Government of Western Australia
North Metropolitan TAFE

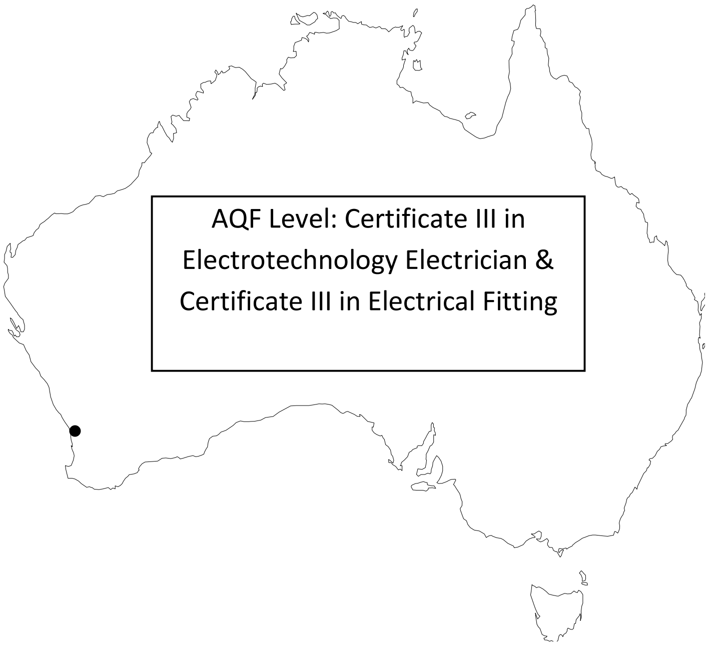
UEE11 Training Package Support Material
(Non-Endorsed Component)

Based on:
National Electrotechnology Industry Standards

Resource Book

UEENEEG101A

Solve problems in electromagnetic devices and related circuits.



North Metropolitan TAFE
V11 August 2018

Version 10 – 06/2018
Version 11 – 08/2018- Alignment to AS/NZS3000:2018

Acknowledgements

This Unit Guide has been prepared by Balga Campus Lecturers.

It is intended for North Metropolitan TAFE students only.

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Certificate III in Electrotechnology Electrician UEE 30811

UEENEEG101A – Solve problems in electromagnetic devices and related circuits.

C O N T E N T S

Training Achievement Record:
Part A - Magnetism

Part B – Machines

References

- The Occupational Safety and Health Act 1984 (WA).available at *www.worksafe.wa.gov.au*
- The Occupational Safety and Health Regulations 1996 (WA). available at *www.worksafe.wa.gov.au*
- Electrical Wiring Practice – Volume 1 (7th ed.) Pethebridge & Neeson
- Code of Practice – Safe electrical work on low voltage electrical installations *www.commerce.wa.gov.au/**energysafety***
- St John's First Aid and C.P.R. Available library and or St Johns.
- Wiring Rules AS/NZS 3000:2018

Required Skills and Knowledge
UEENEEG101A – Solve problems in electromagnetic devices and related circuits

Licensing/Regulatory Information

License to practice
During Training: Competency development activities are subject to regulations directly related to licencing, occupational health and safety and where applicable contracts of training such as apprenticeships.
In the workplace: The application of the skills and knowledge described in this unit require a license to practice in the workplace where work is carried out on electrical equipment or installations which are designed to operate at voltages greater than 50 V a.c. or 120 V d.c.

Other conditions may apply under State and Territory legislative and regulatory requirements.

Prerequisite Unit(s)

UEENEEE101A	Apply Occupational Health and Safety regulations, codes and practices in the workplace
UEENEEE104A	Solve problems in d.c circuits

ELEMENT		PERFORMANCE CRITERIA	
1	Prepare to work on electromagnetic devices and circuits.	1.1	OHS procedures for a given work area are identified, obtained and understood.
		1.2	OHS risk control work preparation measures and procedures are followed.
		1.3.	The nature of the device(s)/circuit(s) problem is obtained from documentation or from work supervisor to establish the scope of work to be undertaken.
		1.4	Advice is sought from the work supervisor to ensure the work is coordinated effectively with others.
		1.5	Sources of materials that may be required for the work are identified and accessed in accordance with established procedures.
		1.6	Tools, equipment and testing devices needed to carry out the work are obtained and checked for correct operation and safety
2	Solve electromagnetic devices/circuit problems.	2.1	OHS risk control work measures and procedures are followed.
		2.2	The need to test or measure live is determined in strict accordance with OHS requirements and when necessary conducted within established safety procedures.
		2.3	Circuits are checked as being isolated where necessary in strict accordance OHS requirements and procedures.
		2.4	Established methods are used to solving circuit problems from measure and calculated values as they apply to electromagnetic devices/circuits.
		2.5	Unexpected situations are dealt with safely and with the approval of an authorised person.
		2.6	Problems are solved without damage to apparatus, circuits, the surrounding environment or services and using sustainable energy practices.
3.	Complete work and document problem solving activities.	3.1	OHS work completion risk control measures and procedures are followed.
		3.2	Work site is cleaned and made safe in accordance with established procedures.

ELEMENT	PERFORMANCE CRITERIA	
	3.3	Justification for solutions used to solve circuit problems is documented.
	3.4	Work completion is documented and an appropriate person or persons notified in accordance with established procedures.

UEENEEG101A Required Skills and Knowledge Topics:

KS01-EG101A Electromagnetic devices and circuits

Evidence shall show an understanding of electromagnetic devices and circuits to an extent indicated by the following aspects:

T1 Magnetism encompassing::

- magnetic field pattern of bar and horse-shoe magnets.
- magnets attraction and repulsion when brought in contact with each other.
- common magnetic and non-magnetic materials and groupings (diamagnetic, paramagnetic and ferromagnetic materials).
- principle of magnetic screening (shielding) and its applications.
- practical applications of magnets
- construction, operation and applications of reed switches.

T2 Electromagnetism encompassing:

- conventions representing direction of current flow in a conductor.
- magnetic field pattern around a single conductor and two adjacent conductors carrying current.
- Using the “right hand rule” to determine the direction of magnetic field around a current carrying conductor.
- direction of force between adjacent current carrying conductors.
- effect of current, length and distance apart on the force between conductors (including forces on bus bars during fault conditions).
- magnetic field around an electromagnet.
- Using the “right hand rule” to determine the direction of magnetic field around a current carrying coil.
- magnetomotive force (m.m.f.) and its relationship to the number of turns in a coil and the current flowing in the coil.
- practical applications of electromagnets.

T3 Magnetic circuits encompassing:

- magnetic characteristic curve for various materials and identify the various regions.
- Identify the various conditions of a magnetic material from its Hysteresis loop.
- factors which determine losses in magnetic material.
- methods used to reduce electrical losses in a magnetic circuit.
- magnetic flux (definition, unit and symbol).
- reluctance as the opposition to the establishment of magnetic flux.
- permeability (definition, symbol and unit).
- difference for magnetic and non-magnetic materials in regards to reluctance and permeability.
- calculation of m.m.f., flux or reluctance given any two values.
- flux density (definition, symbol, unit and calculation).
- magnetising force (definition, symbol, unit and calculation).
- common magnetic circuit types.
- effect of an air gap in a magnetic circuit.
- terms “magnetic leakage” and “magnetic fringing”.

T4 Electromagnetic induction encompassing:

- principle of electromagnetic induction (Faraday’s law of electromagnetic induction).

- applying "Fleming's right hand rule" to a current a carrying conductor under the influence of a magnetic field.
- calculation of induced e.m.f. in a conductor given the conductor length, flux density and velocity of the conductor.
- calculation of induced e.m.f. in a coil given the number of turns in a coil and the rate of change of flux.
- calculation of force on a conductor given the flux density of the magnetic field, length of the conductor and the current being carried by the conductor.
- Lenz's law
- applications of electromagnetic induction

T5 Inductance encompassing:

- construction of an inductor, including a bifilar winding inductor.
- Australian Standard circuit diagram symbol for the four types of inductor.
- effect of physical parameters on the inductance of an inductor.
- common types of inductor cores.
- applications of the different types of inductors.
- definition of terms self induction, inductance and mutual inductance.
- calculation of value of self induced e.m.f. in a coil.
- mutual induction occurs between two coils.
- graphical relationship between load voltage, current and self induced e.m.f. in a single d.c. circuit having inductance.
- practical applications for the effects of self and mutual induction.
- undesirable effects of self and mutual induction.
- definition of term "time constant" and draw the characteristic curve as applied to a series circuit containing an inductor and a resistor. (LR circuit)Calculation of value of the time constant for an LR circuit given the values of the components.
- time constants required for the current in an LR circuit to reach its final value.
- determining of instantaneous values of voltage and current in an LR circuit using a universal time constant chart.

T6 Measurement Instruments encompassing:

- moving coil, moving iron, dynamometer meter movements and clamp testers.
- practical applications for moving coil, moving iron and dynamometer meter movements.
- Calculation of resistance of shunts and multipliers to extend the range of ammeters and voltmeters.
- factors to be considered in selecting meters for a particular application.
- safety category of meters and their associated applications.
- steps and procedures for the safe use, care and storage of electrical instruments.

T7 Magnetic devices encompassing:

- construction, operation and applications of relays.
- construction, operation and applications of contactors.
- magnetic methods used to extinguish the arc between opening contacts.
- construction, operation and applications of Hall Effect devices.
- operation and applications of magnetostriction equipment.
- construction, operation and application of magnetic sensing devices.

T8 Machine principles encompassing:

- basic operating principle of a generator.
- applying Fleming's right hand rule for generators.
- basic operating principle of a motor.
- applying Fleming's left hand rule for motors.
- calculation of force and torque developed by a motor.

T9 Rotating machine construction, testing and maintenance encompassing:

- components of a d.c. machine.
- difference between a generator and a motor in terms of energy conversion.
- nameplate of a machine.
- using electrical equipment to make electrical measurements and comparison of readings with nameplate ratings.
- Identification of faults in a machine from electrical measurements.
- care and maintenance processes for rotating machines
- safety risks associated with using rotating machinery.

T10 Generators encompassing:

- basic operation of a d.c generator.
- calculation of generated and terminal voltage of a d.c. shunt generator
- prime movers, energy sources and energy flow used to generate electricity.
- types of d.c. generators and their applications.
- methods of excitation used for d.c generators.
- equivalent circuit for a d.c. generator.
- importance of residual magnetism for a self-excited generator.
- open circuit characteristics of d.c. generators.
- load characteristics of a d.c generator.
- reversing the polarity of a d.c. generator
- Connect and test a d.c generator on no-load and load
- Identify safety risks associated with using generators.

T11 Motors encompassing:

- operation of a motor and its energy flow.
- effect of back e.m.f. in d.c. motors
- torque as the product of the force on the conductors and the radius of the armature/rotor.
- types of d.c. motors and their applications.
- circuit diagrams for the types of d.c. motors.
- equivalent circuit for the types of d.c. motors.
- calculation of power output of a motor.
- characteristics of the different types of d.c. motors.
- connection and testing a d.c. shunt motor on no-load and load
- reversing the direction of rotation of a d.c. motor.
- safety risks associated with using motors (include risks of series d.c. motors).

T12 Machine efficiency encompassing:

- losses that occur in a d.c machine.
- methods used to determine the losses in a d.c. machine.
- calculation of losses and efficiency of a d.c machine.
- efficiency characteristic of a d.c. machine and the conditions for maximum efficiency.
- application of Minimum Energy Performance standards (MEPS).
- methods used to maintain high efficiency.

Workplace Rules:

Rule 1	Follow the instructions
Rule 2	Tolerate ambiguity
Rule 3	Meet your obligations

Note: This information and current details of critical aspects for each competency standard unit (CSU) in this qualification can be found at the Australian Training Standards website: www.training.gov.au**.**

Q-TRACKER REQUIREMENTS:

60 hours of practical training.

1. Performance requirements:

1a. Related to the following elements:

1. Prepare to work on electromagnetic devices and circuits.
2. Solve electromagnetic devices/circuit problems.
3. Complete work and document problem solving activities.

1b. For each element demonstrate performance:

− across a representative body of performance criteria,
− on at least 2 occasions,
− autonomously and to requirements,
− within the timeframes typically expected of the discipline, work function and industrial environment.

2. Representative range includes the following:
All listed tasks related to performance across a representative range of contexts from the prescribed items below:

Group No	**The minimum number of items on which skill is to be demonstrated**	**Item List**
A.	All of the following: **Electromagnetic applications**	• Correctly connect electromagnetic circuits • Using methodical problem solving techniques. • Solving electromagnetic device problems. • Demonstrate an understanding of the behaviour of current and voltage in circuit with electromagnetic devices • Calculating parameters accurately.
B.	All of the following: **Circuit and device testing**	• Choose correct instruments and ranges for testing • Connect meters to measure parameters in circuits with electromagnetic devices
C.	At least four of the following: **Installing and maintaining electromagnetic devices**	• Reed switches • Solenoids • Relays • Contactors • Inductive limit switches • Bells • Lifting magnets • Core balance devices • Magnetic overloads • Motors • Generators • Magnetic brakes • Magnetic circuit breakers

Learning and Assessment Plan

Name of Lecturer: ____

Delivery Mode/s: ☑ Face to Face ☐ On-Line ☐ Blended Delivery ☐ Other

Using:

Session	Nominal Duration	**Program of Work (Topics to be covered)**	Primary Reference
1	0.5 hour	Introduction / Overview	Resource Book
2	0.5 hour	Isolation Procedure	Resource Book
3	1 hour	Magnetism	Resource Book
4	0.5 hour	Magnetism Questions	Resource Book
5	0.5 hour	Magnetism Practical Activity 1	Resource Book
6	2.5 hours	Electromagnetism and Magnetic Circuits	Resource Book
7	1 hour	Electromagnetism and Magnetic Circuits Questions	Resource Book
8	2.5 hours	Electromagnetic Induction	Resource Book
9	1 hour	Electromagnetic Induction Questions	Resource Book
10	1 hour	Electromagnetic Induction Practical Activity 1	Resource Book
11	1 hour	Electromagnetic Induction Practical Activity 2	Resource Book
12	1 hour	Measuring Instruments	Resource Book
13	1 hour	Measuring Instruments Questions	Resource Book
14	1 hour	Magnetic Devices	Resource Book
15	1 hour	Magnetic Devices Questions	Resource Book
16	1 hour	Magnetic Devices Practical Activity 1	Resource Book
17	**2.5 hours**	**Part A – Knowledge Assessment**	
18	3 hours	Machine Principles	Resource Book
19	1.5 hours	Machine Principles Questions	Resource Book
20	1.5 hours	Machine Principles Practical Activity 1	Resource Book
21	2.5 hours	Motors and Generators	Resource Book
22	1.5 hours	Motors and Generators Questions	Resource Book
23	1.5 hours	Motors and Generators Practical Activity 1	Resource Book
24	1.5 hours	Motors and Generators Practical Activity 2	Resource Book
25	1.5 hours	Motors and Generators Practical Activity 3	Resource Book
26	2 hours	Motors and Generators Advanced	Resource Book
27	1.5 hours	Motors and Generators Advanced Questions	Resource Book
28	1.5 hours	Motors and Generators Advanced Practical Activity 1	Resource Book
29	1.5 hours	Motors and Generators Advanced Practical Activity 2	Resource Book
30	**2.5 hours**	**Part B – Knowledge Assessment**	
31	**4 hours**	**Part B – Skills Assessment**	

I acknowledge that I have received and read this Learning and Assessment Plan

Student Name:____________________________ Signature: ________________________

Date: ______ ___

Lecturer Name	Lecturer Signature	Date

Assessment Strategy

Conditions of Assessment:

Normally learning and assessment will take place in an integrated classroom/ laboratory environment.

It is essential to work through the worksheets and activities in this workbook and follow the guidance of your lecturer. The worksheets and practical activities will provide the essential skills and knowledge outlined in this Unit and assist you in achieving competency.

Assessment Methods:

Written Knowledge Assessment – based on the Required Skills and Knowledge (RSAK). You must achieve a mark of 75% or more in this assessment.

Observed Skills Assessment – based on the Elements and Performance Criteria of this Competency Unit UEENEEEG101A. You must achieve a mark of 100% in this assessment.

Portfolio. One for Part A, One for Part B. You must achieve a mark of 100% in both assessments.

On-Job-Training:

It is expected that the off-job component of this competency unit will be complemented by appropriate on-job development involving exposure to re-occurring workplace events and supervised experiences. (See Work Performance Tasks.) You are required to log your on-the-job training in your 'Q-Tracker' apprentice work book and on www.qtracker.com.au account.

Sufficiency of Evidence:

In all instances competency is to be attributed on evidence sufficient to show that a person has the necessary skills required for the scope of work. These include:

- Task skills - performing individual tasks
- Task management skills - managing a number of different tasks
- Contingency management skills - responding to irregularities and breakdowns in routines
- Job/role environment skills - dealing with the responsibilities and expectations of the work Environment including working with others.

Evidence must demonstrate that an individual can perform competently across the specified range of activities and has the essential knowledge, understanding and associated skills underpinning the competency.

LABORATORY INSTRUCTIONS

Students working in laboratories at North Metropolitan TAFE Campus's do so on the condition that they agree to abide by the following instructions. Failure to observe the safety instructions will result in IMMEDIATE SUSPENSION.

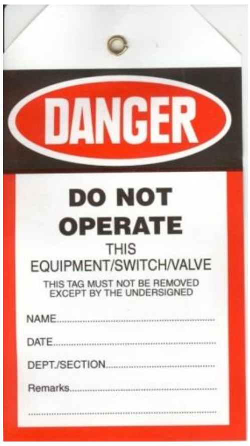
1. No circuit is to be plugged in or switched on without the specific permission of the lecturer in charge of the class. A circuit must be switched off, isolated and tested for ZERO VOLTS before any supply leads are removed. The DANGER TAG PROCEDURE must be used at all times.
2. Do not leave any circuit switched on any longer than necessary for testing. Do not leave any circuit switched on unattended.
3. Check each item of equipment before using. Report any broken, damaged or unserviceable equipment to your Lecturer.
4. All wiring must be disconnected at the end of each practical class or as each project is completed.
5. Make all connections in a safe manner with an appropriate connecting device. Unshielded 4mm banana plugs are not to be used for wiring.
6. Switch off, remove the plug from the socket and attach your DANGER TAG to the plug top before working on any project. It is not sufficient to simply turn the switch off.
7. When disconnecting your wiring from a connection made under a screw, undo the screw to remove the wiring, do not cut the wire off.
8. Observe the correct colour code for all wiring projects.
9. Test your circuit for short circuits with your multimeter before asking your Lecturer to switch circuit on. Test the Tester before and after EACH test.
10. Where an activity sheet is issued for a project, complete each step in the Procedure before moving to the next step. Advise your Lecturer when you have completed the activity.
11. Draw ALL DIAGRAMS in PENCIL so that they can be easily changed or corrected. Mark off each connection on your diagram as it is made.
12. Check the range before taking a reading with a multimeter.
13. Make sure that it is YOUR plug before inserting plug into an outlet.
14. Always switch multimeter OFF, or to the highest possible AC VOLTS range when you have finished using it.
15. Report any unexpected situations or events to your Lecturer.

Student's Signature ___________________________ Date: __________________

DANGER TAG PROCEDURE for ELECTRICAL TRADE LABORATORIES

THE FOLLOWING PROCEDURE IS COMPULSORY

1. The student is to attach a DANGER TAG on to the plug top of the project lead before proceeding with the allocated project. A danger tag must be attached to the plug top at all times, when the lead is NOT plugged into the supply outlet. Plug tops or leads are not to be connected to the supply outlet WHILE A DANGER TAG is attached.



2. The student is to assemble the project according to project instruction procedure and lecturer's directions in its isolated and de-energised state and report to the lecturer as necessary and on completion.

3. The lecturer is to:-
   a. Check the project for safety and
   b. Ensure that the student has performed a safety check, including a short circuit test using the recommended procedure.

4. When the lecturer is satisfied that the project is safe to connect and energise the lecturer is to instruct the student to REMOVE the DANGER TAG from the plug top.

5. The student is to plug in the project and switch it on in the presence of the lecturer.

6. The lecturer is to determine whether or not the project is operating satisfactorily.

7. If the project operates satisfactorily the student may take measurements using correct meters with regard to the safety risks associated with using the particular item of test equipment including;
   a. Selecting correct meter function,
   b. Holding meter probes correctly during measuring with fingers behind knurls (finger guards) at all times.

   This is to be done under general supervision of lecturer. The student is NOT to modify, disassemble or carry out ANY unsafe act.

8. If the circuit is to be modified the student must:
    a. Switch the circuit off,
    b. Disconnect the project from the supply,
    c. Attach the DANGER TAG to the plug top,
    d. Report to the lecturer for instructions,
    e. In the lecturer's presence the student is to:-
    f. TEST and VERIFY for ZERO VOLTAGE.
    g. Restart the DANGER TAG procedure from step 2 above.
9. When the student is satisfied that the project has been completed the student is to:-
    a. Switch the project off,
    b. Remove the plug,
    c. Replace the DANGER TAG on the plug top,
    d. Report to the lecturer for instructions,

    In the lecturer's presence the student is to:-
    e. TEST and VERIFY for ZERO VOLTAGE.

    The lecturer is then to instruct the student to:-
    f. Disassemble the project
    g. Remove the DANGER TAG and store the equipment in its designated place.

Failure to follow Danger Tag Procedures when working on practical activities and practical assessments will result in a '**Not yet competent'** comment recorded for this Unit of Competency – UEENEEG101A

Student's Signature __________________________ Date: _________________

UEENEEG101A – Solve problems in electromagnetic devices and related circuits

Task:

To understand magnetism and its practical applications, including motors and generators.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in both knowledge tests for each Required Skills and Knowledge (RSAK) topic.

2. You must satisfactorily complete the set activities and laboratory tasks.

3. You must achieve 100% in a final skills assessment.

Equipment

Nil

Resources

- Electrical Wiring Practice – Volume 1 (7th ed.) Pethebridge & Neeson
- AS/ANZ 3000:2018 Wiring Rules.

UEENEEG101A – Solve problems in electromagnetic devices and related circuits

Suggested Self-Study Guide

1. Study the following sections in the text and recommended references:

Electrical Principles for the Electrical Trades 6th Edition

Volume 1 Chapter 3 MAGNETISM

Volume 1 Chapter 6 INDUCTORS

Volume 1 Chapter 8 SINGLE-PHASE ALTERNATING CURRENT

Standards Australia Wiring Rules AS/NZS 3000:2018

2. Read the Summary and practise answering the Work Sheets and the Review Questions provided in Electrical Principles for the Electrical Trades 6th Edition. Refer to other relevant texts if you feel it is necessary.

3. Submit your answers to the Work Sheets to your Lecturer for discussion and feedback.

Magnetism

Magnetism

1. A solid substance is said to be a magnet if it has the property of attracting certain materials such as iron, cobalt, nickel and steel. An area in which a magnetic force can be detected is known as a magnetic flux or magnetic field.

Types of Magnets

2. There are three basic forms of magnets.

   a) Natural Magnets - Some materials such as lodestone are natural magnets, but they have no significant industrial applications.
   b) Artificial Magnets - Special alloys can be magnetised, and retain their magnetism even after the magnetising force is removed. They are known as permanent magnets. Permanent magnets are used in some small d.c. motors and generators, magnetic compasses, magnetos and some electrical measuring instruments.
   c) Electromagnets - These are temporary magnets which are magnetised by the flow of electric current through a conductor wound around a magnetic material. When the electric current is switched off the material loses its magnetism. Many electrical devices involve the use of electromagnetism in some form.

Magnetic Fields

3. All magnets are surrounded by a magnetic flux or field; this flux is usually said to consist of imaginary lines of force between the two extremities of the magnet. The extremities are known as the north pole and the south pole. Magnetic flux lines cannot be seen, but their effect can be seen if iron filings are sprinkled over a magnet. The magnetic flux or lines of force are shown below (Figure 1) for both a bar magnet and a horseshoe magnet.

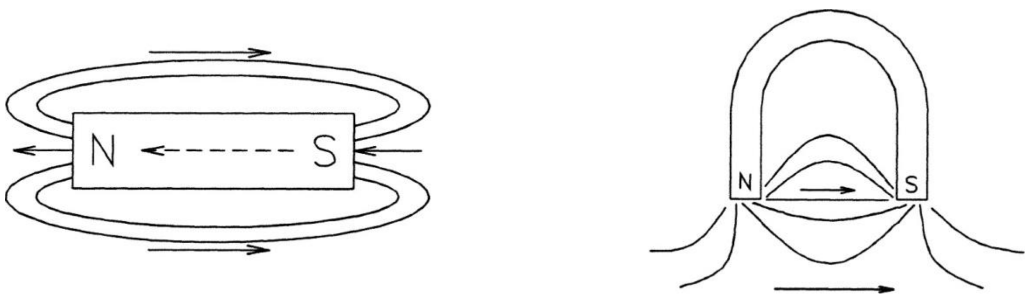


Figure 1. Bar and Horseshoe Magnet

4. Magnets and magnetic fields have several basic properties:

   a. Unlike magnetic poles attract each other.

   b. Like magnetic poles repel each other.

   c. Magnetic flux lines influence each other but they do not cross they must be continuous.

   d. The magnetic flux is strongest at the poles of the magnet.

   e. If a permanent magnet is cut in half, two magnets will be formed.

   f. Magnetic flux lines are conducted easily through magnetic materials. Materials which conduct or concentrate magnetic flux are said to have a high permeability.

g. There is no known insulator for magnetic flux.

h. Every magnet must have two poles; one pole cannot exist alone.

i. Strong magnets have more flux per unit area than weaker magnets.

j. Magnetic flux lines are assumed to travel from north to south externally for the purposes of certain electromagnetic 'rules'. Each magnetic line passes through the magnet to form a closed loop.

k. The test for magnetism is repulsion, not attraction.

