b) connect the armature coils in parallel with the supply
    c) connect the armature coils in series with the field coil
    d) connect the armature coils in parallel with field coils

6. The direction of rotation of a shaded pole motor may be reversed by
    a) changing supply connections
    b) changing the run winding connections
    c) turning the motor end for end
    d) open circuiting the shading coils

1. Name a single phase motor that cannot have its direction of rotation reversed by changing supply connections.

2. Explain what could happen if a pistol drill was operated without the gear drive.

3. A series universal motor is found to spark badly at the commutator. What are five faults that could cause this problem?

4. Explain why a series universal motor will operate on both AC and DC supplies.

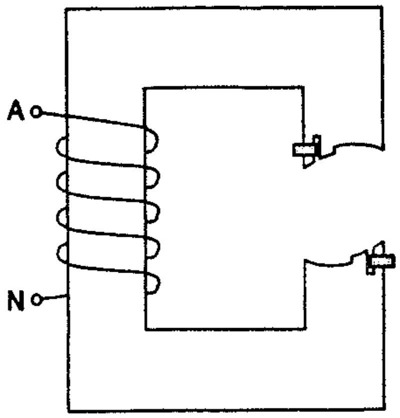
5. List 2 industrial tools driven by a series universal motor.

6. List 2 domestic appliances driven by a series universal motor.

7. Select the motor type and application from the list below.

Motor Type
shaded pole OPSC
series universal
cap start
cap start/cap run

Application
air compressor
circular saw
industrial floor
heater fan
ceiling fan

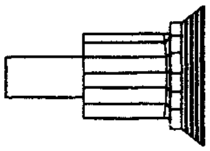


8. One list below has the name of the five basic parts of a series universal motor. The other list tells you what each part does (ie. its function

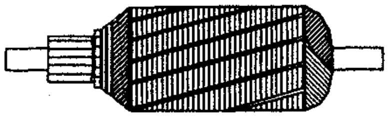
Choose one letter from each list that corresponds to each part that is drawn below and write it in the boxes under each part.

Part		Function	
	field coils		switches armature coil currents
	Armature		develops a field 90° to the main fie
	brushes		develops the main field
	field core		provides a sliding contact
	commutator		provides a flux path for the main field

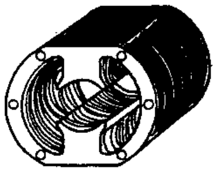
Part	
Function	



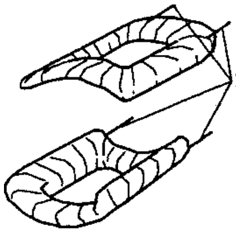
Part	
Function	



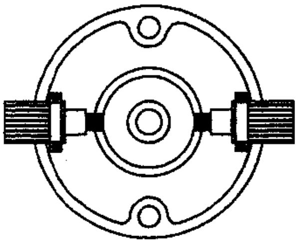
Part	
Function	



Part	
Function	



Part	
Function	



Practical Exercise 7: Synchronous machines 1 (Alternators)

Task:

- To plot the no-load characteristics of an alternator.
- To plot the load characteristic curves of an alternator for a resistive, inductive and a capacitive load.

Equipment:

- 1 x three phase alternator
- 1 x DC supply for excitation
- 1 x digital multimeters
- 1 x prime mover (constant speed)
- 1 x AC ammeter
- 1 x DC ammeter
- 1 x resistive load bank 1 x inductive load bank
- 1 x capacitor load bank