Magnetic Induction

5. If a magnetic material such as soft iron is placed in a magnetic flux it will become an 'induced' magnet and the induced magnet will be attracted to the parent magnet. This process is known as magnetic induction.

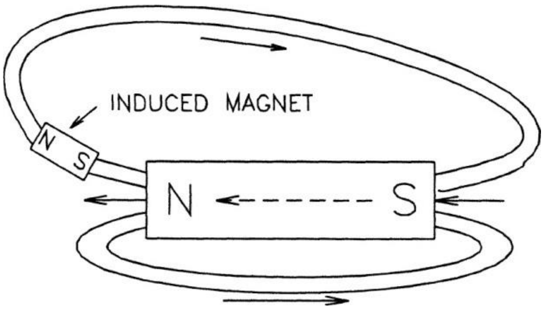


Figure 2. The Induced Magnet is attracted to the Parent Magnet

6. When the magnetic flux is removed, the soft iron will return to its original non-magnetised condition. This principle is used in electromagnets.

7. If an induced magnet retains some of its magnetism after the magnetising force is removed it is said to have 'residual magnetism'. The amount of residual magnetism depends on the original magnetising force and the type of material used. If the amount of residual magnetism is high, the material is said to have high 'retentively'.

The Domain Theory of Magnetism

8. A modern theory of magnetism is based on the electron spin principle. From the study of atomic structure, it is known that all matter is composed of vast quantities of atoms, each atom containing one or more orbital electrons. The electrons are considered to orbit in various shells and sub-shells, depending upon their distance from the nucleus. An electron has a magnetic field about it along with an electric field. The effectiveness of the magnetic field of an atom is determined by the number of electrons spinning in each direction. If an atom has equal numbers of electrons spinning in opposite directions, the magnetic fields surrounding the electrons cancel one another, and the atom is unmagnetised. When a number of such atoms are grouped together to form an iron bar, there is an interaction between the magnetic forces of various atoms. The small magnetic force of the field surrounding an atom effects adjacent atoms, thus producing a small group of atoms with parallel magnetic fields. This group of magnetic atoms, having their magnetic poles orientated in the same direction, is known as a DOMAIN. Every magnetic material is made up of a large number of domains. The domains in any substance are always magnetised to saturation, but are randomly orientated throughout a material. Thus, the strong magnetic field of each domain is

neutralised by opposing magnetic forces of other domains. When an external field is applied to a magnetic substance, the domains will line up with the external field. Since the domains themselves are naturally magnetised to saturation, the magnetic strength of a magnetised material is determined by the number of domains aligned by the magnetising force.

Magnetic Compass

9. The most common method of detecting a magnetic flux in industry is with a magnetic compass. The needle of a magnetic compass is a small bar type permanent magnet. The end of the needle which points to the north geographic pole is called the North Pole. When using a small magnetic compass it should be frequently checked for correct indication because a strong magnetic flux can sometimes reverse the polarity of the needle.

Magnetic Keepers

10. A magnet can be weakened if it is not stored correctly. Horseshoe magnets should be stored with a "keeper" to minimise loss of magnetic flux (Figure 4). Bar magnets should be stored in pairs with north and south poles adjacent (Figure 3).

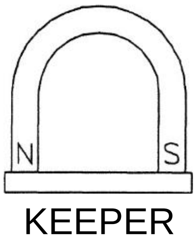


Figure 4. Horseshoe Magnet with Keeper

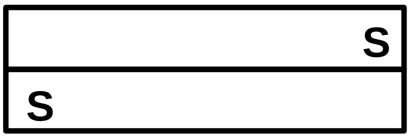


Figure 3. Bar Magnets Stored as pair

Magnetic Screening or Shielding

11. Sensitive instruments can be screened (shielded) from the effects of magnetic fields by surrounding them with a magnetic material with a high permeability. The magnetic lines take the path of least resistance (through the material with a high permeability).

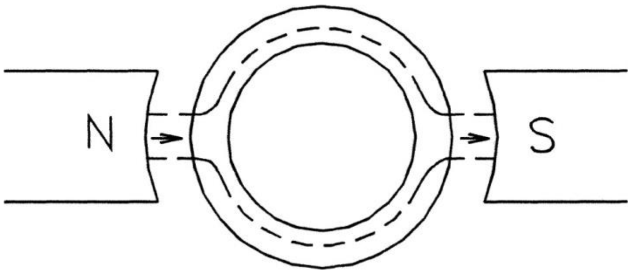


Figure 5. Example of Screening

Terrestrial Magnetism

12. The earth is a magnet. The North Pole of a magnetic compass points to the geographic North Pole. The north geographic pole behaves as a South magnetic pole and visa versa. The geographic pole does not coincide exactly with the magnetic pole.

Methods of Magnetisation

13. A magnetic material can be magnetised by:-

a. Placing it in a strong magnetic field, such as the field produced by a direct current electromagnet.

b. Stroking the material with a permanent magnet.

c. Tapping the material while it is pointing north and south.

14. Saturation Magnetisation cannot be continued indefinitely, as saturation is reached after a particular value of magnetising force. The region at which saturation occurs depends on the type of magnetic material used. When a magnetic material is saturated, an increase in magnetising force fails to produce any significant increase in magnetic flux.

Methods of De-magnetising

15. A magnet can be de-magnetised by:

a. Placing the magnet in an AC field (such as in a growler).

b. Heating the magnet to red heat.

c. Tapping or vibrating the magnet if it is not pointing north and south.

Magnetic Materials

16. Magnetic materials are classified in one of three groups:

a. **Ferromagnetic** materials are those which are relatively easy to magnetise such as iron, steel, cobalt, Alnico, and Permalloy, the latter two being alloys. Alnico consists primarily of aluminium, nickel, and cobalt. These alloys can be very strongly magnetised, with Alnico capable of obtaining a magnetic strength great enough to lift five hundred times its own mass.

b. **Paramagnetic** materials are those that become only slightly magnetised even though under the influence of a strong magnetic field. This slight magnetisation is in the same direction as the magnetising field. Materials of this type are aluminium, chromium, platinum and air.

c. **Diamagnetic** materials can also be only slightly magnetised when under the influence of a very strong field. These materials, when slightly magnetised, are magnetised in a direction opposite to the external field. Some diamagnetic materials are copper, silver, bismuth, gold, and mercury.

17. Some grades of stainless steel are non-magnetic. When some ferromagnetic materials are heated they reach a temperature where they lose most of their magnetism, then regain it when the temperature is reduced. The particular temperature for a given alloy is known as the Curie point. This principle is used in some temperature controlled electric soldering irons.

Ferrites

18. Ferrites are hard, brittle ceramic like material that are chemical compounds of iron oxide and one or more other metal oxides. The chemical composition can be varied during manufacture to produce an almost infinite variety of characteristics from temporary magnets to powerful permanent magnets. They are basically crystalline in structure and they have a high electrical resistance.

19. Ferrite magnetic materials cannot be machined using conventional metal shaping techniques.

20. Regions in a solid ferrite magnet can have different magnetic properties, so an annular ring (for example) can have its magnetic poles in different places as shown below.

Figure 6. Annular Ring

21. Ferrite magnetic materials are often used in loudspeaker cores, small motors and generators, solenoids, measuring instruments and small transformers.

Non-magnetic Materials

22. Some materials cannot be magnetised and are not effected by magnetic fields - these are known as non-magnetic materials, and include:

a. Copper, brass, aluminium

b. Air

c. Water

d. Glass

e. Paper

f. Plastics

Applications of Permanent Magnets

23. Typical applications for permanent magnets in electrical devices are:

 a. Magnets in some analogue measuring instruments.
 b. Magnetic chucks for supporting the work piece in machines.
 c. Permanent magnet speakers.
 d. Magnetic compasses.
 e. Some temperature controlled soldering irons.
 f. Microwave ovens.
 g. Magnetos.
 h. Bicycle generators.
 i. Refrigerator door seals.
 j. proximity relays
 k. Credit cards.
 l. Magnetic reed switches.

Construction and Operation of Reed Switches

24. A reed switch is a simple electrical switch operated by the application of a magnetic field. It is made up of a pair of contacts that are on thin ferrous metal reeds that are sealed in an airtight glass container.

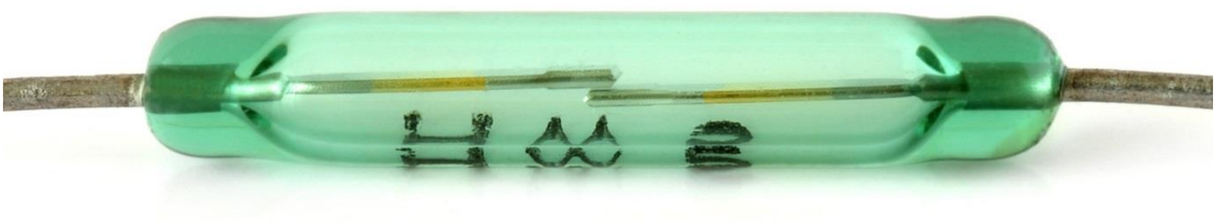


Figure 7. Normally Closed Reed switch

25. The contacts are operated by the presence of a magnetic field acting on the iron reeds. When the magnetic field is removed, the reeds return to their original position. Magnetic field can either be created by a coil (typically called a reed relay) or a magnet. Contacts may be normally open, closing when a magnetic field is present, or normally closed and opening when a magnetic field is applied.

Application of Reed Switches

26. Reed switches are normally used for proximity detection in security systems or control circuits.

Worksheet T1 Magnetism Questions

1. List four basic properties of magnets or magnetic fields. (T1.1)
2. The strongest magnetic flux of a magnet is at the…………of the magnet. (T1.1)
3. Do unlike magnetic poles attract or repel each other? (T1.2)
4. Is magnetic flux strongest at the pole ends or in the middle of a magnet? (T1.1)
5. In which direction are magnetic flux lines assumed to travel around a magnet? (T1.1)
6. Name an insulating material that can insulate against the effects of magnetic flux. (T1.4)
7. What are the three classifications for magnetic materials? (T1.3)
8. What is a 'magnetic shield' or ‘magnetic screen’? (T1.4)
9. What is meant by the term 'magnetic induction' and give an example of its application in industry. (T1.4)
10. What is the polarity of the end of magnetic compass needle which points to the north geographic pole? (T1.2)
11. Are ferrite materials usually good electrical conductors or poor conductors? (T.1.3)
12. List four applications for permanent magnets in industry. (T1.5)
13. Draw a neat sketch of a bar magnet and a horseshoe magnet and show the magnetic field around them. (T1.1)
14. Draw a neat sketch of two identical bar magnets laid end to end with a 5 mm gap between the NORTH poles. Show the expected magnetic field in the region of the gap between the poles. (T1.1, 1.2)
15. What type of material is suitable for use as a magnetic screen? (T1.3)
16. What is a reed switch? (T1.6, 7.6)
17. How does a reed switch operate? (T1.6, 7.6)
18. What is a reed switch used for? (T1.6, 7.6)
19. Explain how magnetic screening shields sensitive equipment from the effects of magnetic fields. (T1.4)
20. Explain the term Ferromagnetic material. (T1.3)
21. List five Ferromagnetic material. (T1.3)
22. List six non-magnetic materials. (T1.3)

Magnetism Practical

Task:

To identify types of permanent magnets and their magnetic field patterns.

Equipment:

Sample permanent magnets with keepers
Toroidal ferrite permanent magnet
Magnetic compasses
Small pieces of soft iron (about 10x3x10 mm)
Small transparent PVC separators (about 10x3x10 mm)
Transparent plate and iron filings

Method:

1. Examine the sample permanent magnets supplied. Place each permanent magnet under a transparent plate and sprinkle iron filings on top of the plate. Tap the plate gently to distribute the iron filings. Do not allow the iron filings to come in contact with the magnet - they would be difficult to remove.

2. Sketch each magnet and the pattern formed by the iron filings. Use the outlines on the attached sheet as a guide.

3. Use the magnetic compass to determine the polarity of the poles of each magnet (check the polarity of the magnetic compass before each observation - the marked end should be pointing to geographic North).

4. Position two bar magnets as shown on the attached sheet and sketch the resulting magnetic fields. Use a non-magnetic spacer to keep the magnets apart where necessary.

5. Select one permanent magnet and a piece of soft iron, and devise a method of demonstrating the principle of magnetic induction. Sketch the resulting magnet field.

Questions:

1. What is the assumed polarity of the marked end of a magnetic compass?

____

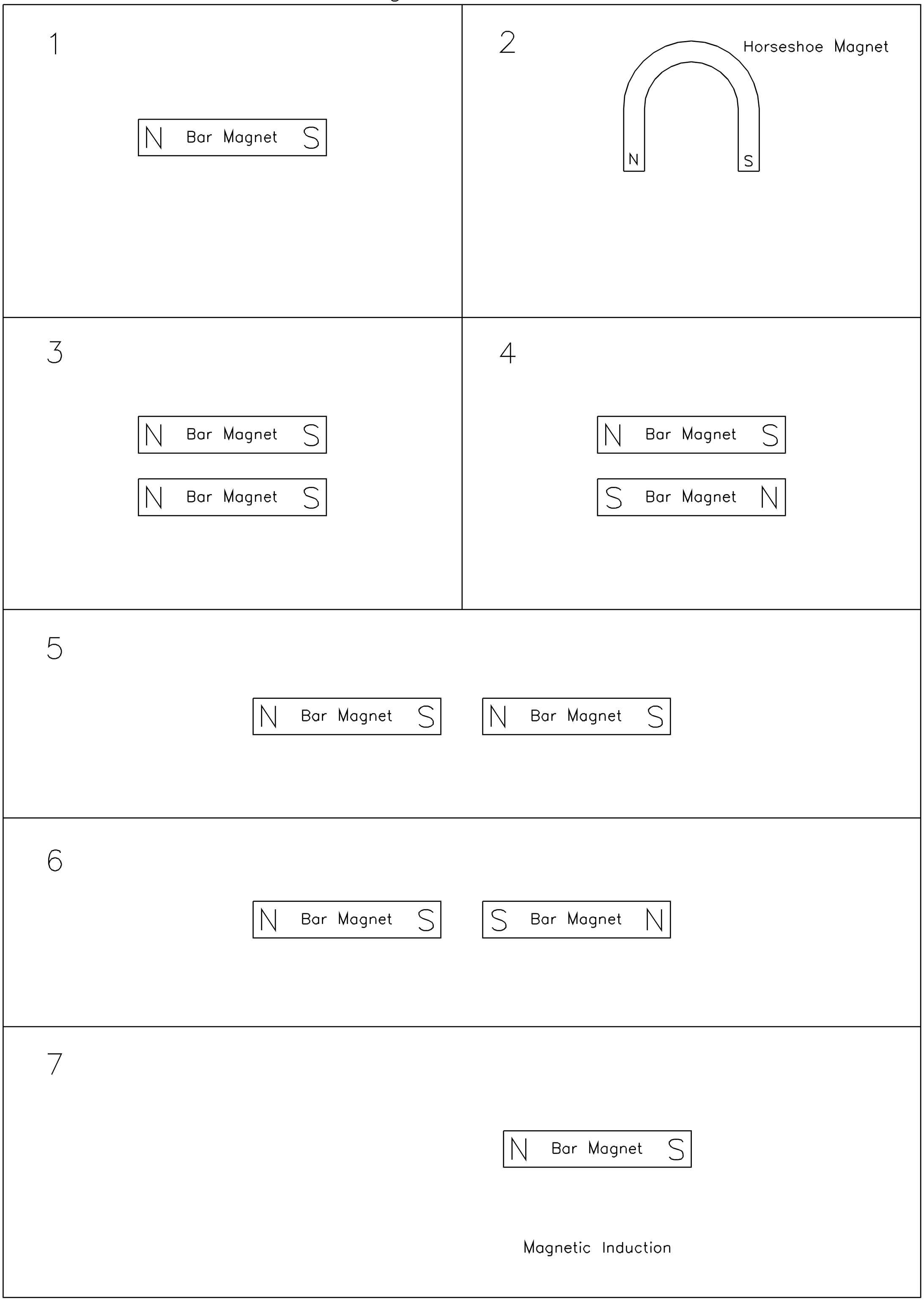
2. Where the magnetic field strongest around a magnet?

____

3. Do like magnetic poles attract or repel?

____

Magnetic Fields



Feedback and Recommendations:

Student's Signature: ____________________________ **Date:** ______________

Assessor's Signature: ____________________________ **Date:** ______________

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Electromagnetism and Magnetic Circuits

Electromagnetism

1. When current passes through a conductor, a magnetic field is produced around the conductor and at right angles to it. If the current flow is away from the observer, the magnetic field is in a clockwise direction around the conductor.

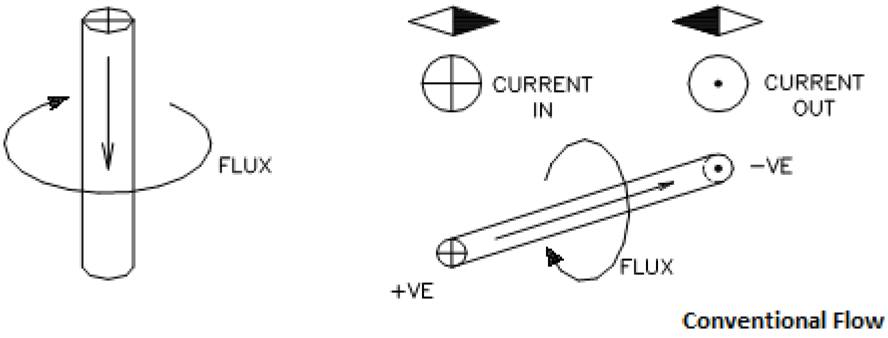


Figure 8. Conventions representing direction of current flow in a conductor

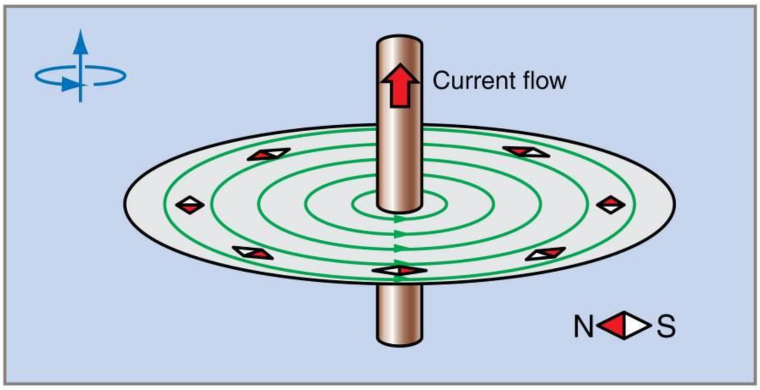


Figure 9. Magnetic field pattern around a single conductor

Right Hand Rule for Single Conductors

2. To determine the direction of the magnetic field around a current carrying conductor, you can use the RIGHT-HAND RULE FOR SINGLE CONDUCTORS which states:

> 'Place the thumb of the right hand in the direction of current flow in the conductors and the fingers will point in the direction of flux'.

Adjacent Current Carrying Conductors

3. The magnetic fields of two conductors close to each other will interact. Conductors with current flowing in the same direction will experience magnetic forces causing them to attract. Whilst conductors with current flowing in opposite directions will repel.

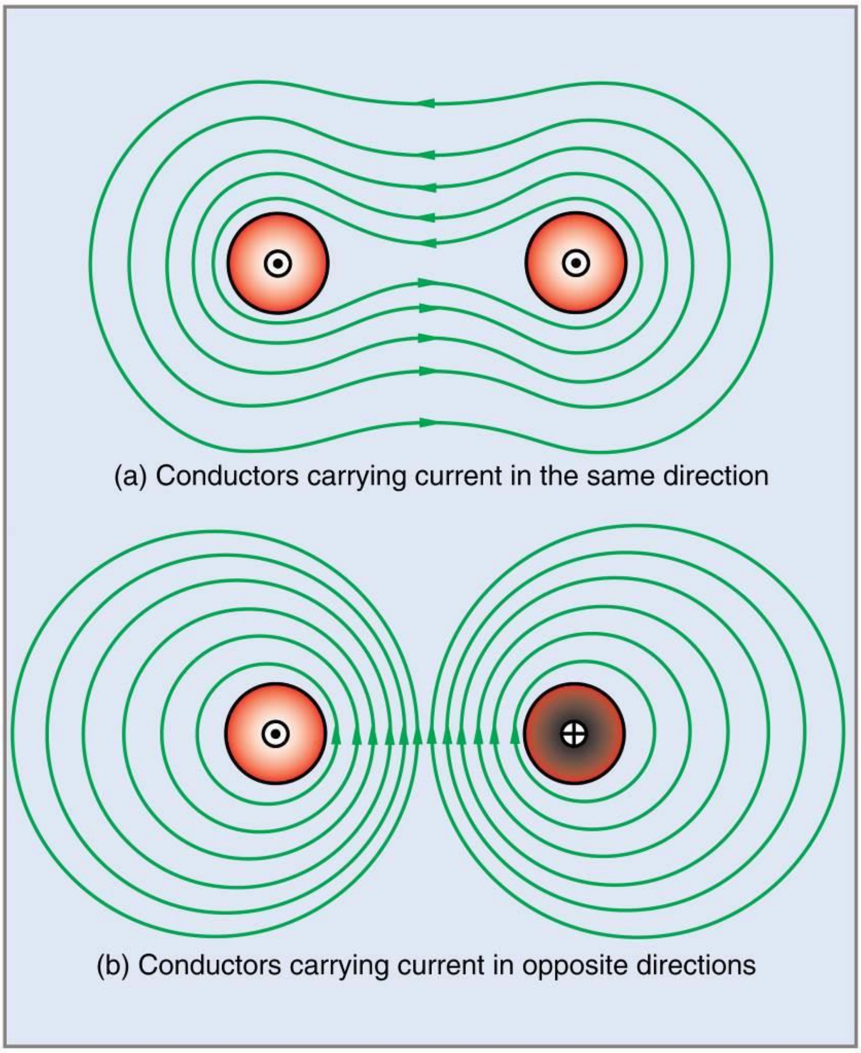


Figure 10. Magnetic field pattern around two conductors

4. This attraction or repulsion can result in severe mechanical stress between adjacent conductors when very high currents flow under fault conditions, and such conductors need to be mechanically braced to be able to withstand high magnetic stresses (such as in the rising mains in high-rise buildings) or busbars in switchboards.

Factors That Affect the Strength of the Force between Conductors

5. The force acting on the two adjacent cables is affected by the amount of current carried by the respective conductors and the distance between them. As shown in the following formula:

$$F = \frac{2 \times 10^{-7} \times I_1 \times I_2}{d}$$

Where:

F = the force in newtons
I_1 = the current in one conductor
I_2 = the current in the other conductor
d = the distance between the conductors in metres

6. **Example** Calculate the force exerted on two parallel conductors, each carrying 100 amps, if the distance between them is 50 mm (0.05 metres).

Solution

$$F = \frac{2 \times 10^{-7} \times I_1 \times I_2}{d}$$

$$F = \frac{2 \times 10^{-7} \times 100 \times 100}{0.05}$$

$$F = 0.04\ Newtons\ per\ meter$$

Electromagnets

7. This magnetic field can be connected by winding the conductor into a coil. The device is then known as an electromagnet.

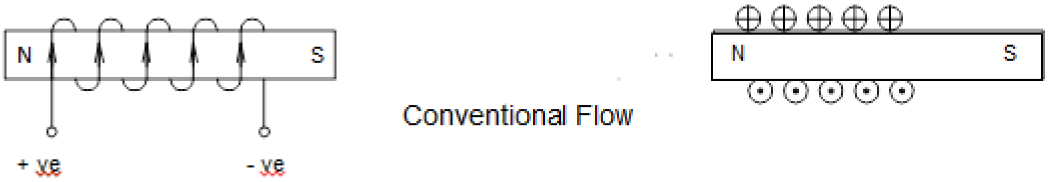


Figure 11. Electromagnets

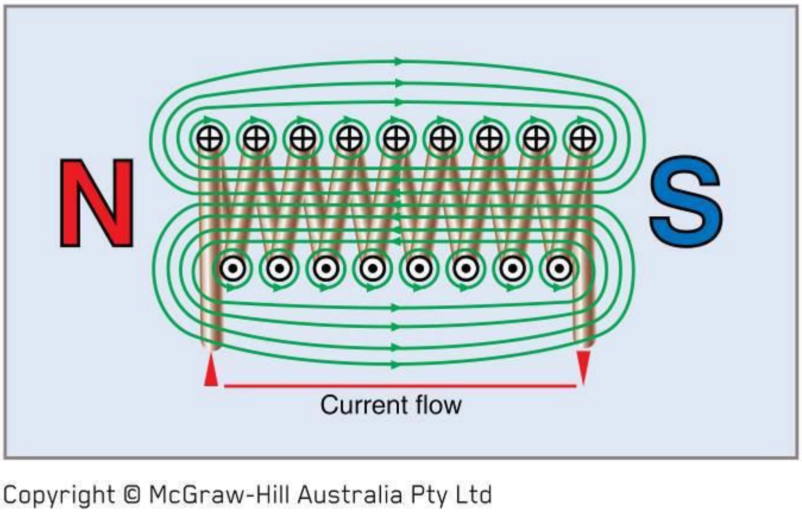


Figure 12. Magnetic field pattern around an electromagnet

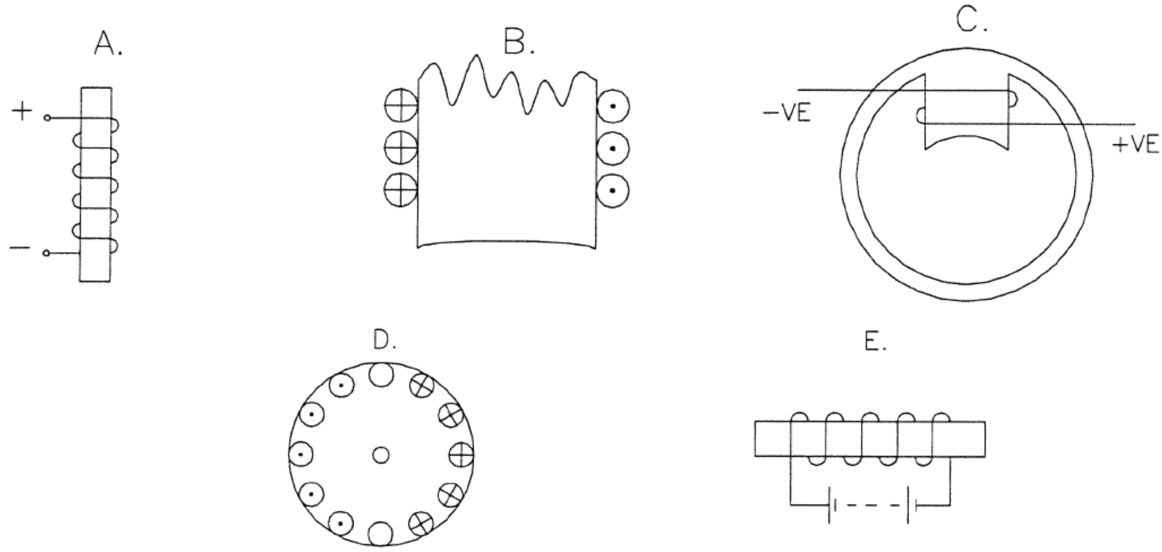
Right Hand Rule for Electromagnets

7. To determine the polarity of an electromagnet, use the RIGHT-HAND ELECTROMAGNET RULE or solenoid rule which states:

> 'Place the fingers of the right hand in the direction of current flow in the conductors and the thumb will point to the North Pole of the electromagnet'.

Examples

8. Find the polarity of the following electromagnets (using conventional flow):



Strength of an Electromagnet

9. The strength of an electromagnet is called its magnetomotive force and is governed by:

   a. The current flowing in the conductors.
   b. The number of turns on the electromagnet.
   c. The area of the magnetic core.
   d. The permeability of the material in the core (or the type of material), between certain limits.

10. In an electromagnet, the strength of the magnetic field depends on how much current flows in the turns of the coil. The greater the current, the stronger the magnetic field. Also, more turns in a specific length concentrates the field. An electromagnet has the same properties as a bar magnet, with opposite poles at the ends, providing a magnetic field proportional to the ampere-turns.

$$Ampere - turns \ = \ IN$$

Where I is the current in amperes and N is the number of turns.

The quantity IN is the magnetomotive force (Fm or mmf).

11. A coil of 200 turns, with a current of 2 amperes flowing produces 400 ampere turns of magnetising force. The same magnetising force could be produced for the same length of coil former by 20 amperes through 20 turns, or 100 turns and 4 amperes.

12. **Example** An electromagnet has 500 turns and its resistance is 4 ohms. How much magnetising force will it produce when connected to a 12 V d.c. supply?

Solution

$$I = \frac{V}{R}$$

$$I = \frac{12}{4}$$

$$I = 3\ A\ (coil\ current)$$

$$Magnetising\ force\ (Fm) = I \times N$$

$$Fm = 3 \times 500$$

$$Fm = 1500\ ampere\ turns$$

Applications of an Electromagnet

13. Electromagnets are used in most machines where electrical energy is converted into motion and visa versa. Typical uses are:

a. MRI machines.

b. Door Strikes.

c. Speakers.

d. Motors.

e. Generators.

f. Magnetic relays, starters and contactors.

g. Electromagnets for lifting steel objects.

h. Solenoids (electromagnets with a moving core).

i. Magnetic brakes and clutches.

j. Magnetic circuit breakers and overload sensors.

k. Magnetic reed switches and inductive limit switches.

Electromagnetic Terms

14. **Magnetic Flux (Ø)** this is the total magnetic flux in a magnetic circuit expressed in webers (Wb). 1 weber is flux of 10^8 lines of force.

15. **Magnetic Flux Density (B)** Flux density is the number of flux lines per unit area. It is usually expressed in lines of force per square metre. A flux density of 10^8 lines per square metre is called one tesla (T). Since 10^8 lines of force is one weber, 1 tesla = 1 Wb/m^2. A typical flux density in a transformer core is around 1 tesla. The flux density can be calculated using the flowing formula:

$$B = \frac{\emptyset\ (in\ webbers)}{Area\ (in\ square\ meters)}$$

16. **Magneto motive Force (Fm)** In an electric circuit, the current is due to the existence of an electromotive force. By analogy, we may say that in a magnetic circuit the magnetic flux is due to the existence of a magneto motive force (m.m.f) caused by a current flowing through one or more turns. The value of the magneto motive force is proportional to the current and to the number of turns, and the quantity is descriptively expressed as ampere turns (IN). The unit of magneto motive force is the ampere, but it is usually expressed in ampere turns (At).

17. **Reluctance (Rm)** Reluctance is the opposition offered by a magnetic circuit to the establishment of magnetic flux. Reluctance is the magnetic equivalent of electrical resistance. Reluctance is expressed in ampere/turns per weber (At/Wb). The reluctance of a given magnetic circuit can be calculated using the following equation:

$$Rm = \frac{length\ (in\ meters)}{\mu_r \times \mu_o \times Area\ (in\ square\ meters)}$$

18. **Magnetic Field Strength (H)** Magnetic field strength is the magneto motive force per metre length of the magnetic circuit. The unit of magnetic field strength is the ampere turns per metre. Magnetic field strength is sometimes referred to as magnetising force. The field strength can be calculated using the following formula:

$$H = \frac{I\ (in\ amperes) \times N\ (number\ turns)}{L\ (length\ in\ meters)}$$

19. **Relative Permeability (μ_r)** Relative permeability is the ratio of the flux density produced in a material to the flux density produced in a vacuum (or a non-magnetic core) by the same magnetic field strength. The relative permeability of a ferromagnetic material varies for different values of flux density in the core. The relative permeability of air is 1. Absolute permeability (μ_o) is the permeability of free space. The absolute permeability (μ_o) of free space is taken as $4\pi \times 10^{-7}$H/m. **Actual permeability (μ),** the ease with which a material allows a flux to be created, can be found by multiplying relative permeability by absolute permeability, or by dividing the flux density in webers per square metre (teslas) by the magnetising force in amp turns per metre. In equation form the relationships between the types of permeability are:

Actual permeability $\mu = \mu_r \times \mu_o$ and $\mu = \frac{B\ (in\ Teslas)}{H\ (in\ Ampere\ turns\ per\ meter)}$

Relative permeability $\mu_r = \frac{\mu}{\mu_o}$

20. Diamagnetic materials have a relative permeability slightly below unity while paramagnetic materials have a relative permeability slightly above unity. Ferromagnetic materials however have incredibly large permeability. Materials that are easily magnetised have a low reluctance and a high permeability, and non-magnetic materials have a high reluctance and a low permeability.

Magnetic Circuit

21. The behaviour of a magnetic circuit can be considered as analogous to an electrical circuit when current flows through a coil wound on a magnetic core. In an electrical circuit an electromotive force causes a current which depends on the resistance of the electrical circuit. In a magnetic circuit an magneto motive force causes a magnetic flux which depends on the reluctance of the magnetic circuit, i.e.:

$Current\ (I) = \frac{V}{R}$ $\quad\quad$ $Magnetic\ Flux\ (\emptyset) = \frac{Fm}{Rm}$

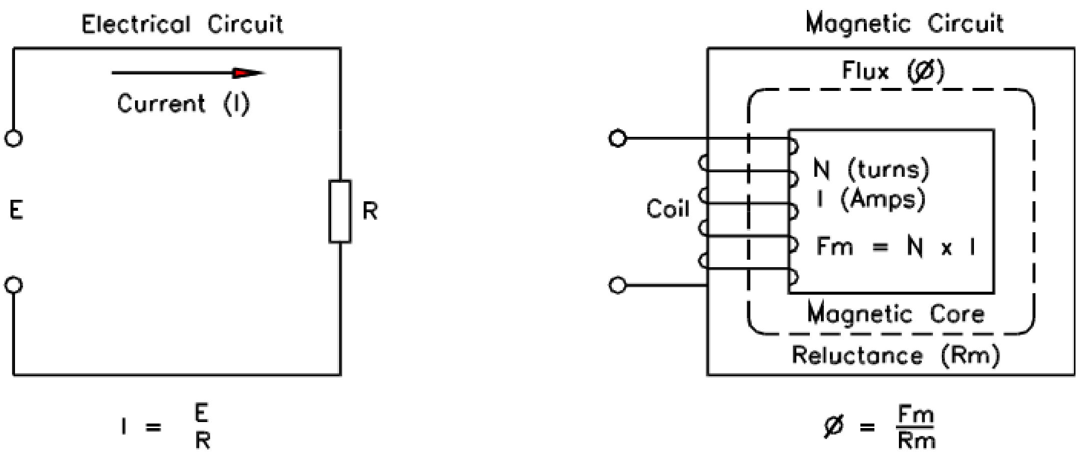


Figure 13. Comparison of electrical circuit to a magnetic circuit

Calculating Magnetic Flux

22. An electromagnet has 1000 turns wound on a magnetic core, and a current of 5 amps is flowing in the coil. If the reluctance of the magnetic core is 900 At/Wb the resulting flux in the core can be calculated as follows:

$$Flux\ (\emptyset) = \frac{Fm}{Rm}$$

$$\emptyset = \frac{1000 \times 5}{900}$$

$$\emptyset = 5.56\ Webbers$$

Calculating Flux Density

23. An electromagnet has 2500 turns, wound on a magnetic core rectangular in section, and having dimensions of 40 mm X 55 mm. If the flux produced in the magnetic circuit is 20 Wb, calculate the flux density of the magnetic core.

$$B = \frac{\emptyset}{A}$$

$$where\ A = (40 \times 55) \times 10^{-6} m^2$$
$$= 0.0022\ m^2$$

$$B = \frac{20}{0.0022}$$

$$B = 9090.9\ T$$

Calculating Magnetic Field Strength

24. An electromagnet has 3 A flowing through 4000 turns wound on a magnetic core 250 mm in length. Calculate the magnetic field strength produced by the magnetic core.

$$H = \frac{I \times N}{L}$$

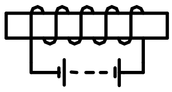
$$H = \frac{3 \times 4000}{250 \times 10^{-3}}$$

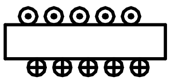
$$H = 48\,000\ At/m$$

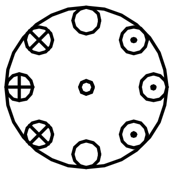
Worksheet T2 (Part A) Electromagnetism and Magnetic Circuits Questions

1. What is the direction of the magnetic flux around a single conductor when current is flowing away from the observer? (T2.1)

2. What is the polarity of each of the following electromagnets and draw the resulting magnetic field: (T2.6, 2.7)

a. 

b. 

c. 

3. State four factors which govern the strength of an electromagnet. (T2.8)

4. Define the following terms. Give their symbol, unit of measurement and unit symbol:

   a. Magnetic Flux. (T3.5)
   b. Permeability. (T3.7)
   c. Magnetic Flux Density. (3.10)
   d. Magnetising Force (or Magnetic Field Strength). (T3.11)
   e. Magneto motive Force. (T2.8, 3.5)
   f. Reluctance (T3.6)

5. What is the meaning of the term permeability (μ)? (T3.7)

6. What is the general meaning of the term 'relative permeability'? (T3.7)

7. What is the relative permeability of AIR? (T3.7)

8. Sketch the magnetic field around a single current carrying conductor. Showing the direction of current using appropriate conventions. (T2.2, 2.3)

9. Which quantity is the magnetic equivalent to electrical resistance and what is the quantity symbol? (T3.6)

10. Give four examples of the application of electromagnets in industry. (T2.9)

11. Sketch the magnetic field around two adjacent current carrying conductors. Showing the direction of current using appropriate conventions. (T2.2)

12. Calculate the force exerted on two parallel conductors, each carrying 200 amps, if the distance between them is 0.06 metres. (T2.5)

13. Calculate the force exerted on two parallel busbars, each carrying a current under fault conditions of 1.5 kA, if the distance between them is 0.06 metres and their length in 1 metre. (T2.5)

14. Two large insulated cables are installed beside each other. If each conductor had a high current flowing in it, and both currents were in the same direction, would the resulting magnetic force between them be attraction or repulsion? (T2.2, 2.3, 2.4)

15. What is a typical working value of flux density in the core of an a.c. electromagnet? (T3.10)

16. Which two values in an electromagnetic coil when multiplied together are expressed as Magneto Motive Force (FM)? (T2.8)

17. What would be the result of high current flow between adjacent conductors? (T2.4)

18. Draw a solenoid coil with the magnetic field around it and label the poles. (T2.6)

19. State the two factors that govern the value of **Magneto motive Force (Fm)** produce in an electromagnet. (T2.8)

20. An electromagnet has 120 turns wound on a magnetic core, and a current of 5 amps is flowing in the coil. Calculate the value of **Magneto motive Force (Fm)** creating a magnetic flux. (T3.9)

21. An electromagnet has 550 turns and its resistance is 4.5 ohms. How much **Magneto motive Force (Fm)** will it produce when connected to a 12 V d.c. supply? (T3.9)

22. An electromagnet has a magneto motive force of 4000 At producing a magnetic flux of 6 Wb. Calculate the **reluctance (Rm)** of the magnetic core.(T3.9)

23. An electromagnet has 1000 turns wound on a magnetic core, and a current of 5 amps is flowing in the coil. If the magnetic flux in the core in 5.56 Wb, calculate the **reluctance (Rm)** of the magnetic core. (T3.9)

24. An electromagnet has 1000 turns wound on a magnetic core, and a current of 4 amps is flowing in the coil. If the reluctance of the magnetic core is 950 At/Wb. Calculate the resulting **magnetic flux (Φ)** in the core. (T3.9)

25. An electromagnet has 600 turns and the total reluctance of the magnetic core is 800 At/Wb. Calculate the resulting **magnetic flux (Φ)** produced in the core when 10 A flows through the coil. (T3.9)

26. How much **magnetic flux (Φ)** would be produced in the core of an electromagnet which has 500 turns, if the reluctance of the core is 900 At/Wb? The current in the coil is 3 amps. (T3.9, 2.8)

27. A contactor coil has 7200 turns, which are wound on an iron core, rectangular in section, and having dimensions of 20 mm X 30 mm. If the flux produced in the e magnetic circuit is 20Wb, Calculate **flux density (B)** of the magnetic core. Use formula $B = \Phi/A$. (T3.10)

28. An electromagnet has 1 A flowing through 7500 turns wound on a magnetic core 100 mm in length. Calculate the resulting **magnetising force (H) or Magnetic Field Strength (H)** produced by the magnetic core. Use formula H = IN/L. (T3.11)

29. A contactor coil wound on an iron core 120 mm in length produces a magneto motive force 9000 At. Calculate the resulting **magnetising force (H) or Magnetic Field Strength (H)** produced by the magnetic core. Use formula H = IN/L. (T3.11)

30. List three types of magnetic circuits. (T3.12)

31. What is difference for magnetic and non-magnetic materials in regards to reluctance and permeability? (T3.8)

Magnetisation Curve

25. A Magnetisation Curve (or BH Curve) is a graph showing how the flux density of a particular magnetic material varies as the magnetising force varies. The flux density (B) is shown on the vertical +Y axis and magnetising force (H) is shown on the horizontal +X axis - see BH Curve. As the magnetising force is increased there is a greater repulsive force between flux lines so the rate of magnetisation is reduced. As the magnetising force is increased, a stage is reached where the increase in magnetic flux is negligible - this is known as the region of magnetic SATURATION. It is not wise to increase the magnetising force much past this point as all it results in is heat, loss of efficiency and high currents. The trade name of one commonly used magnetic core material for motor and power transformer laminated cores is 'Stalloy'.

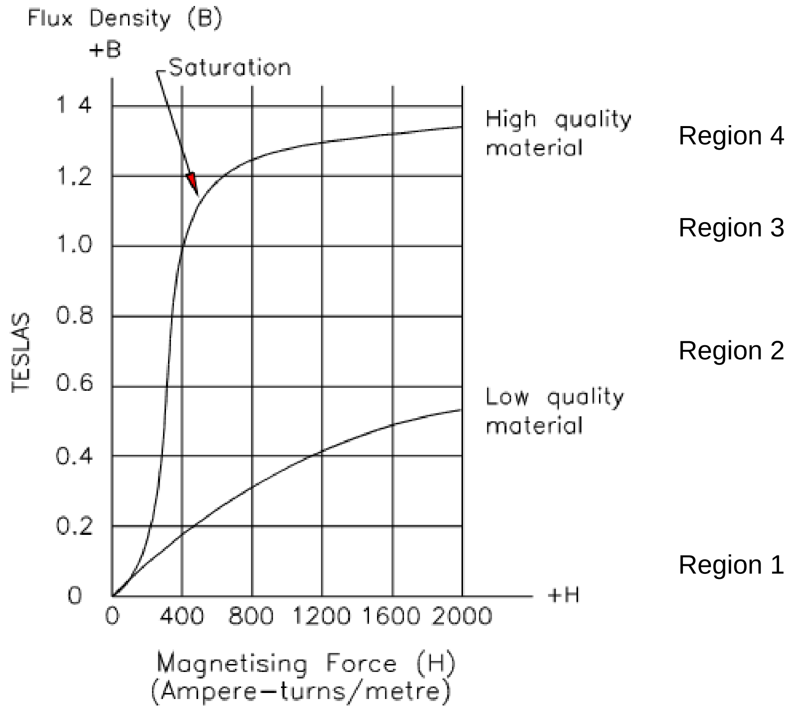


Figure 14. B-H Curve

26. Four distinct regions can be found on most magnetisation curves as shown on the high-quality material.

Region 1: Near to the point of origin a slow increase due to initial absorption of energy.

Region 2: A longer consistent rapid growth with little increase in the magnetising force. This is the region in which most magnetic materials are operated.

Region 3: A slowing of the growth representing the ‘knee of change’.

Region 4: The levelling of growth as the ferromagnetic material becomes saturated and cannot absorb any more flux growth.

Magnetic Losses

27. When electromagnets experience a changing electrical current. The continually changing magnetic flux in the magnetic core results in two types of *'iron loss'* - hysteresis loss and eddy current loss. Both losses result in electrical power being used unnecessarily (reducing efficiency), and can be reduced at the design stage.

28. **Hysteresis** when an electromagnet is connected to an a.c. supply the resulting magnetic field is continuously increasing and decreasing. The magnetic core is magnetised when the current is increasing and de-magnetised when the current is decreasing. As the current is decreased the magnetic field decreases, but not at the same rate as the current. When the current has fallen to zero there is still some residual magnetism in the core, and this residual magnetism must be reduced to zero before the core can be magnetised to the opposite polarity. The power required to reduce the residual magnetism to zero is an 'iron loss' and it is different for each type of magnetic material. The force required to reduce the residual magnetism to zero is known as the 'coercive force'.

29. The effect of hysteresis can be shown on a graph known as an 'hysteresis loop'. The area contained within the hysteresis loop is directly proportional to the hysteresis loss - the better the material the smaller the hysteresis loop - as shown below. Hysteresis loss can be reduced by using a better-quality material for the magnetic core.

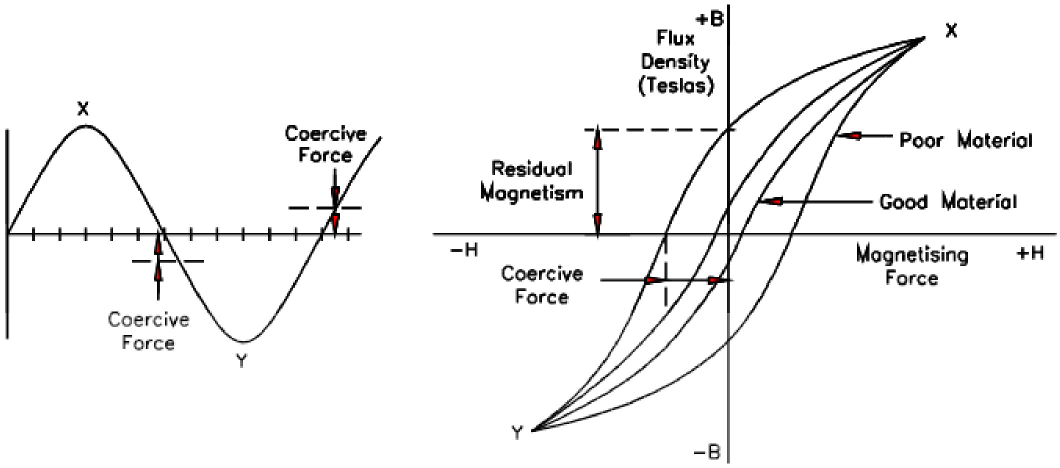


Figure 15. Hysteresis Loop

30. **Eddy Current Loss** Since the magnetic core of many electromagnets is an electrical conductor, the changing magnetic field around the core induces current in the magnetic material as well as in the winding. This induced current is a loss which reduces efficiency and causes unwanted heating in the core - it needs to be kept as low as possible. One method of reducing eddy current loss is to laminate the magnetic core and provide electrical insulation between the laminations (usually in the form of a thin oxide film). The laminations break the electrical circuit in the core and the eddy currents are reduced. Another method of reducing eddy current loss is to use a ferrite core. The magnetic particles in ferrite are electrically insulated from each other so eddy currents are virtually eliminated. The magnetic cores of a.c. devices such as motors, transformers, solenoids, armatures and rotors must be laminated to reduce eddy currents.

Air Gaps

31. If an air gap exists in a magnetic circuit, the total magnetic flux in the core is reduced because the relative permeability of air is much lower than the relative permeability of the remainder of the core, so the reluctance of the magnetic circuit is increased. In electromagnetic devices which require an air gap (such as motors and generators), the air gap needs to be as small as possible.

32. **Magnetic Leakage** Where part of the flux that is intended to pass through the core but passes through the air, insulation or structural metal members instead. All magnetic circuits experience magnetic leakage and it can never be completely removed. Because of magnetic leakage the electromagnetic circuit is never 100% efficient.

33. **Magnetic Fringing** where part of the magnetic circuit is an air gap, the flux as it crosses the air gap is spread out wider by the lines of flux repelling each other. This results in a decrease in the magnetic field strength reducing the effectiveness of the electromagnet. This occurs anywhere there is an air gap but is also affected by the length of the air gap. Meaning the effect can be reduced by reducing the size of the air gap.

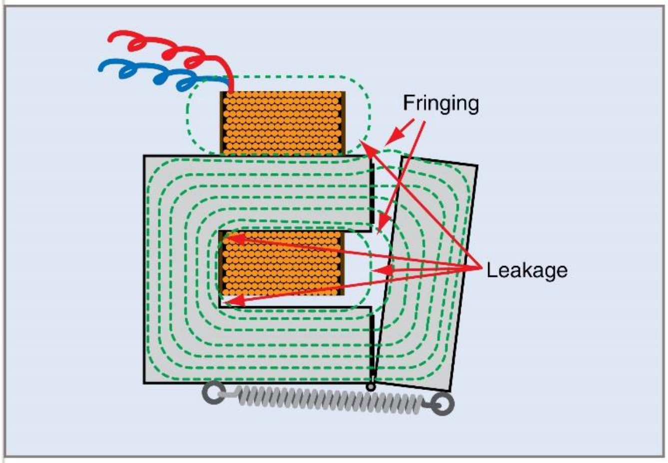


Figure 16. Magnetic Leakage and Fringing

Magnetic Circuit Types

34. There are three main magnetic circuit types. They are identified by the reluctance of the circuit.
1. Low Reluctance – horseshoe magnet with keeper
2. High Reluctance – horseshoe magnet without keeper
3. Variable Reluctance – electric motor

Worksheet T2 (Part B) Electromagnetism and Magnetic Circuits Questions

1. Sketch a typical magnetisation curve (BH Curve) for soft iron. Indicate the units used on the vertical and horizontal axes and show the area of 'saturation'. (T3.1)

2. What is the trade name of one laminated magnetic material which is commonly used in electric motors and power transformers? (T3.1)

3. What is the name given to that property of a magnet which enables it to retain some magnetism after the magnetising force has been removed? (T3.2)

4. Explain the purpose of a Magnetisation Curve (or BH Curve)? (T3.1)

5. What is meant by the term 'saturation' when applied to magnetic materials? (T3.1)

6. State the effect on magnetic flux within a magnetic material if the Magnetising Force (H) is increased beyond the point of Saturation. (T3.1)

7. Draw a Magnetisation Curve showing magnetic characteristics of high quality and low quality magnetic materials. Identify all parts. (T3.1)

8. What material is used to make the laminations of an electromagnetic core? (T3.1)

9. An electromagnetic core has a cross-sectional area of 100 mm^2 and a magnetic flux of 1 Wb (10^8 lines of force). Calculate the **flux density (B)** in the core.
   Use formula $B = \Phi/A$. (T3.10)

10. Sketch a hysteresis loop showing a high quality magnetic material and a lower quality magnetic material (on the same graph). Indicate the residual magnetism and the coercive force on the graph. (T3.2)

11. Name two types of Iron Loss in a magnetic circuit.

12. What is the purpose of a Hysteresis Loop? (T3.2)

13. What is meant by the terms **Residual Magnetism** and **Coercive Force** identified in regions of a Hysteresis loop? (T3.2)

14. Why is Hysteresis a problem in poor magnetic material? (T3.3)

15. What type of magnetic material identified on a Hysteresis Loop has a low iron loss? (T3.3)

16. How is Hysteresis Loss reduced in the magnetic circuit of a motor or transformer? (T3.4)

17. What is an **Eddy Current Loss?** (T3.4)

18. How is Eddy Current Loss reduced in the magnetic circuit of a motor or transformer? (T3.4)

19. What effect does an air gap have in a magnetic circuit? (T3.13)

20. What is magnetic leakage and magnetic fringing? (T3.14)

21. Which type of iron loss would be increased in an a.c. electromagnet if the magnetic core had a high retentivity? (T3.4)

22. What effect does high eddy current loss and high hysteresis loss have on the operation of a practical a.c. electromagnetic device? (T3.4)

Electromagnetic Induction

Electromagnetic Induction (EMI)

1. When a conductor is moved across a magnetic field, a voltage is INDUCED in the conductor. The process is known as electromagnetic induction (EMI) or Faraday's Law of magnetic induction. If the conductor is part of a closed electrical circuit a current will flow.