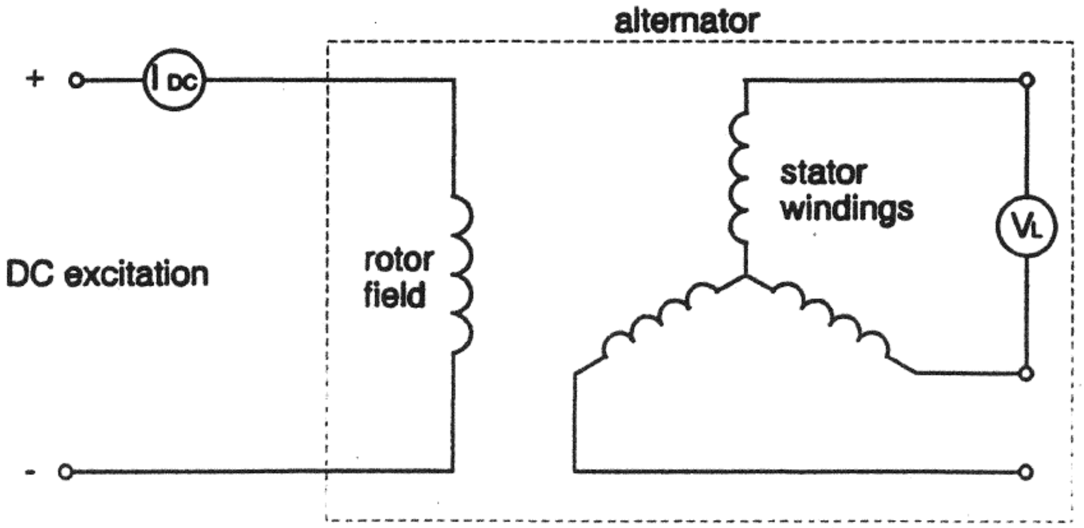
REMEMBER·

WORK SAFELY AT ALL TIMES

Observe correct isolation procedures

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

Procedure: 1. Connect the equipment as shown in the diagram below.



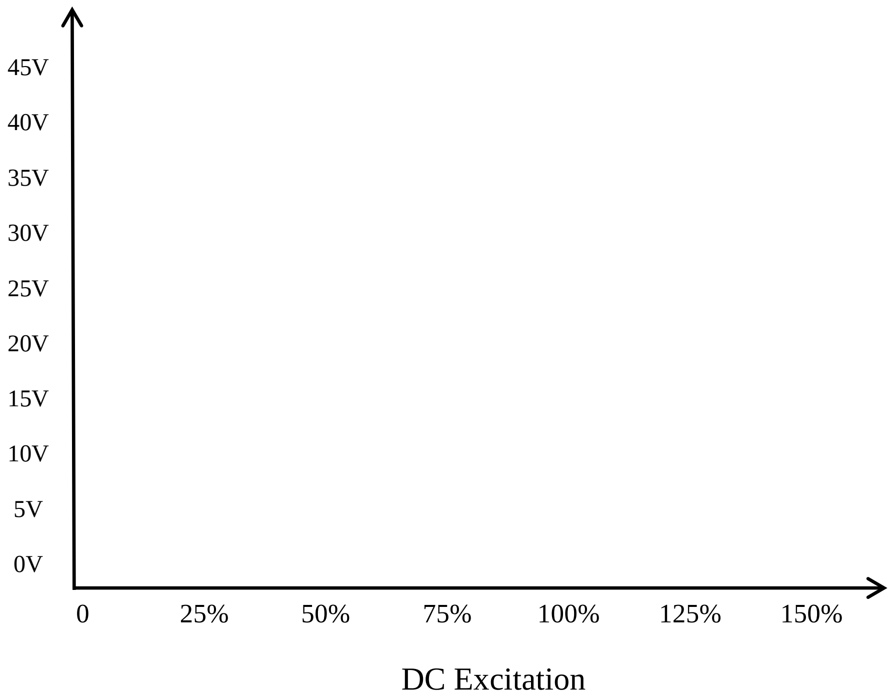
2. Start the prime mover and adjust the DC excitation until the alternator is generating rated voltage. Record the value of the DC excitation in the table below.

3. Reduce the DC excitation to a minimum value. Open circuit the DC supply and record the value of generated voltage in the table below.

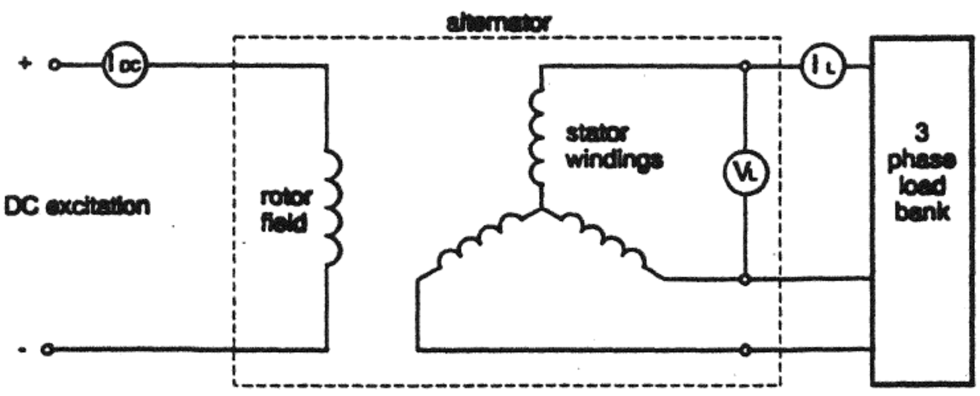
4. Reconnect the DC supply and adjust the excitation for the given values shown in the table. Record the calculated excitation values.