2. The value of the voltage induced in the conductor, and hence the current, will be proportional to:

    a. The strength of the magnetic field - a stronger field causes a higher voltage.

    b. The number of turns in series - more turns gives a higher total voltage.

    c. The speed at which the conductor cuts or links with the lines of magnetic force - the greater the speed the greater the voltage.

    d. The angle at which the conductor cuts the lines of magnetic force - the closer the angle of cutting is to 90º, the greater will be the voltage induced. Thus, a conductor moving at 0º (or parallel) to a flux has no voltage induced in it.

3. The direction of induced current in a conductor depends on the polarity of the magnetic field and the direction of movement of the conductor in that field. If the conductor is not moving, no voltage is induced so no current will flow.

4. A conductor moving CLOCKWISE under the influence of a NORTH magnetic pole has induced current flowing away from the observer, assuming that current flows from positive to negative (conventional flow) in an external circuit.

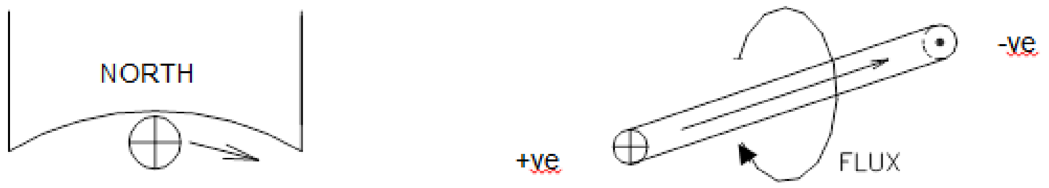


Figure 17. Conductor under a North Pole

5. If any one of the three variables are changed, the induced current will be reversed. If two variables are changed, the induced current remains in the same direction.

Right Hand Generator Rule

6. This relationship can also be expressed as a 'RIGHT HAND GENERATOR RULE' (or Fleming's Right Hand Rule for Generators), which states:

    'Place three fingers of the RIGHT hand mutually at right angles. Place the forefinger in the direction of the magnetic field (north to south), the thumb in the direction of motion of the conductor, then the middle finger will indicate the direction of current in the conductor'.

Fleming's Right Hand Generator Rule

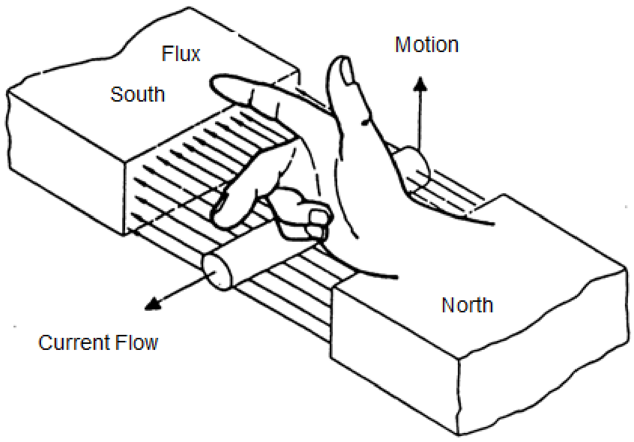


Figure 18. Right Hand Generator Rule

Main Applications of Electromagnetic Induction

7. **Generation** If a loop or coil of wire is rotated through a magnetic field an emf will be induced in the coil - if the coil forms a closed loop a current will flow in the circuit. This is the principle on which alternators and generators are based. If the coil is rotated at a constant speed sinusoidal alternating current can be produced as shown below:

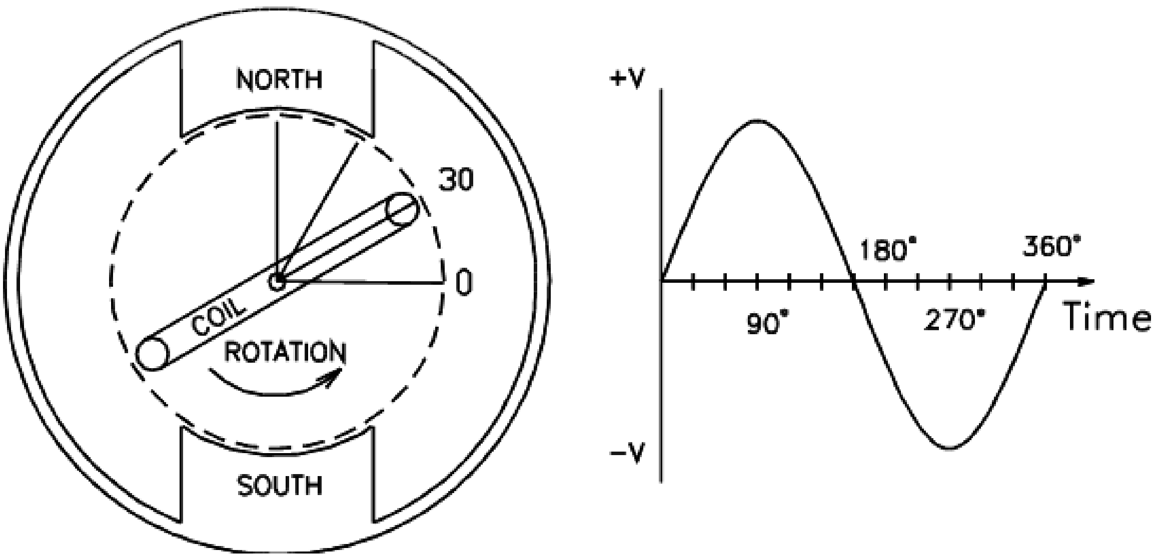


Figure 19. Coil rotated through a magnetic field

8. **Induction Motors** mainly a.c. motors have a series of stationary electromagnetic coils wound in such a way as to produce a magnetic flux within which a rotor is located. The rotor has conductors, but there is no electrical connection between the stationary winding (the stator) and the rotor. The alternating current flowing in the stator induces current in the rotor winding and the interaction between the magnetic fluxes causes the rotor to rotate.

9. **Transformers.** A basic transformer consists of two coils wound on a ferromagnetic core - the coils are known as the primary winding and the secondary winding. When a.c. is applied to the primary winding the resulting moving magnetic flux induces a voltage in the secondary winding.

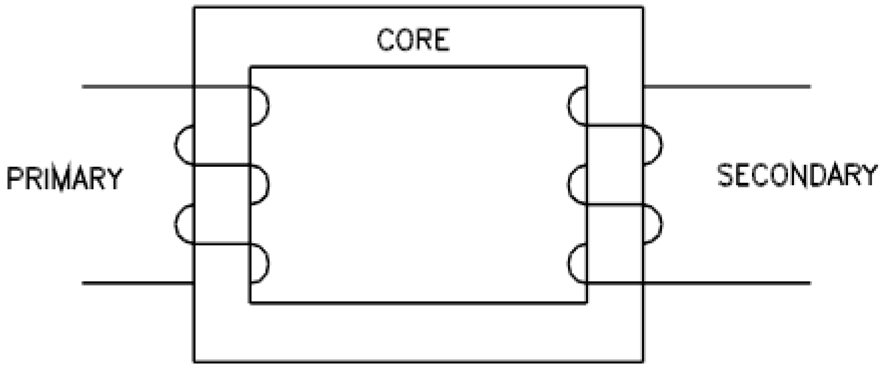


Figure 20. Transformer

10. The detailed operation of alternators, generators, induction motors, transformers and other devices which depend on the principle of electromagnetic induction are covered later in the course.

Left-Hand Motor Rule

11. When a conductor carrying current is placed in a magnetic field and at right angles to it there will be a force exerted on the conductor tending to move it out of the magnetic field in a direction determined by Fleming's left-hand motor rule. The left-hand motor rule is like Fleming's right-hand generator rule except that the left hand is used. The left-hand motor rule states:

> 'If the forefinger of the left hand is pointed in the direction of the flux and the middle finger is pointed in the direction of the current, the thumb will point to the direction of movement of the conductor.'

12. Thus a current flowing away from the observer under a north magnetic pole will have a force exerted on it tending to move it out of the magnetic field in an anti-clockwise direction.

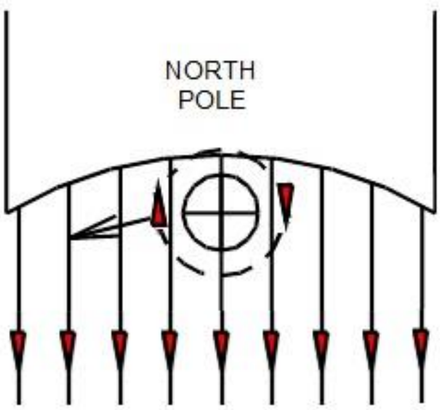


Figure 21. Conductor under a north pole

Force on a Conductor

13. The force exerted on the conductor depends on the flux density of the magnetic flux, the current in the conductor and the length of the conductor. The force can be calculated using the equation:

$$F = B \times I \times l$$

Where: F = the force exerted on the conductor in newtons.
B = the flux density in teslas.
I = the current in the conductor in amps.
ℓ = the length of the conductor in metres.

14. **Example** Determine the force exerted on a conductor 200 mm (0.2 metres) long when is carrying a current of 20 amps in a magnetic field with a flux density of 0.8 teslas.

Solution

$$F = B \times I \times l$$
$$F = 0.8 \times 20 \times 0.2$$
$$F = 3.2\ newtons\ exerted\ on\ the\ conductor$$

Self-Inductance and Mutual Induction on AC

15. When an insulated coil is wound on a magnetic core and connected to an a.c. supply the magnetic field or flux is constantly changing in direction and magnitude. This changing magnetic field causes a voltage to be induced in the coil by electromagnetic induction - the induced voltage is known as a back-e.m.f or counter e.m.f and it has a significant effect on the electrical behaviour of the coil.

16. While magnetic flux is changing in an a.c. coil it generates an e.m.f. in the conductor by electromagnetic induction; the e.m.f. generated is opposite in polarity to the e.m.f. causing the current flow (this effect is known as Lenz's Law - induced current produces a magnetic flux which tends to oppose the flux creating it), so the net voltage across the conductor an any instant is the difference between the applied voltage and the induced voltage. The effect of a current flow in a conductor being limited by its own flux is known 'self-inductance' and can be seen in fluorescent lamp ballasts. If another coil is wound over the first or merely shares the first coils magnetic field, it also has voltage induced into it by the changing magnetic field - this voltage is said to be induced by 'mutual inductance' and is how transformers work.

Inductance

17. Inductance is the property of a device or circuit which enables an electromotive force to be generated in it by electromagnetic induction. The effect of inductance is to oppose any change in the current flow which is causing it. A device which is designed to make use of the property of inductance is known as an inductor and it can take several forms. A major effect of inductance in coils on a.c. is that the current drawn by the coil is limited mainly by factors other than the resistance of the coil.

18. The quantity symbol for inductance is L and the basic unit of inductance is the henry (H). One henry is defined as the inductance of a closed circuit in which an electromotive force of 1 volt is produced when the current flowing in the circuit varies uniformly at the rate of 1 amp per second.

Calculation of Value of Self-Induced e.m.f. in a Coil with a Change in Current

19. The voltage generated in an inductor can be calculated using the equation:

$$V = L \times \frac{\Delta I}{\Delta t}$$

Where: V = Voltage generated.
L= Inductance in henrys.
ΔI = the change of current in the conductor in amps.
Δt = how long the current took to change in seconds.

20. **Example.** Determine the voltage generated in a 2.25 H inductor, when the current is reduced uniformly from 5 A to 1.5 A in 0.3 seconds.

Solution

$$V = L \times \frac{\Delta I}{\Delta t}$$
$$V = 2.25 \times \frac{3.5}{0.3}$$
$$V = 26.25\,Volts$$

Calculation of Value of Self-Induced e.m.f. in a Coil with a Change in Flux

21. The voltage generated in an inductor can also be calculated using the equation:

$$V = N \times \frac{\Delta\emptyset}{\Delta t}$$

Where: V = Voltage generated.
N = number of turns.
$\Delta\Phi$ = the change of flux in the conductor in webbers.
Δt = how long the current took to change in seconds.

22. **Example.** A coil of 500 turns has a flux of 70µ Wb passing through it. If the flux is reduced to 20µ Wb in 15 ms, find the average induced voltage.

Solution

$$V = N \times \frac{\Delta\emptyset}{\Delta t}$$
$$V = 500 \times \frac{(70\times10^{-6} - 20\times10^{-6})}{15\times10^{-3}}$$
$$V = 1.67\,Volts$$

Calculation of Value of Induced e.m.f. in a Moving Coil

23. The voltage generated in a moving conductor can be found using the equation. It is worth noting that the angle is measured from the magnetic neutral plane, resulting in 90° being maximum voltage induced and 0° no voltage induced. (Sin 60 = 0.866, sin 45 = 0.707, sin 30 = 0.5).

$$V = B \times l \times v \times \sin\theta$$

Where: V = Voltage generated.
B = flux density in teslas (Wb/m²)
ℓ = length of conductor in metres
v = velocity in metres per second
Sin θ = Motion angle

24. **Example.** A conductor 0.25 m long is rotating on the periphery of an armature at 18 m/s. If the flux density is 0.60 T, calculate the maximum voltage induced in the conductor and the voltage when it is cutting the field at an angle of 45°.

Solution

$$V_{max} = B \times l \times v \times \sin\theta$$

$$V_{max} = 0.6 \times 0.25 \times 18 \times \sin 90$$

$$V_{max} = 2.7\ V$$

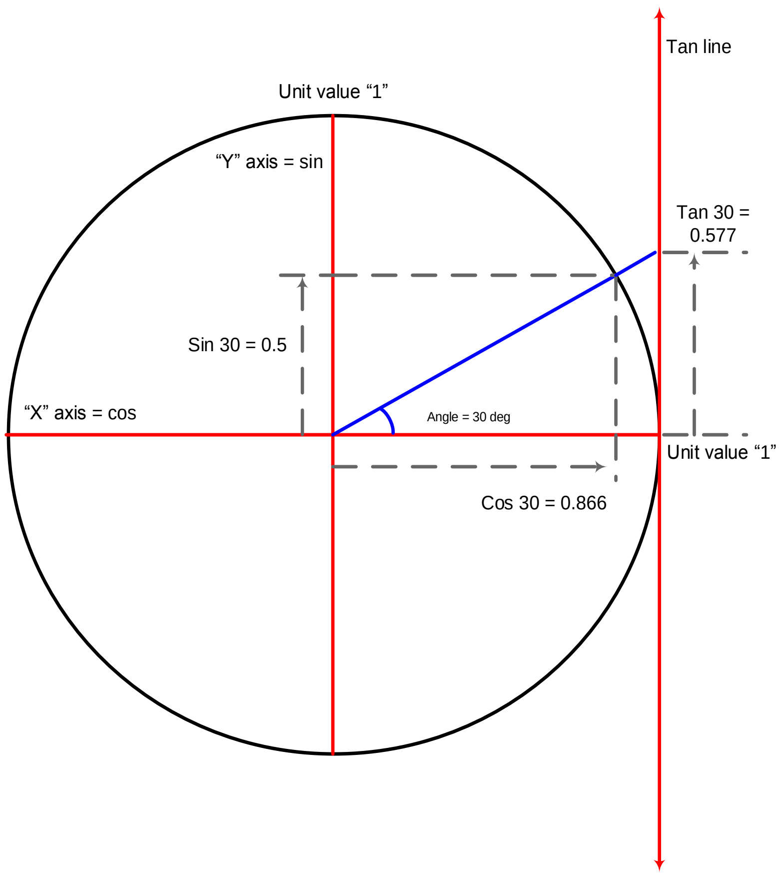
$$V_{45} = B \times l \times v \times \sin\theta$$

$$V_{45} = 0.6 \times 0.25 \times 18 \times \sin 45$$

$$V_{45} = 1.91\ V$$

Trigonometric Function Definition - Sin

Defines the value of an angle on the "y" or vertical axis. We use the sin function to define the output voltage of a generator at any given point in time by the equation Vins = Vpeak sinθ. We view the vector as starting at zero degrees and rotating counter clockwise as the alternator turns through its 360^0 rotation. By multiplying the sin of the angle by the peak output we can calculate the voltage output at any point in time throughout the whole 360^0 cycle.



Worksheet T3 (Part A) Electromagnetic Induction Questions

1. Describe Faraday's law of electromagnetic induction. (T4.1)

2. Identify three main requirements to induce a voltage into a conductor under Faraday's law. (T4.1)

3. State three factors which govern the value of voltage induced in a conductor when it is moved across a magnetic flux. (T4.1)

4. Describe Fleming's Right Hand rule for generators. (T4.2)

5. What is the direction of induced current when a given conductor is moved clockwise across the magnetic flux from a south pole? (T4.2)

6. What is the direction of the force exerted on a conductor when it is carrying current away from the observer under a north pole? (T4.2)

7. If a conductor is carrying current towards the observer in the magnetic field under a north magnetic pole, what is the direction of the force exerted on the conductor? (T4.2)

8. A conductor 0.35 m long is rotating on the periphery of an armature at 23 ms. If the flux density is 0.45 T, calculate the maximum voltage induced in the conductor, and the voltage when it is cutting the field at an angle of 60º, 45º, and 30º. (Sin 60 = 0.866, sin 45 = 0.707, sin 30 = 0.5). (T4.3)

9. A coil of 650 turns has a flux of 82u Wb passing through it. If the flux is reduced to 31u Wb in 13 ms, find the average induced voltage. (T4.4)

10. Determine the force exerted on a conductor 300 mm (0.3 metres) long when it is carrying a current of 10 amps in a magnetic field with a flux density of 0.8 teslas. (T4.5)

11. Determine the force exerted on a conductor 200 mm (0.2 metres) long when it is carrying a current of 30 amps in a magnetic field with a flux density of 0.9 teslas. (T4.5)

12. A conductor is placed at right angles to a magnetic field with a flux density of 0.68 T over a length of 0.12 m of the conductor. If a current of 24 A is passed through the conductor, calculate the force exerted on the conductor. (T4.5)

13. Describe Lenz's law. (T4.6)

14. List three applications of electromagnetic induction. (T4.7)

15. Determine the voltage generated in a 2 H inductor, when the current is reduced uniformly from 4 A to 1.5 A in 0.3 seconds. (T5.7)

16. Determine the voltage generated in an inductor of 1.6 H if the current is reduced uniformly from 0.6 A to 0 A in 1.5ms. (T5.7)

17. Determine the Voltage generated in a 0.5 Henry inductor if the current through it is reduced from 3 Amps to zero in 1 millisecond. (T5.7)

18. What is meant by the term 'mutual induction' between two coils? (T5.8)

19. Name one common electrical device which relies on the effect of self-induction for its operation. (T5.10)

20. Name one common electrical device which relies on the effect of mutual induction for its operation. (T5.10)

Factors Affecting Inductance

25. The factors which govern the inductance of a coil are:

    a. The number of turns - as the turn increases the inductance increases.

    b. The area of the magnetic core - the larger the core the higher the inductance.

    c. The relative permeability of the core - the higher the permeability the higher the inductance.

    d. The length of the inductor - the inductance decreases as the mean length of the magnetic core increases.

Construction of Inductors

26. Inductors are devices that have inductance. Certain devices are designed to have set inductances and the most common way to achieve this is to wrap a conductor into a coil. Inductors that are wrapped around toroidal (doughnut shaped) cores have greater inductance than straight due to the higher concentration of the magnetic field.

27. The conductor can be single core or multi core. The most common multicore is bifilar, which is two cores wrapped together and can be arranged in two distinct ways to either increase the inductance or remove it.

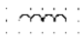
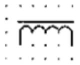
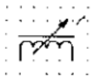
28. The conductor core is not to be confused with the core of the inductor. They are two distinct parts. The core of an inductor can be one of three types:

    a. **Air Cores** (no core) – coils wrapped without a core or around non-magnetic materials like plastic or ceramic are said to be air core inductors. Used in circuits for low power and minimal distortion e.g. Radio transmitters.

    b. **Ferrite Cores** (Iron powder) – coils wrapped around a core made from iron powder mixed with insulating material (ceramic) are said to be ferrite core inductors. They are often used in high frequency switch mode power supplies.

    c. **Iron Cores** (solid or laminated) - coils wrapped around a core made from iron (either solid or laminated) are said to be iron core inductors. Most iron cores are found to be laminated to reduce the losses caused by eddy currents. Iron core inductors are used in electric motors/generators and transformers.

29. Symbols for inductors are drawn according to AS1102.104.

No.	Symbol	Description
04-03-01		Inductor Coil Winding Choke If it is desired to show that the inductor has a magnetic core, a single line may be added parallel to the symbol. The line may be annotated to indicate non-magnetic materials; it may be interrupted to indicate a gap in the core. Note — For transformer windings, see IEC 617-6.
04-03-02	deleted	Transferred to Annex A: 04-A3-01
04-03-03		EXAMPLES: Inductor with magnetic core
04-03-04		Inductor with gap in magnetic core
04-03-05		Continuously variable inductor, shown with magnetic core
04-03-06		Inductor with fixed tappings (taps), two shown

Examples of Inductors on A.C.

30. Typical practical examples of inductors on a.c. include:

a. Electric motors.
b. Transformers.
c. Fluorescent ballasts or chokes.
d. Alternators.
e. Relay or contactor coils.
f. Solenoids.

Inductors on D.C.

31. When the supply voltage is applied to a d.c. coil the current does not rise to its full value instantly - it takes a precisely predictable time based on mathematical laws, due to the effects of self-inductance. Similarly, when the supply voltage is removed, the current does not fall to zero instantly - it falls in accordance with a mathematical law which is the 'reverse' of the mathematical laws governing the increase of current.

32. A circuit of an inductor connected to a battery via a two-way switch is shown below. The inductor has inductance and internal resistance. When the switch is placed in the ON position, current flows in the inductor and a magnetic field is created in the core. When the switch is placed in the OFF position the magnetic field in the core collapses suddenly; the collapsing magnetic field cuts the turns of the coil and a voltage is generated in the coil by electromagnetic induction (it is assumed that the switching action from ON to OFF is instantaneous). When the switch is in the OFF position the coil is short circuited (via its internal resistance) so the voltage generated in the coil causes a current to flow until the magnetic field is reduced to zero.

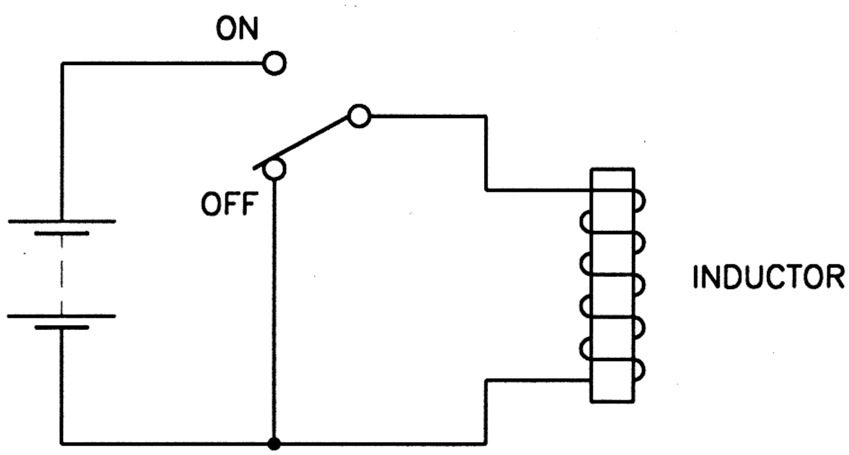
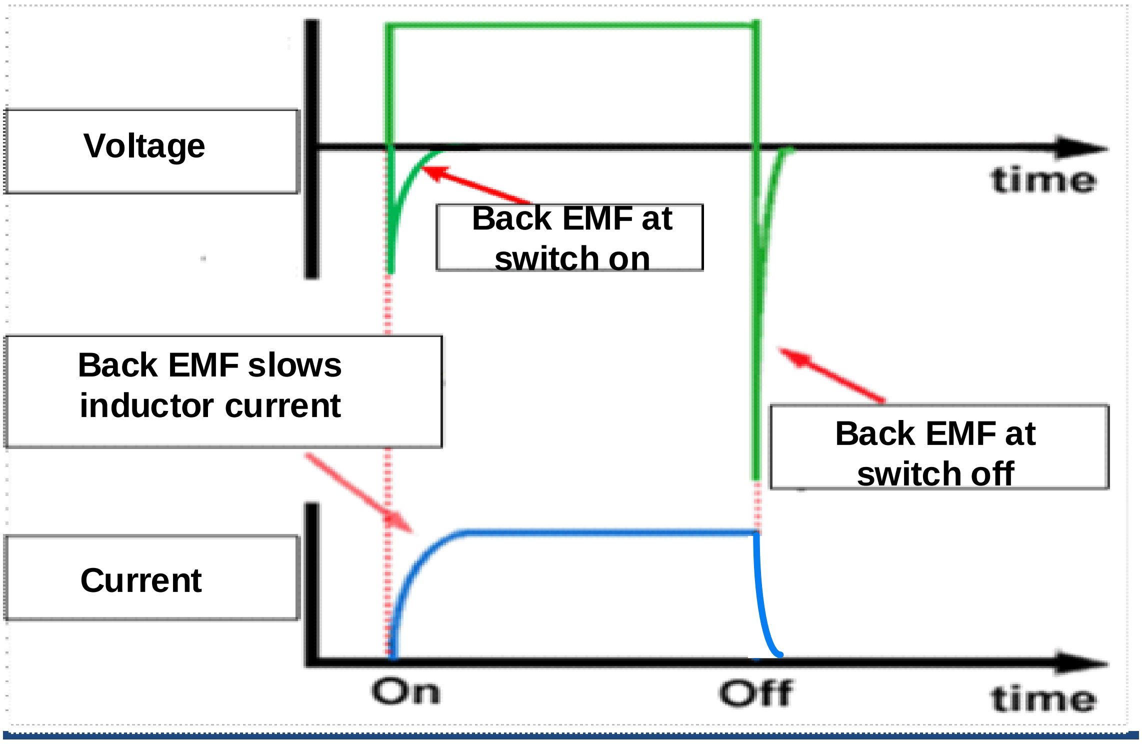


Figure 22. Inductor test circuit

33. The following graph shows the rate of increase in current from the instant when the switch is placed in the ON position, and the rate of decrease of current when the switch is changed from ON to OFF instantaneously. The time taken for the current to reach its maximum value depends on the inductance of the coil and its resistance. The effects of inductance on D.C. are only significant when the circuit is switched on or off; when the current has reached its full value its magnetic field is stationary and inductance has no effect until the circuit is switched off.



Energy Storage in an Inductor.

34. When a DC voltage is connected across an inductor, a current is made to flow through the inductor. As this current increases at switch on, an increasing magnetic field is created around the coils of wire. The electrical energy used in creating the magnetic field is therefore being stored as magnetic energy. Also when the energy in a magnetic field is changing, this will induce a voltage into those same coils that are setting up the magnetic field.

However the induced voltage, called an 'electromagnetic force of self induction' will be in the opposite polarity to the applied voltage that is setting up the magnetic field; therefore this induced e.m.f. is also commonly called a 'back e.m.f.' and its effect is to slow down the otherwise rapid change of current that takes place at switch on.

As the current through the inductor builds up, the rate of change of current has reduced, due to the back emf, and so has the back emf due to the reduced rate of change of the current. The electrical energy applied to the inductor has now been converted into magnetic energy and is stored in the magnetic field set up around the inductor.

Induction at the Opening of a Contact.

35. According to Faraday's law of induction, if the current through an inductance changes, this inductance induces a voltage so the current will go on flowing as long as there is energy in the magnetic field. If the voltage applied to the inductor is now switched off, the energy stored in the magnetic field is released back into the coils of the inductor, this time there is no opposing supply voltage applied so the entire magnetic field collapses instantly, and the stored energy, now in the form of a voltage across the inductor, but with opposite polarity to the original applied voltage. If the current can only flow through the air, the voltage is therefore so high that the air conducts. That is why in mechanically-switched circuits, the near-instantaneous dissipation which occurs without a flyback diode is often observed as an arc across the opening mechanical contacts. Energy is dissipated in this arc primarily as intense heat which causes undesirable premature erosion of the contacts. Another way to dissipate energy is through electromagnetic radiation.

Similarly, for non-mechanical solid state switching (i.e., a transistor), large voltage drops across an unactivated solid state switch can destroy the component in question (either instantaneously or through accelerated wear and tear).

Some energy is also lost from the system as a whole and from the arc as a broad spectrum of electromagnetic radiation, in the form of radio waves and light. These radio waves can cause undesirable clicks and pops on nearby radio receivers.

To minimise the antenna-like radiation of this electromagnetic energy from wires connected to the inductor, the flyback diode should be connected as physically close to the inductor as practicable. This approach also minimises those parts of the circuit that are subject to an unwanted high-voltage — a good engineering practice.

Time Constant

36. The time taken for the current to reach 63% of its final value in an inductor on d.c. is known as the 'Time Constant (T)'. After five time constants the current would be over 99% of its final value, so five times the time constant is generally regarded as the amount of time required for the current to reach its full steady value.

37. When the switch is placed in the OFF position one time constant is defined as the time required for the current to fall to 37% (a reduction of 63%). After five time constants the current would be less than 1%, so five times the time constant is generally regarded as the time required for the current to be reduced to zero.

38. The time constant for an RL circuit can be calculated using the equation:

$$\tau = \frac{L}{R}$$

Where: τ = the time constant in seconds (τ is the Greek letter Tau)
L = the inductance in henrys
R = the resistance of the inductor in ohms

39. **Example** Calculate the time constant in an RL circuit consisting of an inductance of 4 henrys and a resistance of 100 ohms.

Solution

$$\tau = \frac{L}{R}$$

$$= \frac{4}{100}$$

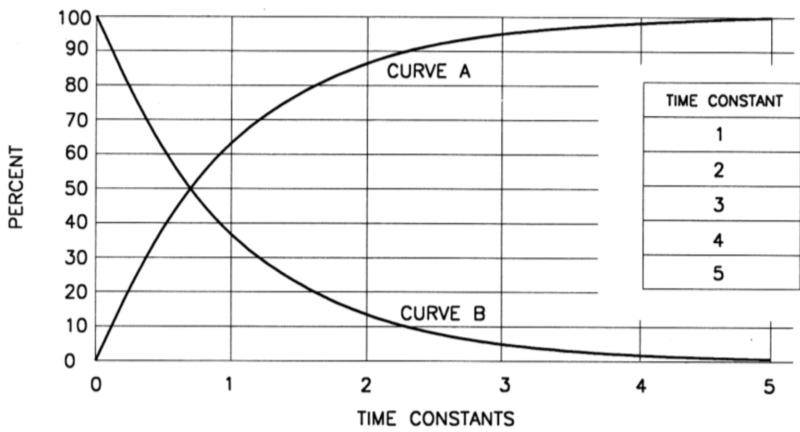
$$= 0.04\ seconds$$

$$= 40\ milliseconds$$

40. Magnetism occurs in any conductor carrying current, and when such a conductor is near another conductor the effects of electromagnetic induction result in a voltage being induced in the other conductor. In cases where this induced voltage is unintended, it can cause damage to sensitive components such as sensors or instruments. Sensitive components can be shielded from the effects of unwanted electromagnetic induction by enclosing them in a box made of magnetic material.

Instantaneous Currents

41. The instantaneous current in an inductor from the instant of switch on or switch off to a time equivalent to five time constants can be shown on the universal time constant graph shown below. Curve a shows the rate of increase of current after switch on and Curve B shows the rate of decrease of current after switch off. The percentage values for up to five time constants are shown in the table as part of the graph.



TIME CONSTANT	CURVE A	CURVE B
1	63%	37%
2	86%	14%
3	95%	5%
4	98%	2%
5	99%	1%

Figure 23. Universal time constant graph

Instantaneous Voltage

42. The instantaneous voltage in an inductor from the instant of switch on to a time equivalent to five time constants can be shown on the universal time constant graph shown above. Curve B shows the rate of decrease of induced voltage after switch on remembering that the induced voltage is an opposing voltage and is often shown as a negative value. The percentage values for up to five time constants are shown in the table under the graph. However due to the need for more information, it is beyond the scope of this course to calculate the instantaneous voltage.

Determining Instantaneous Current

43. One method of calculating the instantaneous current in an inductor when it is switched on, is to use the universal time constant graph and the fact the maximum current can be determined by Ohm's law. Having knowledge of how many time constants have passed and the maximum current, it becomes a matter of multiplying the maximum current by the percentage (as a decimal) at the particular time constant.

44. **Example** Calculate the current in an inductor after it's turned on if the inductor is in series with a 20 Ohm resistor connected to a 12 Volt supply after 2 time constants.

Solution

$$I_{max} = \frac{V_{supply}}{R}$$
$$I = \frac{12}{20}$$
$$I_{max} = 0.6\ Amps$$

Two time constants is 86% or 0.86, after two time constants the instantaneous current will be:

$$I_{ins} = \% \times I_{max}$$
$$I = 0.86 \times 0.6$$
$$I = 0.516\ Amps$$

Worksheet T3 (Part B) Electromagnetic Induction Questions

1. Describe how an inductor is constructed. (T5.1)

2. Describe the construction of a bifilar multi-core inductor. (T5.1)

3. Draw the standard Australian symbol for the following inductor types: (T5.2)
   - Inductor or coil
   - Inductor with magnetic core
   - Variable inductor
   - Inductor with fixed tapping's

4. What are four factors which govern the inductance of a coil? (T5.3)

5. Name three types of inductor cores. (T5.4)

6. List four practical examples of inductors on AC. (T5.5)

7. What is meant by the term 'self-inductance'? (T5.6)

8. What is meant by the term 'inductance'? (T5.6)

9. Name one situation in which the effects of high self-induced voltage are unwanted. (T5.11)

10. Name one device which can be connected in parallel with the coil of a large D.C. electromagnet to protect the coil from the effects of unwanted high self-induced voltage (back-emf) when it is switched off. (T5.11)

11. Name one situation in which the effects of mutual electromagnetic induction are unwanted? (T5.11)

12. What method can be used to protect against the unwanted effects of mutual electromagnetic induction? (T5.11)

13. What is meant by the term 'Time Constant'? (T5.12)

14. How many Time constants are required for current to reach full potential in an RL circuit? (T5.12)

15. Draw a diagram showing the characteristic curve for current and voltage applied to an RL circuit from the moment it is switched on until maximum values are reached. Include all time constants and their percentage values. (T5.12)

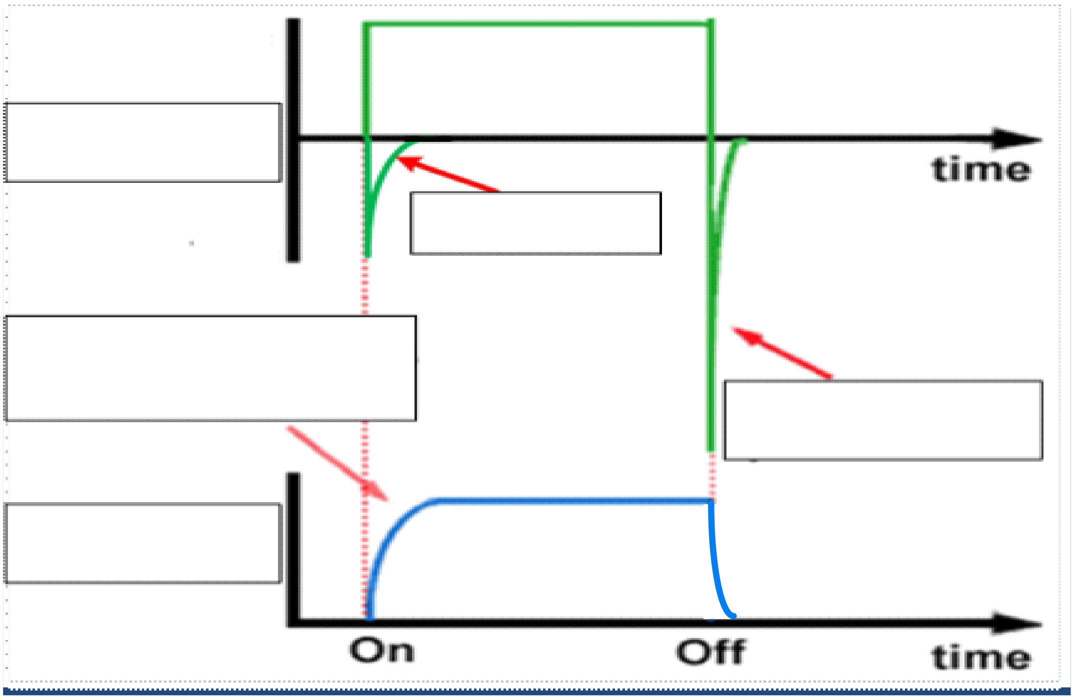
16. Calculate the time constant in an RL circuit consisting of an inductance of 2 henrys and a resistance of 50 ohms. (T5.12)

17. Calculate the time constant in an RL circuit consisting of an inductance of 1.2 henrys and a resistance of 24 ohms. (T5.12)

18. Calculate the total time required for current to reach maximum value in an RL circuit consisting of an inductance of 3 henrys and a resistance of 100 ohms. (T5.13)

19. Calculate the total time required for current to reach maximum value in an RL circuit consisting of an inductance of 4 henrys and a resistance of 1k ohms. (T5.13)

20. Complete the diagram below by filling in the question marked boxes. (T5.9)



21. Calculate the value of current reached after one time constant in an RL circuit Consisting of an inductance of 2.5 henrys and a resistance of 1k ohms when maximum circuit current is 10 A. Use the Universal Time Constant Graph to calculate your answer. (T5.13)

22. Calculate the value of current reached after three time constant in an RL circuit consisting of an inductance of 1.5 henrys and a resistance of 800 ohms when maximum circuit current is 10 A. Use the Universal Time Constant Graph to calculate your answer. (T5.13)

23. Calculate the value of **self-induced voltage** reached after one time constant in an RL circuit consisting of an inductance of 1 henrys and a resistance of 500 ohms when maximum self-induced voltage at **switch-on** is 200 V. Use the Universal Time Constant Graph to calculate your answer. (T5.14)

24. Calculate the value of **high induced voltage** reached after one time constant in an RL circuit consisting of an inductance of 1.5 henrys and a resistance of 2k ohms when maximum high induced voltage at **switch-off** is 400 V. Use the Universal Time Constant Graph to calculate your answer. (T5.14)

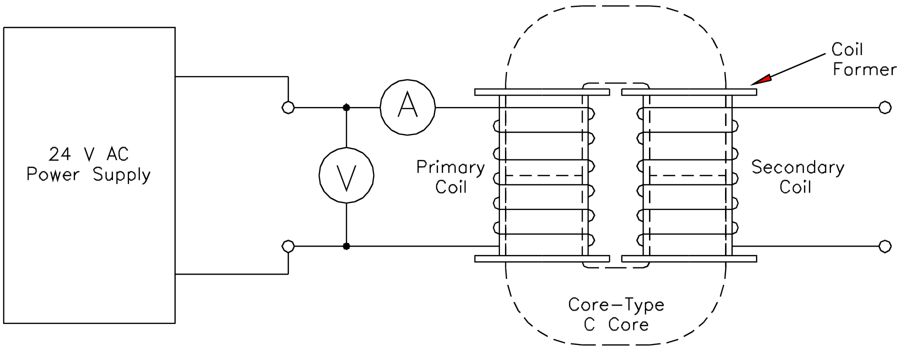
Task:
To observe the effects of electromagnetic induction between two coils on a magnetic core.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:
One complete core type 'C core' (2 halves) or similar.
Pre-prepared 24 volt a.c. primary coil with known turns and wire size.
Insulated coil former to suit the C core and match the primary coil former.
240:24 volt a.c. power supply.
0-5 amp a.c. ammeter.
Multimeter.
Hand tools as required.

Circuit and Layout



Method:

1. Examine the prepared primary coil and note the voltage rating, the turns and the wire size.

2. Examine the prepared secondary coil and note the voltage rating, the turns and the wire size.

3. Measure the resistance of the primary and secondary coils and record the results in the Results Table.

4. Ensure that the input to the 24 volt a.c. power supply is unplugged and switched off. Connect the output from the 24 volt a.c. power supply to the input terminals of the primary coil - including measuring instruments as indicated on the diagram below:

5. Test the secondary circuit for short circuits with a multimeter.

6. Have your connections checked by your Lecturer.

7. Energise the 24 volt a.c. power supply, then measure and record the values required to complete the Results Table.

Results Table

	Turns	**Resistance**	**Voltage**	**Current**
Primary				
Secondary				

8. Switch the circuit off and remove the plug-top from the outlet.

9. Have your results checked by your Lecturer.

10. Disconnect your wiring and return all of the equipment to its proper place.

Questions:

1. Since the secondary winding was not connected to a supply, what caused the voltage to occur in the secondary coil?

   ____

2. Calculate the resistance of the primary coil using the input voltage and input current.

   ____

3. Was the calculated primary resistance about the same value as the measured primary resistance? Why?

   ____

   ____

4. Using the measured value of resistance of the primary coil, how much current would flow in the primary circuit if the supply voltage was d.c. instead of a.c. (using Ohm's Law)?

   ____

Feedback and Recommendations:

Student's Signature: ____ **Date:** ____________

Assessor's Signature: ____ **Date:** ____________

Electromagnetic Induction Practical 2

Task:
To diagnose faults in typical electromagnetic devices.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:
Digital multimeter
High voltage insulation tester
ELV variable power supply
Growler
Hand tools as required

Sample electromagnetic devices such as:

Magnetic relays, starters and/or contactors
Electric bells and buzzers.
Solenoids
Armatures
Magnetic overload sensors

Procedure:

1. Identify each of the electromagnetic devices supplied using a typical common name.

2. Perform a visual inspection of each of the devices and determine its general condition.

3. Use appropriate electrical measuring instruments to check each device for electrical faults.

Results Table

	Common Name	General Condition	Electrical Faults
1			
2			
3			
4			
5			
6			

4. Select one of the serviceable devices and connect it to a suitable ELV supply. Have your connections checked by your lecturer.

5. Energise the circuit and test the device for correct operation.

6. Switch the circuit off and remove the plug from the outlet.

7. Have your results checked by your lecturer.

8. Repeat the process with other devices specified by your lecturer.

9. Disconnect all wiring and return all equipment to its proper place.

Feedback and Recommendations:

Student's Signature: ____________________________________ **Date:** ____________

Assessor's Signature: ____________________________________ **Date:** ____________

Measuring Instruments

Measuring Instruments

1. Most analogue measuring instruments utilise the principles of electromagnetic induction to detect and measure voltage, current and resistance. To do this the meters are constructed with moving parts and are classified depending on the construction method. All construction methods are primarily methods of measuring current but by using a fixed known value of resistance the voltage can be calculated by the meter using Ohm's law. If the meter has a power source, resistance can be calculated by the meter using Ohm's law as a result of measuring the current flow.

Moving Coil

2. A coil is placed inside a set of permanent magnets and as current is allowed to flow through the coil causes the coil to move an attached needle on a scale. Practical examples of moving coil meters are analogue multimeters for use on DC only.

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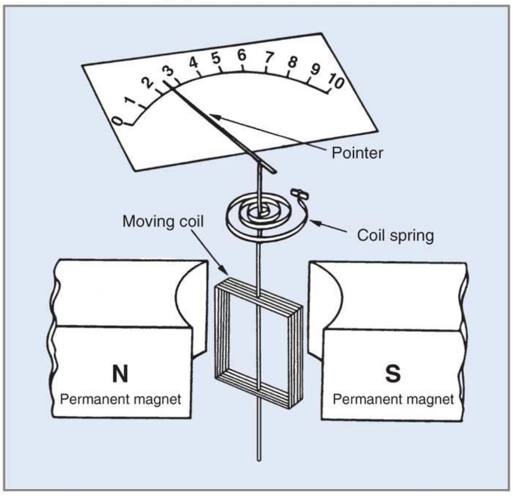

Figure 24. Moving coil

Moving Iron

3. Iron vanes are placed inside a set of coils that form an electromagnet when current is allowed to flow through them, causing the iron vanes to move an attached needle on a scale. Practical examples of moving iron meters are analogue multimeters on AC & DC.

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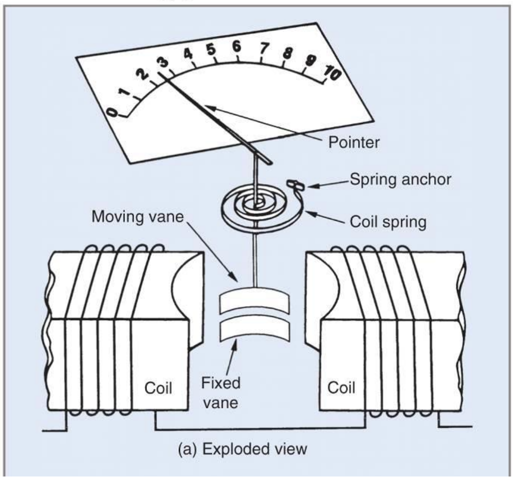


Figure 25. Moving Iron

Dynamometer Movement

4. A combination of moving coil and moving iron used to measure power also known as a wattmeter. With the moving coil part being used to measure current and the moving iron measuring voltage. With the resultant interaction of the magnetic fields causing the coil to move moving the attached needle.

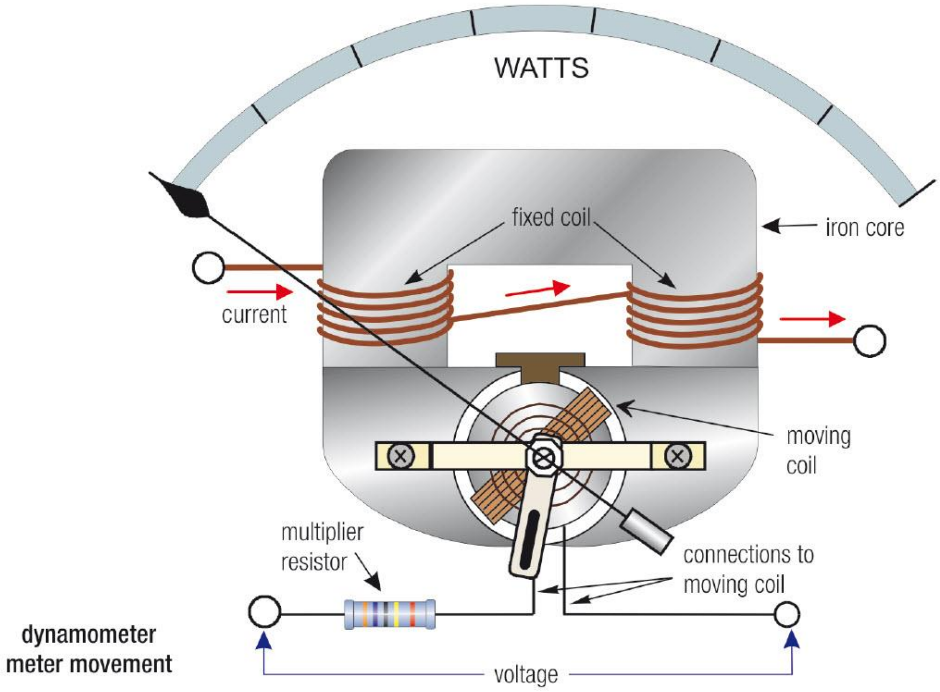
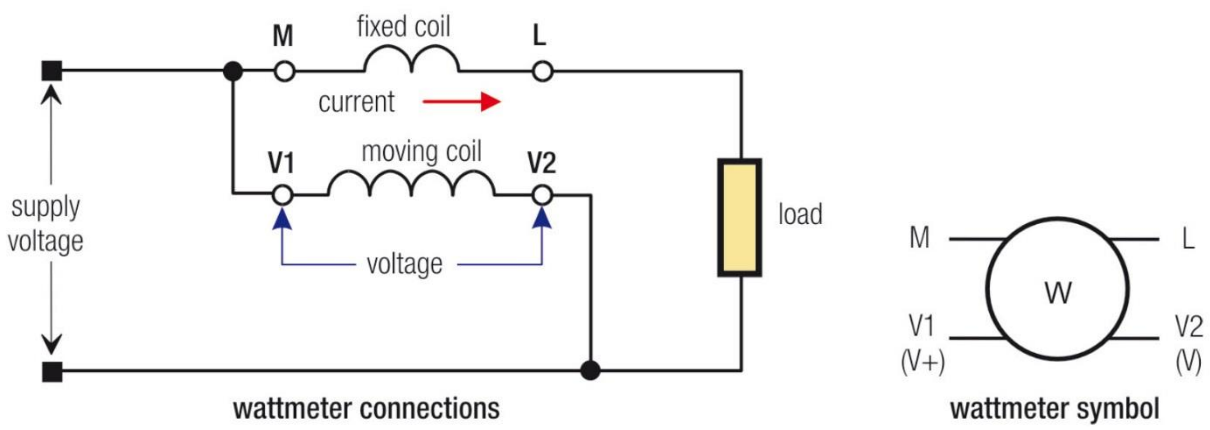
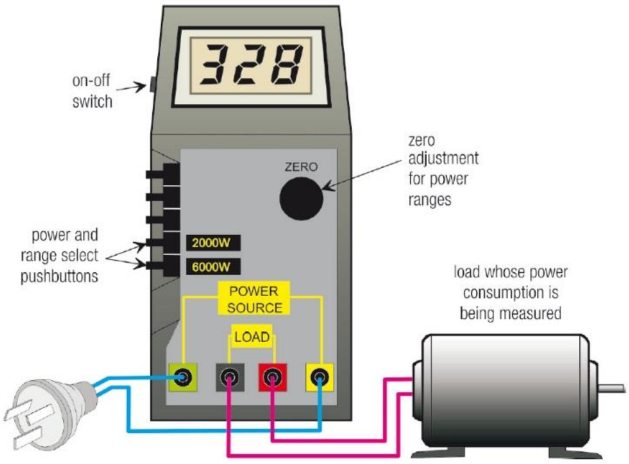


Figure 26. Dynamometer

Equivalent circuit diagram:





Digital Wattmeter

Clamp Meter

5. Analogue clamp meters may be either a form of moving iron (where the clamp has a voltage induced by the cables magnetic field) or Hall Effect (a physical phenomenon of magnetism that causes voltage to appear on a sheet of metal with a current flowing thorough it).