Table 1		
DC Excitation		Generated Voltage Vg
Open circuit, If =	0	
25%, of If =		
50%, of If =		
75%, of If =		
100%, of If =		**Vrated = 41.5V**
125%, of If =		
150%, of If =		

5. Use the values recorded in the table to plot the no-load characteristic of the alternator under test.



6. Connect the equipment as shown in the diagram below.



7. Adjust the DC excitation and the load until the alternator is supplying the rated full load current and voltage for the resistive load. Record the full load voltage and current in table 2 below.

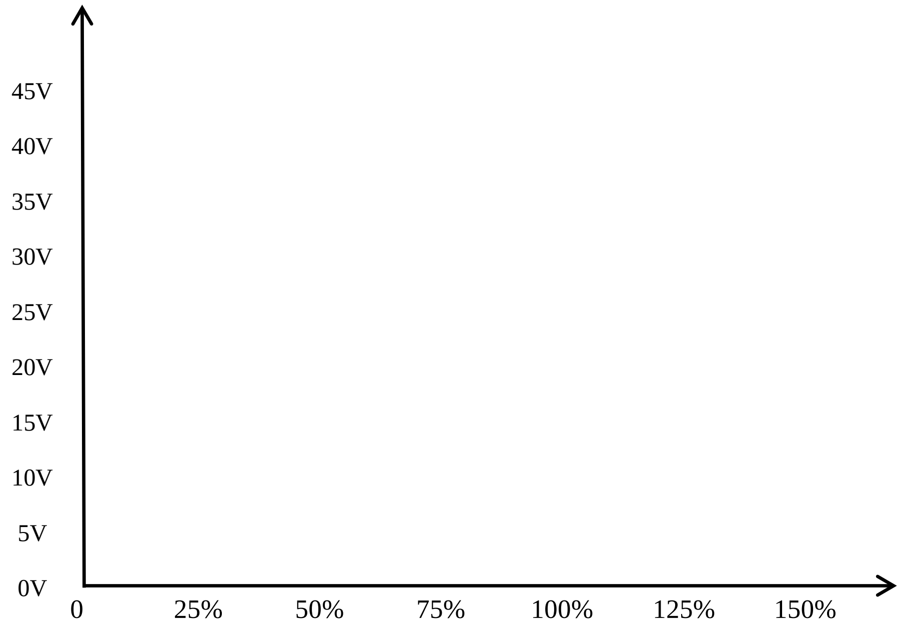
8. **Note: Do not adjust the DC excitation again**

9. Adjust the load current to the values shown in the table below and record the alternator terminal voltage.

10. **Repeat step 9 for the inductive and capacitive loads.**

Table 2				
Load Current		**Alternator Terminal Voltage**		
%	**Actual**	**Resistive Load**	**Inductive Load**	**Capacitive Load**
0%				
25%				
50%				
75%				
100% Rated				
125%				

11. Use the results from the table to plot the load characteristic curves for the alternator under test. Use a different colour for each curve.



LOAD CURRENT

Return all equipment to its appropriate place.