Figure 27. Clamp meter

Range extension of meters

6. Meters are physically limited to being able to measure certain values by the amount the needles will move etc. The chief way to overcome this is to change the resistor or resistance of the meter thereby limiting or letting more current to flow and move the needle. Changing the resistance is done by adding in more resistors.

7. For ammeters the range is extended by connecting in parallel a low value resistor. This resistor provides an extra path for the current and is called a shunt. The value of the shunt resistor required can be calculated by the following formula:

$$R_{shunt} = \frac{I_{meter} \times R_{meter}}{I_{shunt}}$$

Where: R_{shunt} = Resistance of the shunt in ohms.
R_{meter} = Internal resistance of the meter in ohms.
I_{meter} = Maximum allowable current in the meter in amps.
I_{shunt} = Maximum allowable current in the shunt in amps.
= $I_{total} - I_{meter}$

8. **Example** Determine the value of resistance the shunt resistor must be for a 10 A meter with an internal resistance of 2.2 Ohms given that the current to be measured is 20 Amps.

Solution

$$R_{shunt} = \frac{I_{meter} \times R_{meter}}{I_{shunt}}$$

$$R_{shunt} = \frac{10 \times 2.2}{20}$$

$$R_{shunt} = 1.1\ \Omega$$

9. For voltmeters the range is extended by connecting a high value resistor in series with the meter. This resistor limits the current though the meter and is called a multiplier. The value of multiplier required can be calculated by the following formula:

$$R_{multiplier} = \frac{V_{total}}{I_{meter}} - R_{meter}$$

Where: $R_{multiplier}$ = Resistance of the multiplier in ohms.
R_{meter} = Internal resistance of the meter in ohms.
I_{meter} = Maximum allowable current in the meter in amps.
V_{total} = Voltage to be measured in volts.

10. **Example** Determine the value of resistance the multiplier must be for a 1 A meter with an internal resistance of 2.2 Ohms given that the voltage to be measured is 240 Volts.

Solution

$$R_{multiplier} = \frac{V_{total}}{I_{meter}} - R_{meter}$$

$$R_{multiplier} = \frac{240}{1} - 2.2$$

$$R_{multiplier} = 237.8\ Ohms$$

Selecting a meter

11. Meters need to be selected based on the following factors:

    1. **Reliable**: The meter must produce the same result when measuring the same item. Can the meter be trusted to produce a result?

    2. **Accurate**: The meter must be able to produce a result that is close to the actual value. Can the meter give the right answer?

    3. **Sensitive**: The meter must be able to measure the circuit without changing it. Can the meter read the circuit without influencing it?

    4. **Rating**: The meter must be able to measure without being overloaded or becoming a health and safety issue. Can the meter handle the current/voltage?

Worksheet T4 (Part A) Measuring Instruments Questions

1. What principle causes the movements within analogue measuring instruments to respond when measuring voltage, current or resistance? (T6.1)

2. Name two movement types that are used in analogue meters. (T6.1)

3. Describe how the coil in a Moving Coil meter moves to indicate a value of current or voltage the meter is measuring. (T6.1)

4. Describe how the coil in a Moving Iron meter moves to indicate a value of current or voltage the meter is measuring. (T6.1)

5. Give another name for a Dynamometer. (T6.1)

6. Describe how the movement in an analogue dynamometer operates to indicate a value of wattage the meter is measuring. (T6.1)

7. What is the main advantage of a clip-on ammeter over a fixed ammeter? (T6.1)

8. Where are the following types of meter movements used? (T6.2)
   - Moving coil meters
   - Moving iron meters
   - Dynamo meters

9. What is the purpose of a Shunt resistor? (T6.3)

10. How is a Shunt resistor connected to a meter movement? (T6.3)

11. How does a Shunt resistor operate to extend the range of a meter movement? (T6.3)

12. Determine the value of resistance a shunt resistor must be for a 10 A meter with an internal resistance of 2.2 Ohms given that the current to be measured is 35 Amps. (T6.3)

13. Determine the value of resistance a shunt resistor must be for a 10 A meter with an internal resistance of 2 Ohms given that the current to be measured is 20 Amps. (T6.3)

14. What is the purpose of a multiplier? (T6.3)

15. How is a multiplier connected to a meter movement? (T6.3)

16. How does a Multiplier operate to extend the range of a meter movement? (T6.3)

17. Determine the value of resistance a multiplier must be for a 1 A meter with an internal resistance of 2 Ohms given that the voltage to be measured is 240 Volts. (T6.3)

18. Determine the value of resistance the multiplier must be for a 500 mA meter with an internal resistance of 4.4 Ohms given that the voltage to be measured is 240 Volts. (T6.3)

19. Name four factors to be considered when selecting a meter for a particular application? (T6.4)

20. Why should meter “sensitivity”, “accuracy” and “rating” be considered when selecting a meter for a particular application? (T6.4)

21. What is the name of the electrical measuring instrument used to measure the CURRENT flowing in a circuit? (T6.4)

22. What is the name of the electrical measuring instrument used to measure the electrical PRESSURE in a circuit or part of a circuit? (T6.4)

23. What is the name of the electrical measuring instrument used to measure the RESISTANCE of a circuit? (T6.4)

24. What type of measuring instrument gives a direct numerical readout as distinct from one which has a pointer and a graduated numbered scale? (T6.4)

Categories of meters

12. AS/NZS 61010, IEC 60664 and various state electricity acts and regulations require instruments that are used on electricity to conform to the requirements set and to be classed based upon the voltage and current the meter can handle safely. The meters are then classed into one of four categories I to IV (1–4), and written on the instrument as Cat I, Cat II, Cat III and Cat IV.

13. Cat I does not require the instrument to be marked, but unmarked instruments must not be used on live low voltage circuits. Cat II is to be used on final sub-circuits and testing of line voltage appliances. Cat III is suitable for most circuitry within a domestic installation up to the main switchboard. Cat IV is to be used wherever a substantial fault current is possible, in distribution lines and consumer's mains.

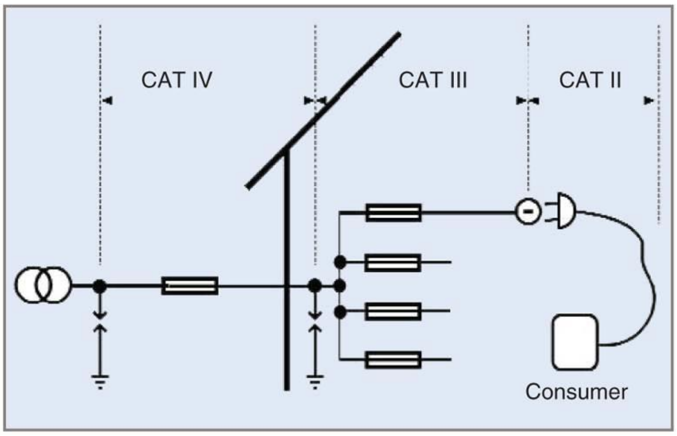


Figure 28. Pictorial representation of categories

Safe use, care, and storage of meters

14. Meters perform a potentially lifesaving function and as such should be treated with upmost care as your life or the life of others depends on it functioning correctly. They should be inspected for damage before every use and not used if found to be damaged.

15. Possible causes of damage are:
    a) Overload – either current or voltage ranges being exceeded

    b) Wrong connections – the meter is connected incorrectly. For example an ammeter connected in parallel.

    c) D.C. meters connected to an a.c. power source.

    d) Meter not earthed.

    e) Physically damaged – meter has been dropped or struck.

16. Some precautions to take with multimeters are as follows:

    a. Always leave a multimeter on the highest AC voltage range when not in use. The most common reason for damage to multimeters is the connecting of a meter into a circuit without prior inspection of the multimeter range setting. Leaving a meter on the high AC voltage range reduces the possibility of damage.

    b) When checking an unknown voltage (or current), always start with the highest range. If the reading is too low, a quick check will soon show if a lower range is more suitable. Many operators disconnect a multimeter from a power source before changing ranges because of the possibility of arcing occurring between contacts during the changeover.

c) Never attempt to take a resistance reading in a circuit while there is power applied to the circuit. Similarly, capacitors in a circuit often hold a charge that can damage a meter. The capacitors should be short-circuited temporarily after the power source is removed, to discharge them, before using the ohmmeter.

d) A similar problem to that in point 3 exists for insulation testers, continuity testers, bridge meggers and the later model battery-operated insulation testers. Each has its own inbuilt power supply and any connection to an external power source can lead to its destruction through excessive current flow.

e) Always keep fingers behind the finger guards on the probe ends.

f) Always store the meter in a case and in a location where it will not be damaged or exposed to harsh climates.

Minimum fault current rating of multimeter fuse

17. What is the minimum fault current rating of the HRC fuse which is required to protect the user when they make a mistake? Typically this occurs by leaving the leads in the current terminals and then attempting to measure 240 V or 415 V. (i.e. for those meters that measure up to 10 A current and comply with AS 61010.1 CAT III 600 V or 1000 V)

18. Assuming a worst case of 1000 V and using typical values from a good quality multimeter and leads, the fault current will be limited by the total series resistance of the two probe contacts (0.01 Ω), the two leads (0.01 Ω) and the internal impedance of the meter (0.04 Ω in 10 A range).

The maximum fault current will be = $\frac{1000V}{(0.01+0.01+0.04)\,\Omega}$

$= 16\,700\ A. Round\ up\ to\ 17\ kA$

This fault level is typically found in commercial and industrial power distribution Systems.

The fuse specification would be:

1. Voltage rating = 1000 V a.c.

2. Continuous current rating = 10 A (Used in 10 A range)
3. Fault current rating = 17 kA

****NOTE: If the fuse in your meter blows, replace it with the manufacturer's recommended fuse.****

Circuit parameters relating categories of meters

19. Prospective fault currents.

CAT I—very low energy circuits	e.g. Vehicles, battery-powered circuits (not connected to 240 V)
CAT II—low energy circuits	e.g. Domestic use (up to 5 kA fault currents)
CAT III—medium energy circuits	e.g. Industrial + commercial use (up to 25 kA fault currents)
CAT IV—high energy circuits	e.g. Industrial + commercial use (above 25 kA fault currents)

20. Potential transient voltage spikes. (Impulse withstand voltages)

Voltage Rating	Cat II	Cat III	Cat IV
150	1500	2500	4000
300	2500	4000	6000
600	4000	6000	8000
1000	6000	8000	12000

21. As distribution systems and loads become more complex, the probability of high transient voltage spikes increases. Motors, capacitors and power conversion equipment such as variable speed drives can generate voltage spikes. Lightning strikes on outdoor transmission lines can also cause extremely hazardous high-energy transients which can be inductively or capacitively coupled to other nearby cables.

22. The intention of AS 61010.1 is to ensure equipment is designed to safely withstand voltage spikes without causing any hazard to the user. The effect of these high voltage spikes is to create an arc across the weakest link in the circuit, typically across the meter and test probes. The arc initiates a short circuit fault across the conductors and/or to earth. The wires may vaporize and create a rapidly expanding plasma fireball engulfing the person using the meter. The fireball can reach temperatures of up to 10,000°C. See Figure 29 below for details of possible scenario.

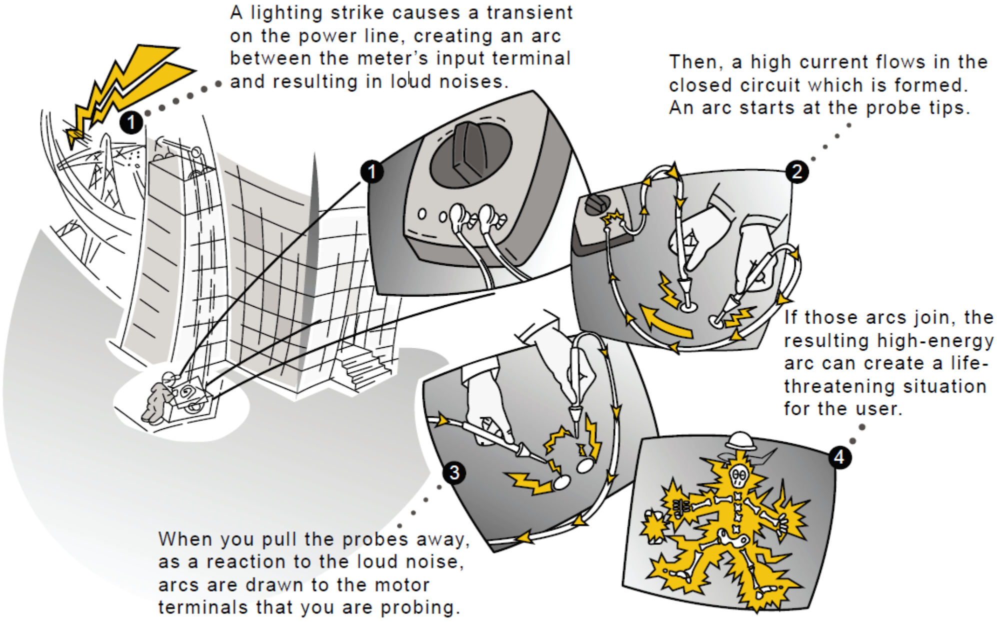


Figure 29

23. Product safety for test leads and accessories AS 61010.1 also applies to test leads and accessories (such as current clamps). They should be certified to a category and voltage as high, or higher than the meter. Do not let the test leads be the weak link. Replace them as they wear out or get damaged.

Figure 30

The need for independent testing and accreditation

24. Common accredited testing laboratories include UL - Underwriters Laboratory (USA), CSA - Canadian Standards Association (Canada), VDE (Germany), TUV-GS, KEMA, Testing Certification Australia (Australia), Austest (Australia), Comtest (Australia), and EMC Technologies (Australia). SAI Global (Australia) also has an accredited approval scheme which issues a 'Certificate of Suitability'.

25. Some manufacturers state that the 'the equipment conforms to IEC 61010-1' or 'is designed in accordance to IEC 61010-1' or 'complies with relevant European Safety Directive'. However, the only means of knowing if the equipment complies with IEC 61010-1 is to look for the test laboratory certification mark stamped on the casing (usually at the rear of the instrument).

26. Common testing laboratory marks are shown below.

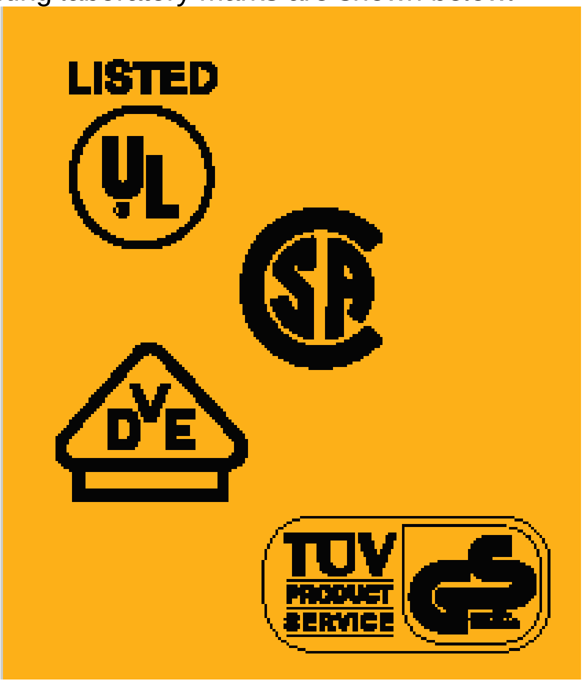


Figure 31

Worksheet T4 (Part B) Measuring Instruments Questions

1. What is meant by the term "Safety Category" when applied to meters used for testing of electrical circuits? (T6.5)

2. On which electrical circuits can meters with the following safety categories be used: (T6.5)
   Cat I ____________________ Cat II______________________
   Cat III ____________________ Cat IV ____________________

3. What should be done before using a digital or analogue meter to test an electrical circuit regardless of whether the supply is connected or isolated? (T6.6)

4. List five possible causes of meter damage? (T6.6)

5, Give six precautions that should be taken when using multimeters. (T6.6)

6. How should AMMETERS be connected in a circuit? (T6.6)

7. How should VOLTMETERS be connected in a circuit? (T6.6)

8. What type of measuring instrument should always be switched to the highest voltage range when not in use? (T6.6)

9. What safety precaution must ALWAYS be taken before attempting to connect a fixed ammeter into an operational circuit? (T6.6)

10. What voltage range should be selected on a multimeter prior to testing a circuit supplied by an AC voltage of unknown value? (T6.6)

11. How should a meter be stored when not in use? (T6.6)

12. What is the potential fault current rating for a Cat III meter? (T6.5)

13. Why is it necessary to replace multimeter fuse with the correct type as specified by the manufacturer? (T6.5, 6.6)

14. Name two of the accredited testing laboratories in Australia? (T6.5)

15. What does the standard AS-61010.1 specify regarding the rating of test leads used with instruments? (T6.5)

16. What precautions need to be taken before attempting any in circuit resistance measurements? (T6.6)

17. Which type of measuring instrument has the lowest internal resistance, an ammeter or a voltmeter? (T6.4)

18. What common marking is used to indicate that a particular ammeter or voltmeter is designed for DC only? (T6.4)

19. What common terminal marking is used to indicate that a particular ammeter or voltmeter is designed for AC only? (T6.4)

20. What measuring instrument would be most appropriate for checking an existing circuit for 'loss of supply'? (T6.4)

Magnetic Devices

Construction and Operation of Solenoids

1. Solenoids are a coil of wire that when energised creates a magnetic field that cause a movable steel core to actuate.

Application of Solenoids

2. Solenoids are used for valves.

Construction and Operation of Relays

3. The general construction of a common type of relay is shown below. Relays are available in many types, each having a particular coil voltage rating and contact current rating. Relays designed for D.C. operation can have a solid magnetic core, but a.c. relays need a laminated core to reduce eddy currents.

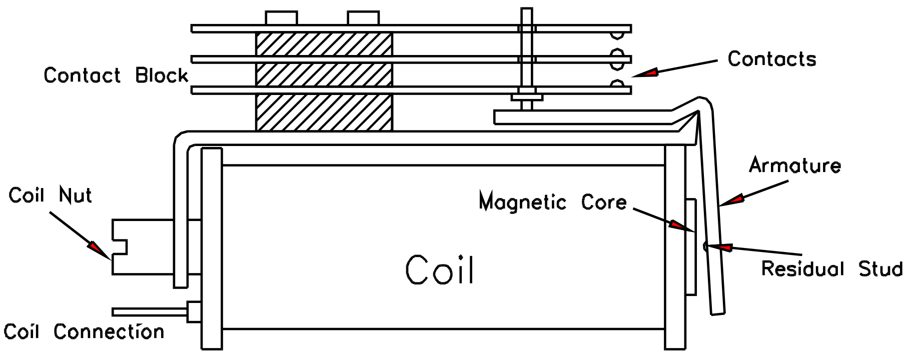


Figure 32. Construction of a relay

4. When current flows through the coil, a magnetic field is established that causes the armature to move towards the core. The movement of the armature causes the contacts to operate. The contacts maybe either normally open (N/O) or normally closed (N/C).

Application of Relays

5. Relays are commonly used in low power situations and form part of a circuit's control.

Figure 33. Relays

Construction and Operation of Contactors

6. The general construction of contactors is the same as for relays and often the names are used interchangeably. However, relays are low power devices and contactors are a high power device capable of switching high value currents and voltages directly.

7. Contactors designed for a.c. operation require a single turn of conducting material embedded in one of the mating magnetic surfaces to prevent 'chattering' when the contactor is energised. The single turn, usually copper, is known as the shading ring.

Application of Contactors

8. Contactors can be used in high power situations with the device capable of switching high value currents and voltages directly.

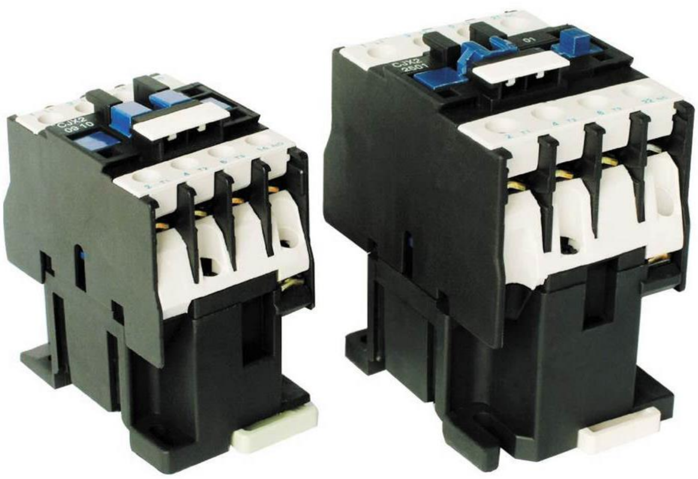


Figure 34. Contactors

Magnetic Methods of Arc Extinguishing

9. Contactors due to their switching of high currents and voltages have a tendency to have arcs forming between the contacts. Arcs when they form cause many problems including welding the contact shut and are a potential hazard. To extinguish the arc the most common method is to use either permanent or electric magnets (called magnetic blowouts) to force the arc to lengthen.

10. Arcs require lots of energy to occur and lengthening the distance the arc needs to travel will require more energy. Ideally the arc will be lengthened to a point that the arc will require more energy than available causing the arc to extinguish.

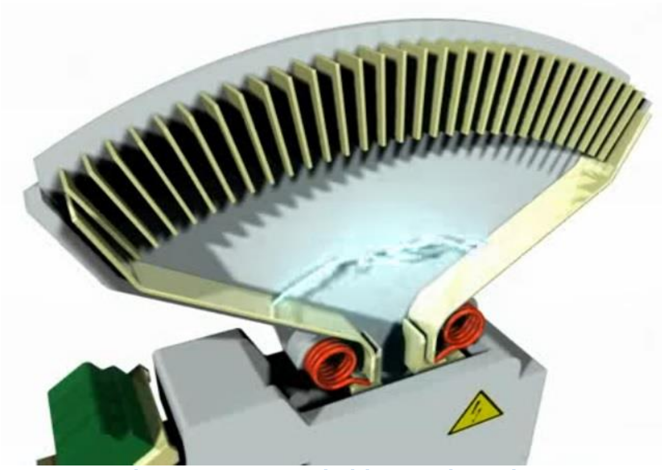


Figure 35. Magnetic blowout in action

Construction and Operation of Hall Effect Devices

11. When current flows along a metal plate, the current moves in a direct line from areas of high potential to low. However, when under the presence of a magnetic field the current is forced to deviate towards one of the sides causing a potential difference called a Hall Voltage that can be measured.