Tutorial 7 Multiple choice 3ph Alternators

1. The fundamental parts of a three phase alternator that house the armature and field windings are the:
   a. Stator and the prime mover
   b. exciter and the stator
   c. stator and the rotor
   d. rotor and the exciter

2. Large power output alternators are of the:
   a. rotating armature type
   b. rotating field type
   c. fixed field type
   d. self-excited type

3. The winding of a three phase alternator which is supplied from a DC source is commonly referred to as the:
   a. amortisseur winding
   b. armature winding
   c. field winding
   d. compensator winding

4. A four poles 50Hz alternator must be rotated at:
   a. 3000 rpm
   b. 1500 rpm
   c. 1000 rpm
   d. 750 rpm

5. The terminal voltage of a three phase alternator is maintained at a fixed value by:
   a. changing the prime mover speed
   b. varying the number of turns on the armature
   c. changing the windings from star to delta
   d. altering the field excitation

6. Alternators are rated in terms of:
   a. speed and voltage
   b. current and power factor
   c. voltage and kVA
   d. current and kW

7. The output frequency of an alternator depends on the:
    a. speed of rotor
    b. size of the field excitation
    c. power factor of the stator current
    d. level of the terminal voltage

8. Three phase alternators generate a sinusoidal waveform due to the fact that:
    a. the majority of machines used in industry require this type of supply
    b. the connection of star and delta to loads is required
    c. single phase equipment as well as three phase equipment can be connected.
    d. this type of waveform retains the same shape when transformed

9. Decreasing the output of the exciter of a three phase alternator will cause the generated:
    a. frequency to increase
    b. voltage to increase
    c. frequency to decrease
    d. voltage to decrease

10. An unregulated alternator supplies a resistive load. If an additional load with a leading power is connected the alternator's voltage would:
    a. decrease
    b. increase
    c. remain unchanged
    d. increase momentarily and then return to normal

Tutorial 7 Short Answer & Diagrams 3ph Alternators

1. The load characteristics of an alternator show the relationship between which two electrical quantities.

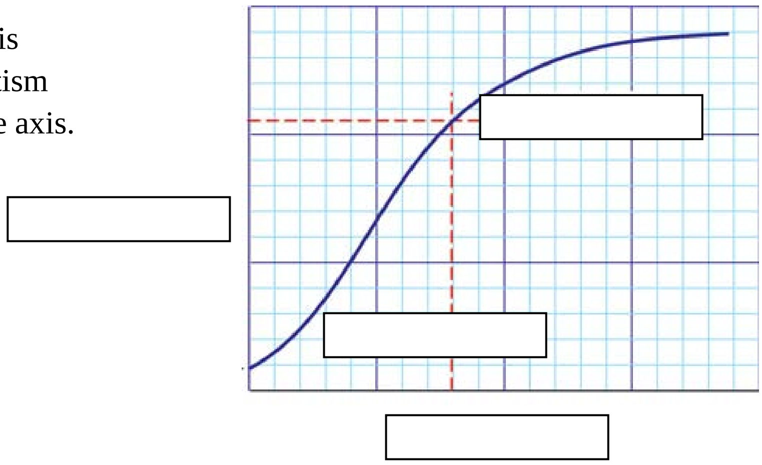
2. What is the most common connection method for the phase windings of a three phase alternator?

3. Name the type of rotor used with water turbine prime movers.

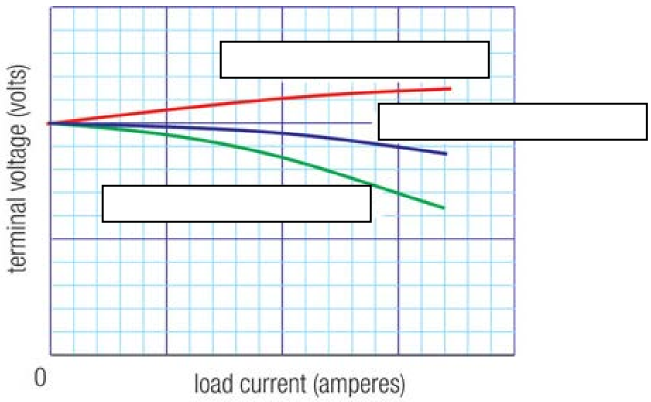
4. Name the section of the generating system that maintains the alternator voltage between fixed limits.

5. What type of prime mover is used with cylindrical rotor alternators.

6. On the graph opposite label the following:
   a. Saturation point
   b. Field Current axis
   c. Residual magnetism
   d. Terminal voltage axis.



7. Label the load characteristics on the graph below.



Tutorial 7 Calculations 3ph Alternators

1. At full load a three phase 11,000 volt alternator supplies a current of 2,670 amperes. Determine the rated output of the alternator.