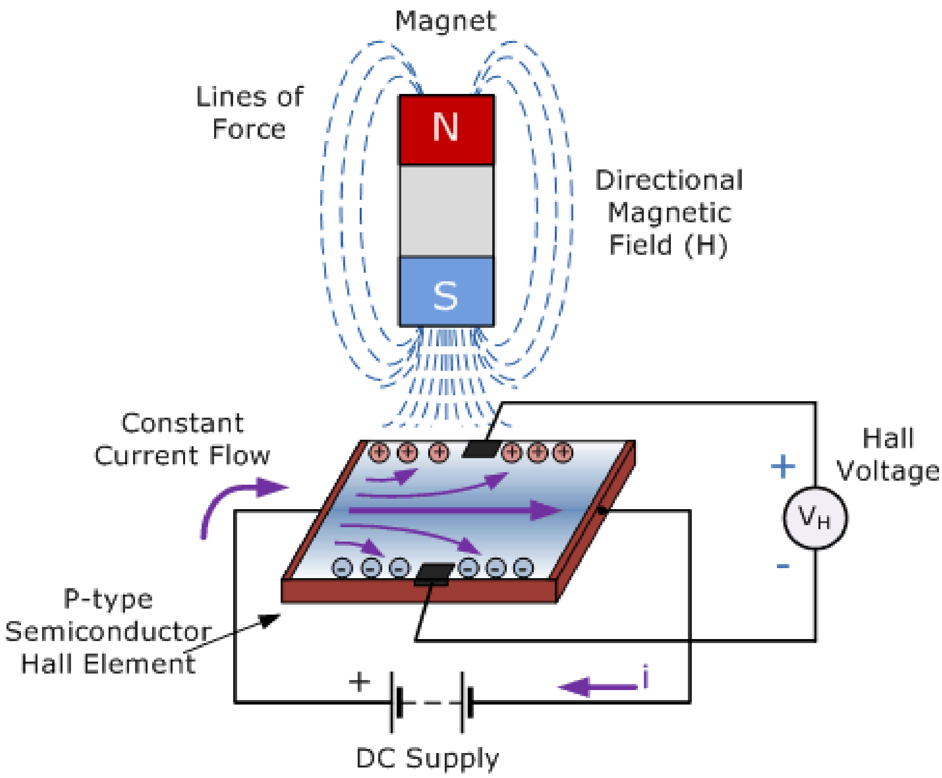


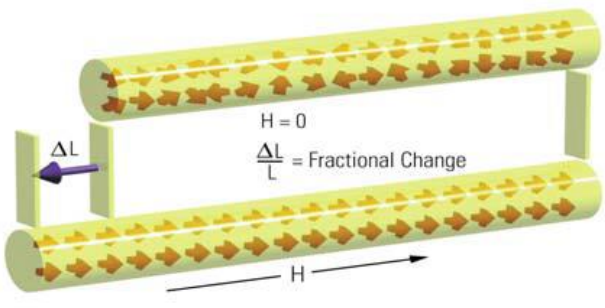
Figure 36

Application of Hall Effect Devices

12. The Hall Effect finds uses in limit switches, sensors, measuring instruments, and brushless motors which use the Hall Effect to detect the position of the rotor.

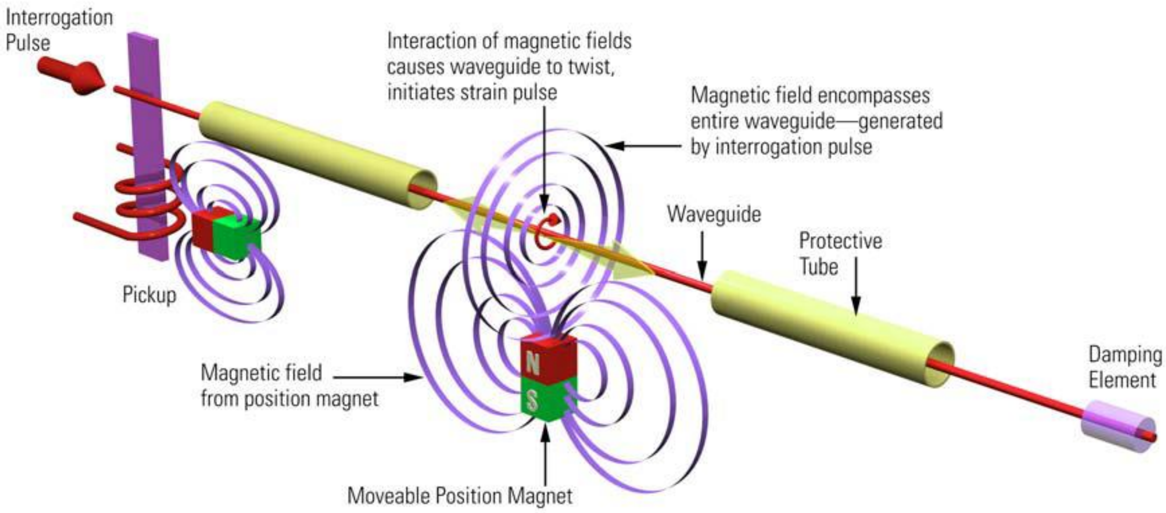
Operation of Magneto striction materials.

13. Magnetostriction is a property of ferromagnetic materials such as iron, nickel, and cobalt to change size and/or shape when placed in a magnetic field.This physical response of a ferromagnetic material is due to the presence of magnetic movements, essentially a collection of tiny permanent magnets, or domains (see Figure below). Each domain consists of many atoms. When a material is not magnetized, the domains are randomly arranged. When the material is magnetized, the domains are oriented with their axes approximately parallel to one another and the change in size or shape is made. Interaction of an external magnetic field with the domains also causes the magnetostrictive effect. The order of the domains, and thus the magnitude of the effect, can be influenced by alloy selection and magnetic field strength.



Application of Magneto striction Equipment

14. Magneto striction equipment is used as high force linear motors, positioners for adaptive optics, active vibration or noise control systems, medical and industrial ultrasonic pumps, saw mills, injection moulding and casting to petrochemical and pharmaceutical level control to off-road construction and agricultural machine control.



The magnetostrictive sensor above functions as follows:

An electrical (interrogation) pulse is sent down the waveguide. At the point where the pulse enters the magnetic field of the permanent magnet, used to detect position, the magnetic field generated by the interrogation pulse reacts with the permanent magnetic field and causes an ultrasonic (strain) pulse to be generated in the waveguide. This resultant ultrasonic pulse travels back up the waveguide and is detected by the pickup device. By measuring the time taken to detect the return pulse the position of the magnet can be calculated.

Magnetic Sensing Devices

15. Most magnetic sensors in use utilise one of three methods to detect magnetic fields:

1. Physical – magnetic field manipulates a physical contact causing it to operate. This is used in security and called reed switches.
2. Hall Effect – magnetic field interacts with flowing current causing a Hall Voltage to appear. This is used in limit switches.
3. Magneto striction – magnetic field causes a material to change shape. This is used in detecting very low strength magnetic fields.

Worksheet T5   Magnetic Devices Questions

1. List eight items used in the construction of a relay. (T7.1)

2. Can a relay with a solid iron core be used on AC? Give a reason for your answer. (T7.1)

3. What is the purpose of the armature in a relay? (T7.1)

4. Describe how a relay operates to cause contacts to open or close. (T7.1)

5. Where are relays generally used? (T7.1)

6. What is the difference between a relay and a contactor? (T7.1, 7.2)

7. What is the purpose and name of a single turn of conducting material, generally copper, embedded in one of the mating magnetic surfaces of a contactor? (T7.2)

8. Where are contactors generally used? (T7.2)

9. What causes an arc to form between contacts being switched open in a contactor? (T7.3)

10. Name a method used to extinguish an arc caused by contacts being switch open. (T7.3)

11. Name three components used to construct a Hall Effect device. (T7.4, 7.6)

12. How is a measurable Hall voltage created in a Hall Effect device? (T7.4, 7.6)

13. List four practical applications where Hall Effect is used. (T7.4, 7.6)

14. Explain the principle of operation of Magneto striction equipment? (T7.5, 7.6)

15. List four practical applications of Magneto striction. (T7.5, 7.6)

16. List three methods used by magnetic sensors to detect the presence of a magnetic fields and give a practical application for each method. (T7.6, 1.6, 7.4, 7.5)

Magnetic Devices Practical

Task:

To identify types of a.c. and d.c. electromagnetic relays and contactors.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:
Sample electromagnetic relays (a.c. and d.c.)
Sample contactors
Multimeter
Hand tools as required
Manufacturers' catalogues where applicable

Method:
Examine the electromagnetic devices supplied and determine their caharcrteistics. Answer the following questions for each device (on a separate sheet of paper).

1. What is the coil voltage?
2. What is the coil resistance?
3. Is the coil a.c. Or d.c.?
4. What is the current rating of the main contacts?
5. What is the current rating of the coil?
6. What is the core material?
7. Is a shading ring fitted?
8. Is a residual stud fitted?
9. How many contacts does it have?
10. How many normally open contacts?
11. How many normally closed contacts?

Feedback and Recommendations:

Student's Signature: ____ **Date:** ____________

Assessor's Signature: ____ **Date:** ____________

Machine Principles. Part B.

Construction of DC Machines

1. The d.c motor and d.c generator are basically the same in both operating principle and construction.

2. Basically a d.c machine consists of a fixed field system with inwardly projecting (salient) poles, a rotating armature with a commutator on one end and a set of brushes.

3. The main component parts of a four pole d.c machine are shown in Figure 38.

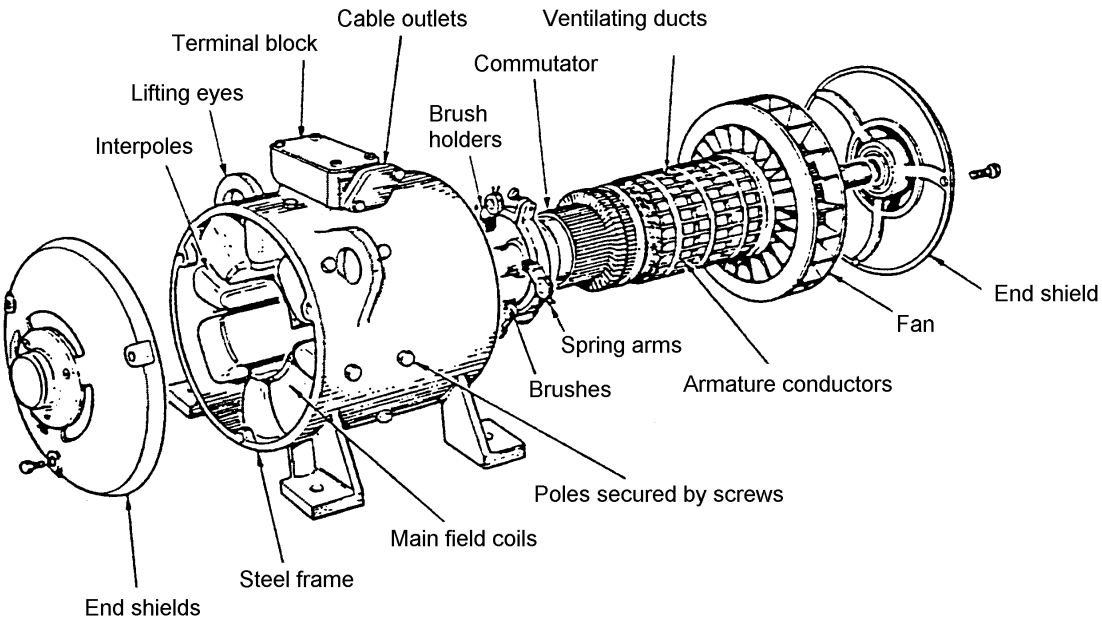
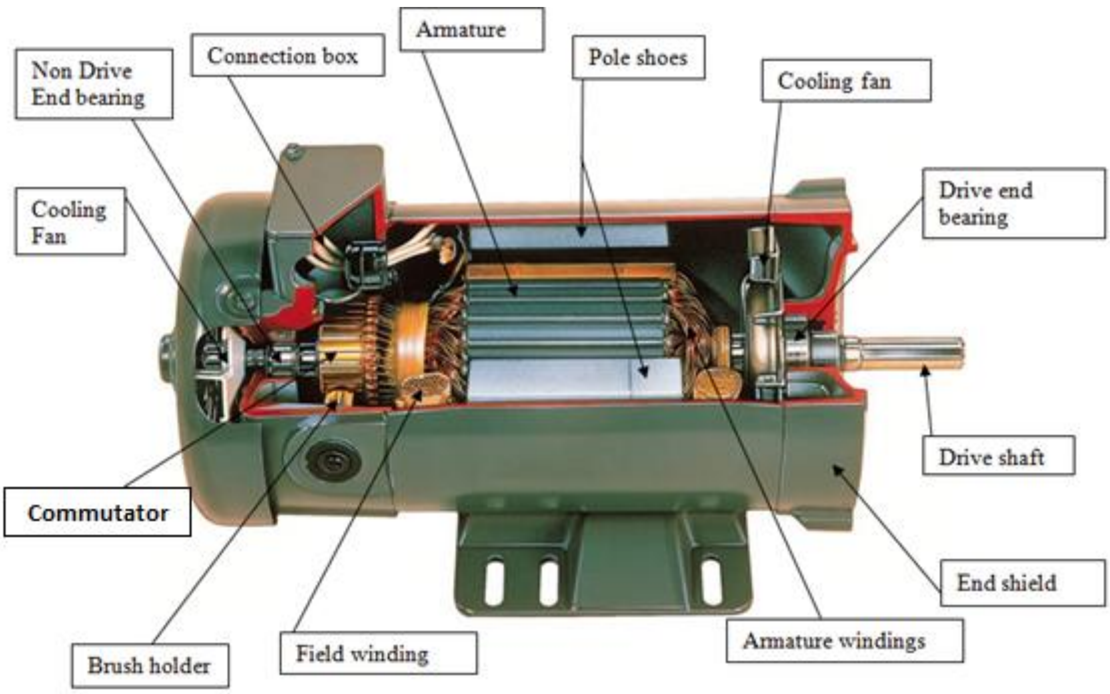


Figure 37. DC machine components



Poles

4. Pole cores are usually made of steel plates riveted together and bolted to the yoke which is usually made of cast steel or fabricated rolled steel. In small machines, the main pole pieces may be constructed of solid steel. In larger machines the pole pieces are usually laminated.

Armature Core

5. The armature core consists of iron laminations, approximately 0.4 to 0.6 mm thick, insulated from each other and assembled on the armature shaft. The purpose of laminating the core is to reduce eddy current loss. Eddy currents are circulating currents which are induced within the iron armature core.

6. It should be realised that although we are considering d.c machines, alternating currents are present in the armature core therefore causing induced currents to flow. The eddy currents generate heat and consequently lower machine efficiency. A fan is usually fitted to the end of the armature shaft, at the opposite end to the commutator, to draw cooling air through the machine.

Armature Windings

7. The armature windings come in two general configurations, lap and wave. Lap winding is suitable for high current machines, whereas wave winding is suitable for lower current machines.

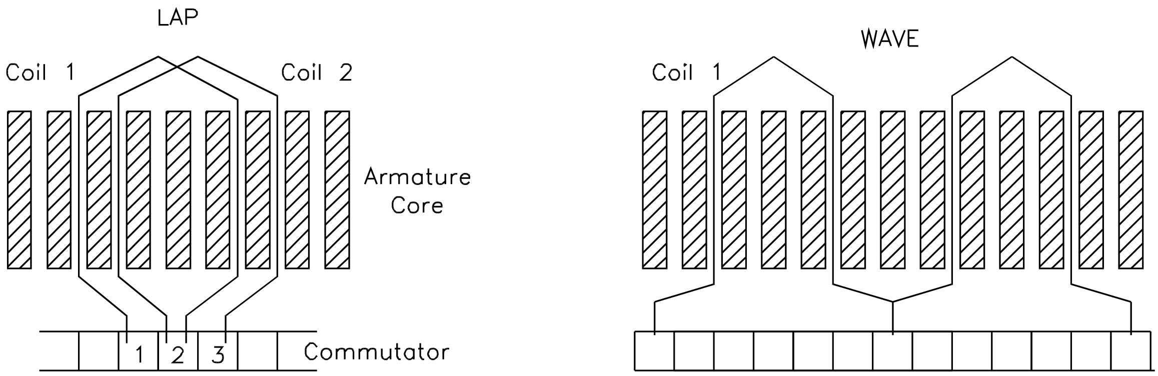


Figure 38. Lap and wave windings

The main difference between lap and wave winding is the position the leads are connected to the commutator in respect to the coil ends, as shown in Figure 39.

Lap Windings

8. Lap windings have as many current paths as there are poles in the machine. The higher the number of poles, or current paths, the more output current.

Wave Windings

9. Wave windings only have two current paths, regardless of the number of poles within the machine. The small number of current paths therefore means a lower output current is achieved.

Commutator

10. The commutator is constructed using wedge shaped, hard drawn copper segments. The segments are insulated from each other using mica insulation and held together with insulated, machined cones called "vees".

11. The winding conductors are attached to the commutator in slots cut into the raised back or ‘riser’ of the copper commutator segment.

Brush gear

12. The armature windings are connected to the external circuit by a rotary contact between the commutator and the stationary carbon or carbon /graphite brushes.

13. The assembly of brushes, springs and brush holders is referred to as the brush gear.

End Shields

14. The end shields are fitted to each end of the main frame and house the armature bearings and brush gear.

Bearings

15. The bearings can be either ball/roller or sleeve bearing. Some manufacturers use a ball bearing for the drive end and a sleeve bearing for the non-drive end.

16. Bearing caps are usually provided on ball or roller bearings to allow for bearing inspection without the need for machine dismantling.

Frame, Yoke or Carcase

17. The magnet frame is usually constructed using cast iron or cast steel. The use of steel reduces the reluctance of the magnetic circuit thereby reducing the size of the field windings.

18. The frame provides mechanical support for the pole pieces and acts as part of the magnetic circuit providing the necessary flux across the air gap as shown in Figure 40.

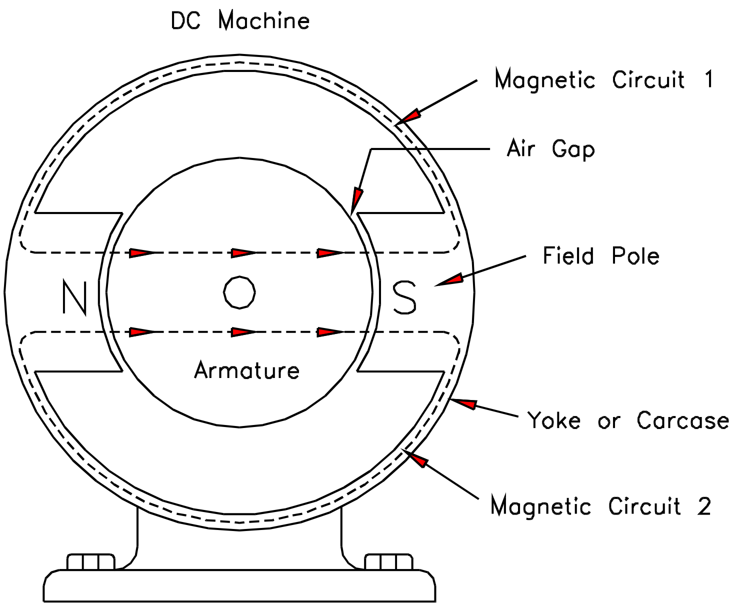


Figure 39. Magnetic circuit

19. Figure 40 shows the magnetic circuit within a d.c machine. The magnetic circuit consists of a series path through the yoke, field poles, air gap and armature. The magneto motive force created by the field coils must be strong enough to force the magnetic flux to flow throughout the magnetic circuit.

20. To keep the reluctance of the magnetic circuit to a minimum, the air gap between the armature and the field poles must be kept to a minimum.

Operating Principles of DC Machines

21. The d.c motor and d.c generator are basically the same in both operating principle and construction.

Generators

22. A single coil rotating through a strong magnetic field can be used to demonstrate generating principles.

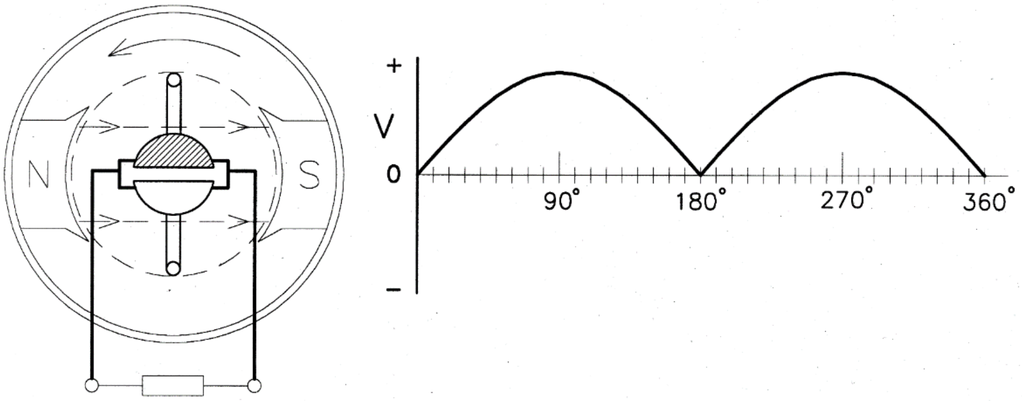


Figure 40. Coil rotating in a magnetic field

23. When the coil shown in Figure 41 is rotated through 360 degrees, the generated e.m.f changes in proportion to the sine of the angle as shown in the graph. The generated voltage is zero when the coil is travelling parallel to the field flux and maximum when it is travelling at 90 degrees to it. The polarity of the output to the load between 180 and 360 degrees is reversed by the action of the commutator and brushes. The output is known as 'pulsating d.c.' if the coil was connected to two slip rings instead of a commutator the output would be a.c. The method of determining the direction of flow of a current in a conductor rotating in a magnetic field is by the use of the RIGHT HAND GENERATOR RULE, as shown in Figure 42.

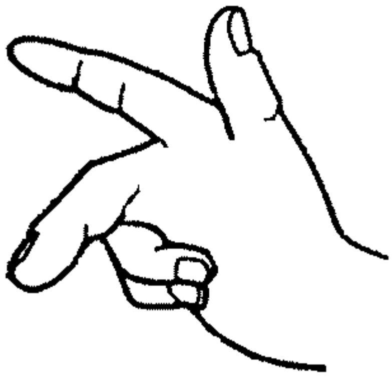


Figure 41

24. In a practical armature the coils are evenly spaced around the armature so that their outputs overlap. The greater the number of coils, the more constant the output, as in Figure 43.

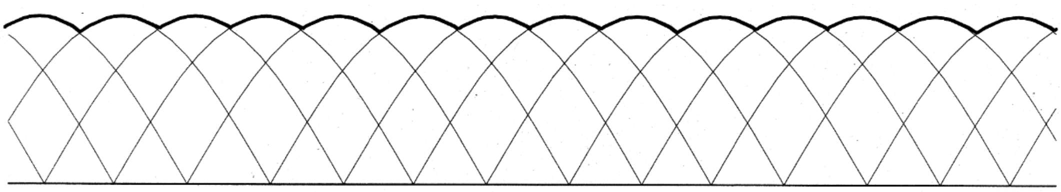


Figure 42

25. It is important to note that the current in the armature is a.c., but the output is d.c. - the commutator and brushes are acting as a rotary switch. Since the current in the armature winding is a.c. the armature core must be laminated to reduce eddy currents in the core.

Generated Voltage

26. The value of emf generated in an armature is dependent upon three factors,

   a. The strength of the main magnetic field.

   b. The number of effective armature conductors in series.

   c. The speed at which the conductors cut the magnetic field.

27. The formula for calculating generated e.m.f is:

$$V_g = \frac{P \times \Phi \times n \times Z}{60 \times a}$$

Where: V_g = generated voltage
P = number of poles
Ø = magnetic flux per pole in Webers
n = revolutions per minute
Z = number of effective conductors
a = number of parallel current paths in the armature
60 = used to allow "n" to be calculated using revs/min

28. **Example 1.** A 4 pole lap wound armature has a total of 400 effective turns, the flux per pole is 0.03 Webers and the revolutions per minute is 1500. Calculate the generated e.m.f.

Solution

$$V_g = \frac{P \times \Phi \times n \times Z}{60 \times a}$$

$$V_g = \frac{4 \times 0.03 \times 1500 \times 400}{60 \times 4}$$

$$V_g = 300\ volts$$

Voltage Control

29. The output of a d.c generator is governed by:

   a. The main magnetic field strength.

   b. The speed of the armature.

   c. The number of conductors in series on the armature.

30. In practice it is not usual to change the speed of the machine or the number of conductors. The most common method is to alter the field strength by inserting a variable resistor in series with the shunt field, Figure 44.

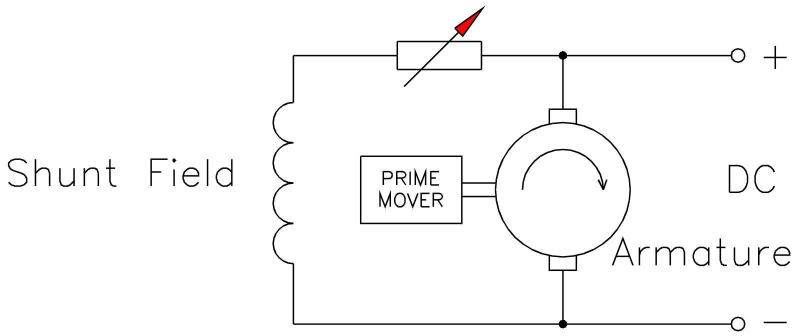


Figure 43

31. By varying resistance we can vary the amount of current flowing in the shunt field. Because the field strength depends on the amount of current flowing in the shunt field winding, the variation of the current in the field will cause a variation of generated terminal voltage.

32. The variable resistor is commonly known as the 'field regulator'.

Armature Reaction

33. As the armature rotates within a d.c machine, the currents in the armature conductors set up their own magnetic field. When this field reacts with the main pole fields the magnetic field becomes twisted, the result is known as 'armature reaction'. Since the armature coil being commutated must be the one moving parallel to the main field flux, one of the main effects of armature reaction is to change the optimum position of the brushes as the load current changes. If the brushes are not located in the correct position on the commutator, excessive sparking at the brushes will occur.

34. The no-load position of the brushes is on a plane known as the geometric neutral plane (GNP) and the on-load position is known as the magnetic neutral plane (MNP). In a generator the MNP is always shifted in the same direction as the rotation of the armature.