2. Determine the kW output of a 240kVA alternator when it is supplying:
   a) a load with a power factor of 0.8 lagging
   b) and a load with a power factor of 0.6 lagging

3. Determine the output current of a three phase 180 kVA, 415V alternator which is supplying a load with a power factor of 0.8 lagging.

4. A three phase, 8kVA, 415V alternator is supplying a resistive load. Determine the value of the load current.

5. A 415V, three phase alternator supplies a load current of 30.6 amperes at a power factor of 0.75 lagging. Determine:
   a. the kVA output of the alternator
   b. the kW output of the alternator

Practical Exercise 8: Synchronous Motors

Tasks: To plot the V-curves for a synchronous motor

Equipment:

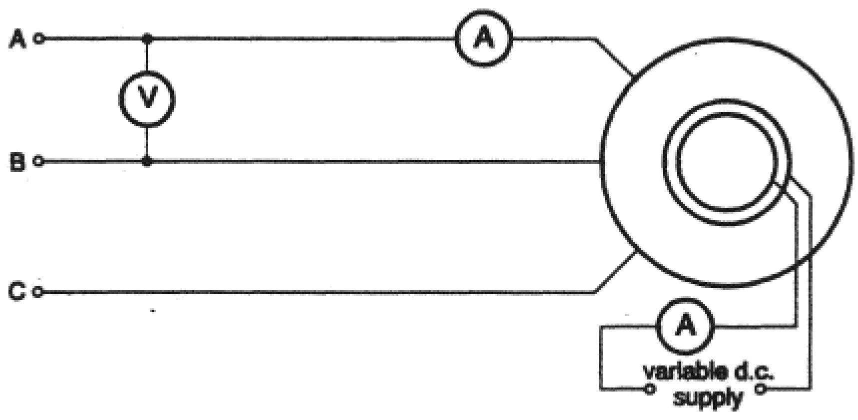
- 1 x synchronous motor
- 1 x AC ammeter
- 1 x digital multimeter
- 1 x DC ammeter
- 1 x handheld tachometer
- 1 x Inertia wheel **(essential)**
- 1 x Betts plate

REMEMBER·
WORK SAFELY AT ALL TIMES
Observe correct isolation procedures

Isolate supply before connecting or altering circuits
Always select the correct test equipment
Be careful when working near rotating machines

Procedure:

1. Connect the equipment as shown in the diagram below and couple the inertia wheel onto the motor using the Betts plate.



2. With the synchronous motor operating at synchronous speed adjust the DC excitation until the motor draws a minimum line current from the supply. Record the value of the DC excitation and the line current in the table below.

3. Vary the DC excitation in steps of 25% of 'I normal' above and below 'I normal' and record the value of the motor line current for each step in table below

DC excitation		Motor line current	RPM
%	Actual		
o%			
25%			.
50to			
75%			
*I normal=		*I min=	
125%			
150%			
175°/o			

* Set-up point

Return all equipment to its proper place

Observations

1. Calculate the power input for normal excitation from P = $\sqrt{3}\, I_L\, V_L\, \cos\phi$

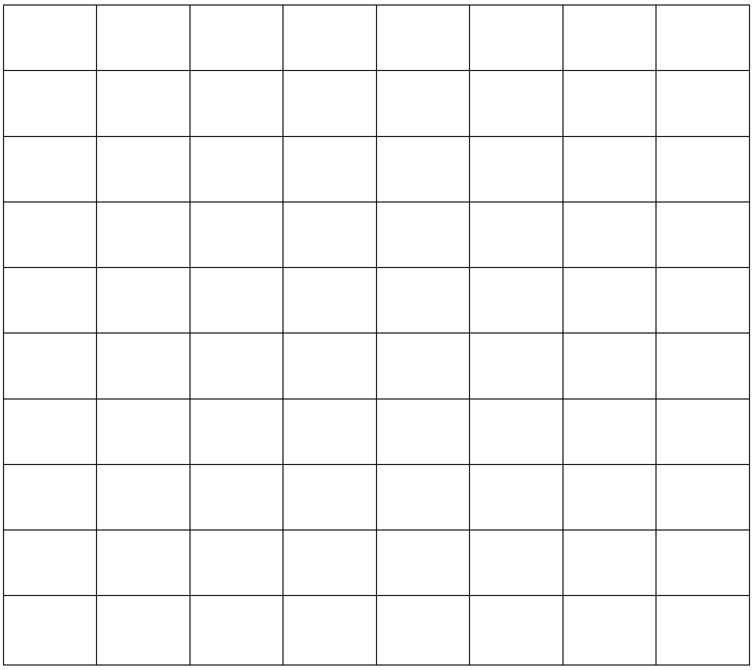
   Note: We will assume unity power factor.

2. Divide the input power value calculated in step 1 for each of the line current values recorded in the table in step 3 to obtain the operating power factor of the motor and record these results in the table below.

DC excitation		Motor power factor	Lead/lag
%	Line Current		
o%			
25%			.
50to			
75%			
*I normal=		*Unity =1	Unity
125%			
150%			
175°/o			

3. Use the results of the two tables to plot the V-curves of the synchronous motor under test. Use a different colour for each curve.

Stator Current Power Factor



DC Excitation

Tutorial 8 Multiple choice 3ph Synchronous Machines

1. The speed of a synchronous motor:
    a. is constant from no-load to full load
    b. is variable from no-load to full load
    c. drops from no-load to full load
    d. increases from no-load to full load

2. The operating power factor of a synchronous motor can be varied by changing the:
    a. field polarity ·
    b. phase sequence
    c. rotor speed
    d. field excitation

3. Normal excitation of a synchronous motor will result in:
    a. maximum stator current, minimum power factor
    b. minimum stator current, minimum power factor
    c. maximum stator current, maximum power factor
    d. minimum stator current, maximum power factor

4. An under-excited three phase synchronous motor would operate with:
    a. more than synchronous speed with a leading power factor
    b. synchronous speed and a leading power factor
    c. synchronous speed and a lagging power factor
    d. less than synchronous speed with a lagging power factor

5. A three phase synchronous motor develops a rotational torque by:
    a. electromagnetic induction between the stator and the rotor
    b. a magnetic coupling between the stator and the rotor
    c. eddy current being induced in the rotor circuit
    d. eddy currents being induced in the stator circuit

6. The speed at which a three phase synchronous motor rotates is governed by the:
    a. exciter
    b. field winding
    c. supply frequency
    d. pony motor

7. The advantages gained from operating a three phase synchronous motor over excited are:
    a. increased pull out torque and increased motor power factor
    b. decreased line current and a leading motor power factor
    c. decreased line current and increased motor power factor
    d. increased pull out torque and a leading motor power factor

8. A three phase synchronous motor with a nameplate rating of 50Hz when connected to 60Hz supply would:
    a. operate with the same speed
    b. operate with the lower speed
    c. operate with the greater speed
    d. not operate at all

Tutorial 8 Short Answer & Calculation 3ph Synchronous Machines

1. Name the windings placed in the rotor pole face of a three phase synchronous motor to improve the operational characteristics and to assist starting.

2. Name the type of starter used to start an auto-synchronous motor.

3. What is the name of the motor used to drive the rotor of a three phase synchronous motor to almost synchronous speed before the DC field is excited?

4. Why would you use a synchronous motor in preference to a squirrel cage induction motor for low speed variable frequency drive applications?

5. List 2 applications of three phase synchronous motors.

6. A four poles synchronous motor is to operate at 2000 rpm. Determine the value of the supply frequency required.

7. A synchronous motor connected to a 50Hz supply operates with a speed of 1000 rpm. Determine the number of poles per phase

Note: The symbols used on this sheet follow AS1046 pt 1. There are alternate recognised symbols in use. The list does not contain every equation used in the course. Transposition of equations will be necessary to solve problems

$Q = It$	$v = \frac{s}{t}$	$a = \frac{\Delta v}{t}$
$F = ma$	$W = Fs$	$W = mgh$
$W = Pt$	$\eta\% = \frac{output}{input} \times \frac{100}{1}$	$I = \frac{V}{R}$
$P = VI$	$P = I^2 R$	$P = \frac{V^2}{R}$
$R_2 = \frac{R_1 A_1 l_2}{A_2 l_1}$	$R_h = R_c(1 + \alpha \Delta t)$	$R = \frac{\rho l}{A}$
$R_T = R_1 + R_2 + R_3$	$V_T = V_1 + V_2 + V_3$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
$I_T = I_1 + I_2 + I_3$	$V_2 = V_T \frac{R_2}{R_1 + R_2}$	$I_2 = I_T \frac{R_1}{R_1 + R_2}$
$R_x = \frac{R_A R}{R_B}$	$C = \frac{Q}{V}$	$\tau = RC$
$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	$C_T = C_1 + C_2 + C_3$	$C = \frac{A \varepsilon_o \varepsilon_r}{d}$
$F_m = IN$	$H = \frac{F_m}{l}$	$B = \frac{\Phi}{A}$
$\Phi = \frac{F_m}{S}$	$S = \frac{l}{\mu_o \mu_r A}$	$V = N \frac{\Delta \Phi}{\Delta t}$
$e = Blv$	$L = \frac{\mu_o \mu_r A N^2}{l}$	$L = N \frac{\Delta \Phi}{\Delta I}$
$V = L \frac{\Delta I}{\Delta t}$	$\tau = \frac{L}{R}$	$F = Bil$
$T = Fr$	$E_g = \frac{\Phi Z n P}{60a}$	$P = \frac{2\pi n T}{60}$
$t = \frac{1}{f}$	$f = \frac{np}{120}$	$V = 0.707 V_{\max}$
$I = 0.707 I_{\max}$	$V_{ave} = 0.637 V_{\max}$	$I_{ave} = 0.637 I_{\max}$
$v = V_{\max} \sin \phi$	$i = I_{\max} \sin \phi$	$I = \frac{V}{Z}$
$Z = \sqrt{R^2 + (X_L - X_C)^2}$	$X_L = 2\pi f L$	$X_C = \frac{1}{2\pi f C}$

$$\cos\phi = \frac{P}{S} \qquad \cos\phi = \frac{R}{Z} \qquad S = \sqrt{P^2 + Q^2}$$

$$S = VI \qquad P = VI\cos\phi \qquad Q = VI\sin\phi$$

$$f_o = \frac{1}{2\pi\sqrt{LC}} \qquad V_L = \sqrt{3}V_P \qquad I_L = \sqrt{3}I_P$$

$$S = \sqrt{3}V_L I_L \qquad P = \sqrt{3}V_L I_L\cos\phi \qquad Q = \sqrt{3}V_L I_L\sin\phi$$

$$\tan\phi = \sqrt{3}\left(\frac{W_2 - W_1}{W_2 + W_1}\right) \qquad Q = mC\Delta t$$

$$V' = 4.44\Phi fN \qquad \frac{V_1}{V_2} = \frac{N_1}{N_2} \qquad \frac{I_2}{I_1} = \frac{N_1}{N_2}$$

$$N_{syn} = \frac{120f}{p} \qquad s\% = \frac{(n_{syn} - n)}{n_{syn}} \times \frac{100}{1} \qquad f_r = \frac{s\% \times f}{100}$$

$$V_{reg}\% = \frac{(V_{NL} - V_{FL})}{V_{FL}} \times \frac{100}{1} \qquad V_{reg}\% = \frac{(V_{NL} - V_{FL})}{V_{NL}} \times \frac{100}{1} \qquad T = \frac{\Phi ZIP}{2\pi a}$$

$$I_{ST} = \frac{1}{3} \times I_{DOL} \qquad T_{ST} = \frac{1}{3} \times T_{DOL} \qquad I_{ST} = \frac{V_{ST}}{V} \times I_{DOL}$$

$$T_{ST} = \left(\frac{V_{ST}}{V}\right)^2 \times T_{DOL} \qquad I_{motor\,st} = \frac{\%TAP}{100} \times I_{DOL} \qquad I_{line\,st} = \left(\frac{\%TAP}{100}\right)^2 \times I_{DOL}$$

$$E = \frac{\Phi_v}{A} \qquad E = \frac{I}{d^2} \qquad \eta_v = \frac{\Phi_v}{P}$$

$$V_L = 0.45V_{ac} \qquad V_L = 0.9V_{ac} \qquad V_L = 1.17V_{phase}$$

$$V_L = 1.35V_{line} \qquad PRV = \sqrt{2}V_{ac} \qquad PRV = 2\sqrt{2}V_{ac}$$

$$PRV = 2.45V_{ac} \qquad V_{ripple} = \sqrt{2}V_{ac} \qquad V_{ripple} = 0.707V_{phase}$$

$$V_{ripple} = 0.1895V_{line}$$