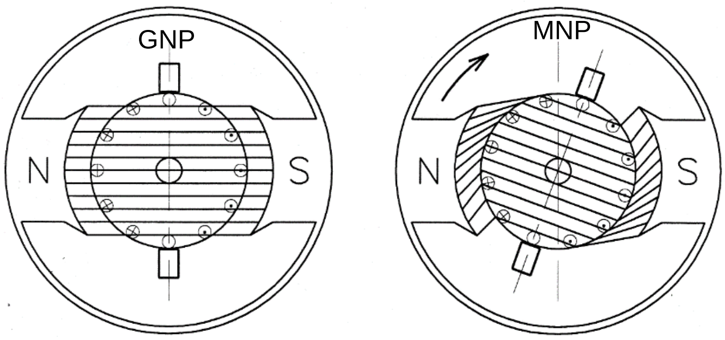


Figure 44

Methods Used to Compensate for Armature Reaction

35. Machines operating with a varying load must have a mechanism for automatically compensating for the effects of armature reaction to minimise sparking at the brushes. The two most common practical methods are:

   a. Using interpoles.
   b. Using a compensating winding
   c. Using manual adjustment of brush gear.

Compensating Windings

36. Compensating windings provide the most effective method of neutralising armature reaction, unfortunately this method is very expensive. The use of compensating windings is most suited to conditions which involve very sudden changes in load conditions.

37. The compensating windings consist of coils which are let into the face of the main field poles and connected in series with the armature coils. The windings are connected so that the field produced by the compensating winding is equal to and opposite to the flux caused by the armature current.

Interpoles

38. The use of smaller interpoles between the main field poles is a more common method of overcoming armature reaction. The interpoles produce an induced e.m.f in the coil under commutation which cancels the e.m.f induced by the field distortion. The interpoles are internally connected in series with the armature coils so they automatically vary in strength as the armature current changes.

DC Motors

39. The d.c motor is constructed in a similar manner to a d.c generator. A machine that performs well as a generator will also operate as a motor.

Motor Principle

40. The operation of a d.c motor is based on the principle that a current carrying conductor placed in, and at right angles to a magnetic field, tends to move at right angles to the direction of the field as shown in Figure 46.

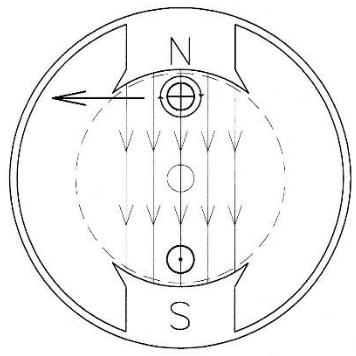


Figure 45

41. The method of determining the direction of motion of a current carrying conductor in a magnetic field is by the use of the LEFT HAND MOTOR RULE, as shown in Figure 47.

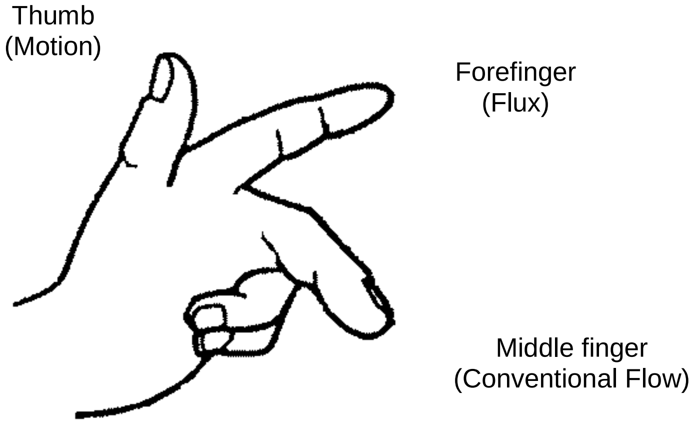
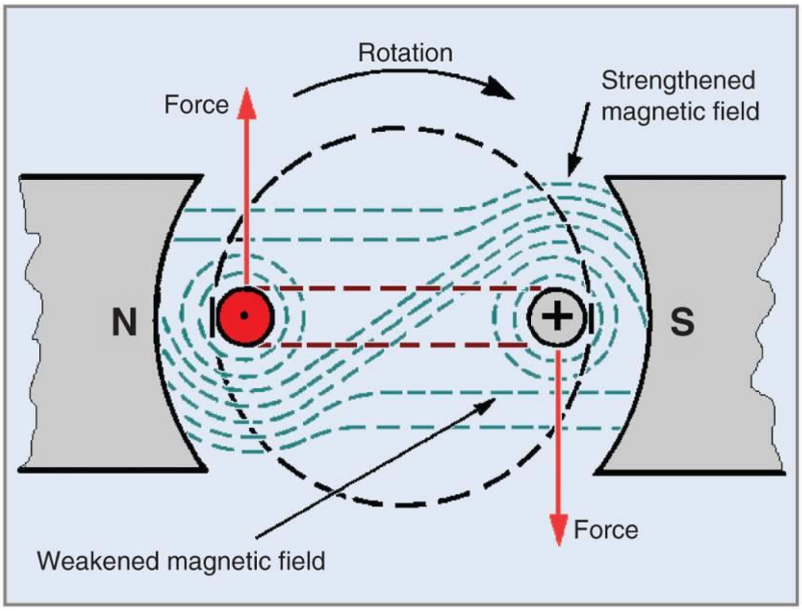


Figure 46

42. When a conductor is rotated in a magnetic field an e.m.f is generated in the conductor. Therefore, when a d.c motor is operating, the armature is rotating due to the action of the magnetic fields interacting with the armature conductors. The armature conductors cut the main field flux and because of this an e.m.f is generated in the same conductors.



Induced EMF in DC Motors

43. As the conductor is moved across the field it cuts the lines of flux and has a voltage induced in it. By applying the right-hand generator rule, it can be seen that the generated voltage or induced e.m.f, is in opposition to the applied e.m.f.

44. The induced e.m.f is directly proportional to the speed of the armature and the field strength.

45. The effective voltage or 'IR drop', in the armature is equal to the supply voltage minus the induced e.m.f or 'back e.m.f' as shown in Figure 48.

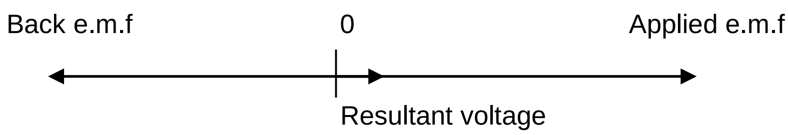


Figure 47

46. Due to the induced e.m.f within a motor being zero at standstill, a large starting current will flow as the motor starts. The current flow is only limited by the very low armature resistance.

47. Due to the high inrush of current, a method of limiting the starting current must be employed.

Worksheet T6 (Part A) Machine Principles Questions

1. List thirteen main components of a DC machine. (T9.1)

2. Name the two windings used in a DC machine. (T9.1)

3. What type of material is used to construct the main pole pieces of a large d.c motor or generator? (T9.1)

4. What is the reason for laminating the core of an armature? (T9.1)

5. What are the names of the two basic types of armature windings? (T9.1)

6. What type of material is used to construct commutator segments? (T9.1)

7. Why is the yoke of a DC machine constructed using a high permeability material such as steel? (T9.1)

8. How many current paths there are in a basic lap winding? (T9.1)

9. How many current paths there are in a basic wave winding? (T9.1)

10. What type of material are commutator brushes made of? (T9.1)

11. What is produced in a coil of an armature when rotated 360^o in a two pole generator? (T8.1)

12. What type of waveform is generated in a coil of an armature when rotated 360^o in a two pole generator? (T8.1)

13. What is the purpose of a commutator in a DC generator? (T8.1)

14. What type of output would be produced if two slip-rings were used instead of a commutator in a generator? (T8.1)

15. At what point is maximum voltage generated in the coil of an armature as it rotates past the magnetic fields of a generator? (T8.1)

16. Explain the effect on the output of a generator if the number of coils in the armature are increased. (T8.1)

17. Explain what the following represent when applying Fleming's **right hand rule for generators**: (T8.2)

    - The thumb
    - The forefinger
    - The middle finger

18. What is the direction of induced current when a given conductor is moved clockwise across the magnetic flux from a south pole in a generator? Draw a diagram to support your answer. (T4.2, 8.2)

19. Explain the basic principle of operation of a DC motor. Use a diagram if required. (T8.3)

20. Explain what the following represent when applying Flemng's **left hand rule for motors**: (T8.4)

    - The thumb
    - The forefinger
    - The middle finger

21. What is the direction of the force exerted on a conductor when it is carrying current away from the observer under a north pole in a motor? Draw a diagram to support your answer. (T4.2, 8.4)

22. State three factors that affect the value of generated e.m.f. in a DC generator. (T10.2)

23. A 4 pole lap wound armature has a total of 400 effective turns, the flux per pole is 0.04 Webers and the revolutions per minute is 1500. Calculate the value of generated e.m.f. (T10.2)

24. A 6 pole lap wound armature has a total of 400 effective turns, the flux per pole is 0.03 Webers and the revolutions per minute is 1000. Calculate the value of generated e.m.f. (T10.2)

25. A 4 pole lap wound armature has a total of 400 effective turns, the flux per pole is 0.03 Webers and the revolutions per minute is 1500. Calculate the value of generated e.m.f. and terminal voltage given a volt drop across the armature is 15 volts. (T10.2)

26. What effect does induced e.m.f (Back e.m.f) have on the supply voltage (applied e.m.f) in a DC motor? (T11.2)

27. What is the effective voltage or I.R. drop in an armature equal to? (T11.2)

28. What value of induced e.m.f is produced when a DC motor is at standstill the instant it is switched on?

29. What is the only limiting factor to starting current when a DC motor is first energised and is at standstill? (T11.2)

30. What causes high starting current in a DC motor the moment it is energised? (T11.2)

31. How should high starting current be dealt with in a DC motor? (T11.2)

32. Explain Armature Reaction in a DC machine. (T9.1)

33. Explain why brushes must be kept within the magnetic neutral plain. (T9.1)

34. Give two methods used to compensate for Armature Reaction. (T9.1)

35. Where are Interpoles installed in a DC machine? How are they connected? (T9.1)

36. Where are Compensating Windings installed in a DC machine? How are they connected? (T9.1)

The Difference between Motors and Generators

48. The operation of a d.c generator is based on the principle that rotating a conductor in a magnetic field will induce a voltage into it. Whereas the operation of a d.c. motor is based on the principle that a current carrying conductor placed in a magnetic field will want to move.

49. Therefore the energy conversion of a d.c. generator can be said to be: mechanical power supplied by a prime mover rotating a coil in a magnetic field that produces electrical power used by a load. A pictorial representation of this can be seen along with losses in Figure 49.

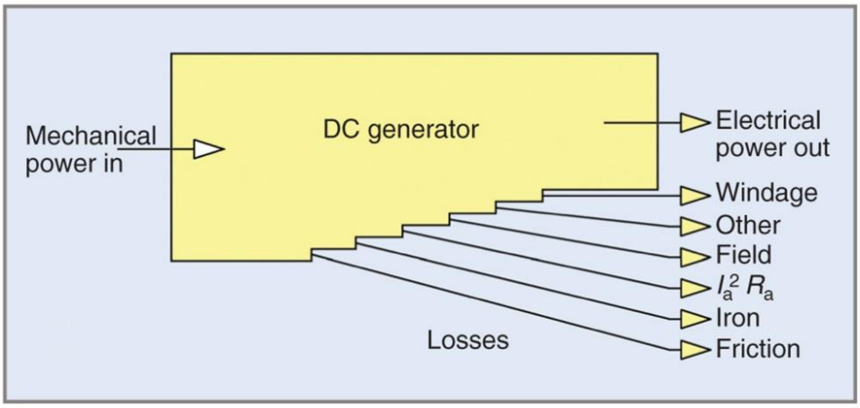


Figure 48. Energy conversion in a d.c. generator

50. Similarly the energy conversion of a d.c. motor can be said to be: electrical power supplied by a source rotating an armature wrapped coil producing mechanical power used by a load attached to the rotor. This can be seen along with losses in Figure 50.

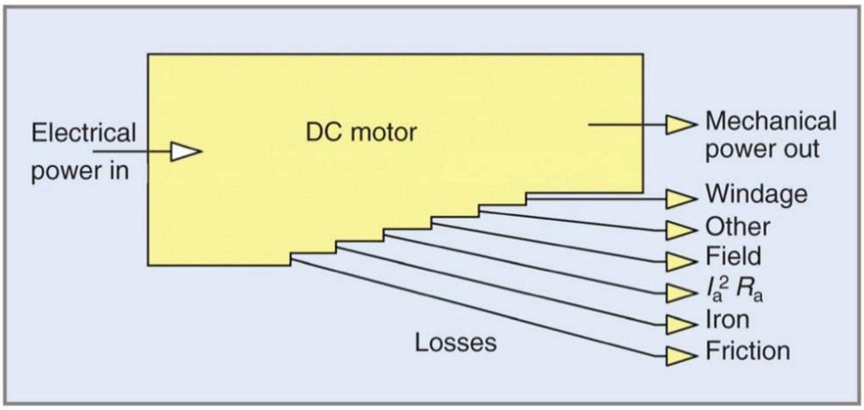


Figure 49. Energy conversion in a d.c. motor

Nameplate

51. The losses incurred by the machines, and the difference in manufacturing makes it hard to gauge the power consumption merely by looking at the machine. Manufactures by law are required to state certain information on the machine, this includes rated voltage, and rated current. An example can be seen below in Figure 51.

Figure 50

52. It is possible to compare the nameplate values with readings taken from various measuring instruments and see if the machine is performing as expected. The more common readings that get compared are current, voltage and power. The measurements are done by using ammeters, voltmeters and wattmeters. If a wattmeter is not readily available power can be calculated using the power formula and readings from both ammeter and voltmeter.

Identification of Faults

53. The comparison of measured values to the nameplate will allow for observation of symptoms that will allow for the identification of a fault on the machine.

Motors

- Low Amperage – multiple pole machine with one or more poles becoming open circuited or a resistive joint (hot spot).
- High Amperage – motor is overloaded or has a short circuit.
- Low/High Voltage – supply to the motor is incorrect.

Generators

- Low/High Amperage – generator is overloaded electrically
- Low Amperage and Low Voltage – low speed prime mover or excitation field is not strong enough.
- High Voltage – prime mover is spinning too fast or one of the excitation field is open circuited.

Inspection and Maintenance of Machines

54. No matter how well a motor is made, sooner or later it will need to be serviced, repaired or replaced. From an economical point of view, electricians and managers often consider that smaller motors are cheaper to replace rather than repair. However, most motors can be quickly serviced by a competent electrician with a spare set of bearings and a little time. For DC machines commutators and brushes must have regular inspection for wear and replacement.

Isolation

55. Before commencing any inspection or maintenance procedures on a motor it must be isolated both electrically and mechanically. Electrical isolation can be achieved by following a test and tag procedure to isolate the supply to the motor. Mechanical isolation is carried out to ensure that there will be no mechanical danger from equipment moving. For example, an elevator may have been stopped with full buckets. If the brake is released in this condition, the shaft may spin backwards and cause serious injury to anyone working on the motor.

Inspection

56. When the motor has been isolated, it should be inspected for damage. The damage could be mechanical, such as broken or worn parts, or chemical, such as corrosion or acid exposure. The condition of the exterior can indicate the value of servicing the motor. After isolating the motor, the terminal cover is removed and the interior sniffed cautiously to check for burnt windings. Most motors will have an electrical smell about them, but burnt windings are usually much more obvious. If the motor is a candidate for repair, continue. Armature and Commutator brushes inspected for wear.

Mounting Details and Direction of Rotation

57. Before the motor is removed and dismantled, a sketch should be made. The sketch should show:

- How the motor is connected.
- Where the terminal block is situated.
- How the end covers are fitted.
- Which direction the motor is rotating when in service.
- How any safety covers are fitted.

58. To ensure that the motor goes back together the right way, 'witness marks' are made at each end of the top of the motor. They are usually made opposite the foot side as shown in Figure 52. Two light centre pop marks, side by side on either side of the drive end cover or frame joint, will locate the drive end cover at the same end and in the same rotation on the frame. A single mark on the non-drive end cover and frame will similarly mark the position of the non-drive end cover. If the motor has been disassembled before, another electrician may have already made witness marks.

Figure 51

Internal inspection

59. When the motor has been fully disassembled all parts should be inspected for damage, corrosion, and especially signs of insulation damage. The stator and rotor should be electrically tested for continuity and insulation, and on larger motors may be hi-pot tested; that is, tested at a high voltage for leakage current from the windings to the laminations. Armature and Commutator inspected for wear. Brush gear cleaned.

Bearings

60. Bearings should not be replaced once removed. Most modern bearings are pre-lubricated and sealed, but if not, a good quality bearing grease should be used to pack the bearings two-thirds of the way around the bearing race. The space allows the grease to expand and avoids it being expelled from the bearing when it all gets to operating temperature.

61. Internal bearing caps must be placed onto the shaft before the bearings. Bearings may need to be heated in an oven or oil bath before fitting over the shaft. Caution is needed to avoid overheating the components, so the permissible temperatures and methods should be checked with the manufacturer's instructions. Once placed onto the shaft the bearing should be quickly pressed or driven up against the shoulder on the shaft as it may cool quickly and seize into position even if only partly installed. Open bearings should be covered with a clean cloth or paper to prevent materials from fouling the exposed grease. Sometimes outer bearing caps can be installed and screwed to the inner caps, temporarily, in order to cover the grease.

Testing the Machine after Reassembly

62. After replacing any broken parts and reassembly, the machine should be electrically tested to ensure that the insulation resistance, earthing, continuity and terminal connections are all correct. Once the machine has passed the electrical tests it is important to run the machine to test the functionality.

Safety Risks

63. Rotating machines by their nature are an OS&H risk. Care should be taken to not be caught up in the moving components or come in contact with any electrically live parts.

Worksheet T6 (Part B) Machine Principles Questions

1. Explain the operational difference between a generator and a motor. (T9.2)

2. Explain the difference between a generator and a motor in terms of **energy conversion**. (T9.2)

3. List six items of information included in a typical name plate on a DC machine. (T9.3)

4. Why are name plate details important when taking electrical measurements on a DC machine? (T9.3, 9.4)

5. List three electrical faults that could occur in a DC machine and identify the test instruments used for each test. (T9.5)

6. Name three items that should be periodically inspected for wear in a DC machine. (T9.6)

7. Identify the safety procedures to be followed before maintenance work is commenced on a DC machine. (T9.6, 9.7)

8. Name two types of non-electrical damage that should be considered during inspection of a DC machine after it has been isolated. (T9.6)

9. What are you looking for when performing an internal inspection of a disassembled DC machine? (T9.6)

10. Which internal parts in a DC machine should be tested for continuity and insulation breakdown? (T9.5, 9.6)

11. Explain the need for bearings to only be packed to two-thirds capacity when servicing a DC Machine. (T9.6)

12. List the electrical tests that should be performed once a DC machine has been reassembled. (T9.5, 9.6)

Machine Principles Practical

Task:

To identify the parts of a typical d.c. compound motor or generator with interpoles.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:

Typical d.c. compound motor or generator - around 2 kW.
Sample d.c. armatures.
Sample d.c. motor brush gear and brushes.
Post it notes

Method:

1. Identify the following parts of the d.c. machine supplied (if applicable) using the number written onto post it notes and stuck on the physical item.

1	Armature	30	Eyebolt
2	Armature banding	31	Field pole retaining bolt
3	Armature slot	32	Full load speed
4	Armature slot insulation	33	Internal cooling fan
5	Armature winding	34	Interpole
6	Ball bearing	35	Interpole coil
7	Bearing cap retaining screw	36	Keyway
8	Bearing cap, inner, DE	37	Laminated armature core
9	Bearing cap, inner, NDE	38	Main field pole
10	Bearing cap, outer, DE	39	Main field pole shoe
11	Bearing cap, outer, NDE	40	Mounting feet
12	Bearing housing	41	Mounting flange
13	Brush holder	42	Nameplate
14	Brush pigtail	43	Non-Drive end
15	Brush gear	44	Roller bearing
16	Brush spring	45	Series field coil
17	Carbon brush	46	Shaft
18	Carcase	47	Shunt field coil
19	Commutator	48	Sleeve bearing
20	Commutator riser	49	Terminal block
21	Commutator segment	50	Terminal box
22	Commutator undercut	51	Terminal box cover
23	Conduit entry	52	Terminals
24	Drive-end	53	Through bolt
25	Drive pulley	54	Yoke
26	Driving key		
27	Earthing terminal		
28	End shield DE		
29	End shield NDE		
30	Eyebolt		

2. Have your results checked your Lecturer.

Feedback and Recommendations:

Student's Signature: ________________________ **Date:** ____________

Assessor's Signature: ________________________ **Date:** ____________

Motors and Generators

Prime movers

1. The prime mover for a d.c. generator is a mechanical engine of some description. Common engine types include the more common hydrocarbon (petrol or diesel) internal combustion engine, steam engine or hydro.

2. The internal combustion engine ignites a flammable fuel that as it explodes expands forcing a piston to rotate the shaft attached to the generator. The steam engine utilises a heat source heating water so that it boils and the steam is forced to turn a turbine, which is attached to the generator. Hydro sources cause a turbine to move as the water moves, whether that be because of the tides or water flowing down hills.

3. Energy flows that are used to create electricity at their simplest are: source creates motion, that motion turns a turbine, the turbine turns the armature of the generator producing electricity.

Types of d.c. machines

4. There are five general types of d.c motor or generator:

   a. Permanent Magnet
   b. Separately Excited
   c. Shunt
   d. Series
   e. Compound

5. The current which flows through the field coils to produce the magnetic field at the poles of a d.c generator is referred to as the EXCITATION current.

6. If the excitation current is obtained from a separate d.c supply it is referred to as 'separately excited'.

7. If the excitation current is obtained from the armature of the generator it is said to be 'self-excited'. Self-excited generators may be shunt, series or compound wound.

Permanent Magnet DC Generator

8. A permanent magnet generator is usually constructed using a permanent magnet rotor and a stationary wound field system. The generator produces a.c, therefore the output is fed through a rectifier to give d.c.

9. Older types used a wound armature and a permanent magnet field system with the output being taken from the armature via brushes.

Permanent Magnet Motors

10. The permanent magnet motor is used for applications such as automotive fans, motorised wheelchairs, cordless drills, office machines and radio controlled models. The motors have a wound armature and brush gear with a permanent magnet field system. The supply is fed into the armature via the brushes.

11. To reverse the direction of rotation the supply polarity must be reversed.

12. This type of motor is generally restricted to small, extra-low voltage applications. One example would be approximately 50 mm in length, excluding shaft, 35 mm in diameter and be capable of speeds in excess of 30 000 RPM. Capacitors are normally fitted to the motor to suppress radio interference.

Separately Excited Machines

13. In this type of machine, the field coils are connected to an external d.c source.

14 The d.c source can be obtained from either a rectified a.c supply or from a small self-excited generator which is normally driven from the main generator shaft. The name given to the small generator in this case is, the EXCITER.

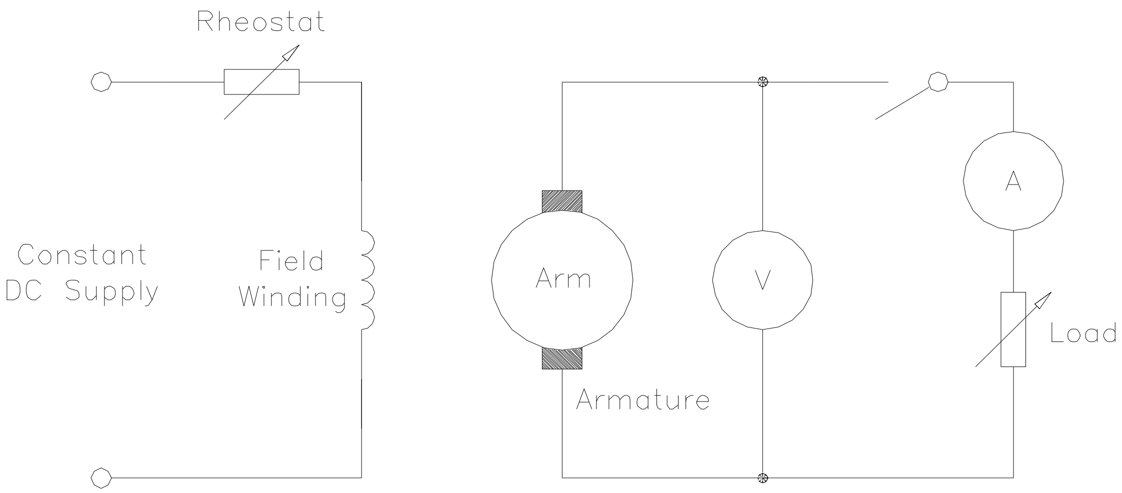


Figure 52. Separately excited generator

15. Figure 53 shows a separately excited generator. It can be seen that the armature is only connected to the load. If the machine is connected as a motor, then the supply must be connected across the armature.

16. The direction of rotation can be reversed by reversing the supply to the armature. The current in the armature is therefore reversed with respect to the field current direction. This method is used in the Ward Leonard system which is used within the lift industry.

17. Voltage control is achieved through the use of series resistance in the field. The series resistance regulates the current flowing in the field. A stronger field, lower resistance, providing a higher output voltage from the same generator speed.

18. If the field voltage supply was disconnected, the result would be a zero field current. In this case there may be a small generated voltage due to 'residual magnetism' within the field pole.

19. The major disadvantage of the separately excited generator is the need for a separate excitation source.

Shunt Generator

20. In the most common form of self-excited generator, the field windings are connected across the armature as shown in Figure 54 and the armature is assumed to be driven by a prime mover. This type of generator is referred to as a SHUNT GENERATOR.

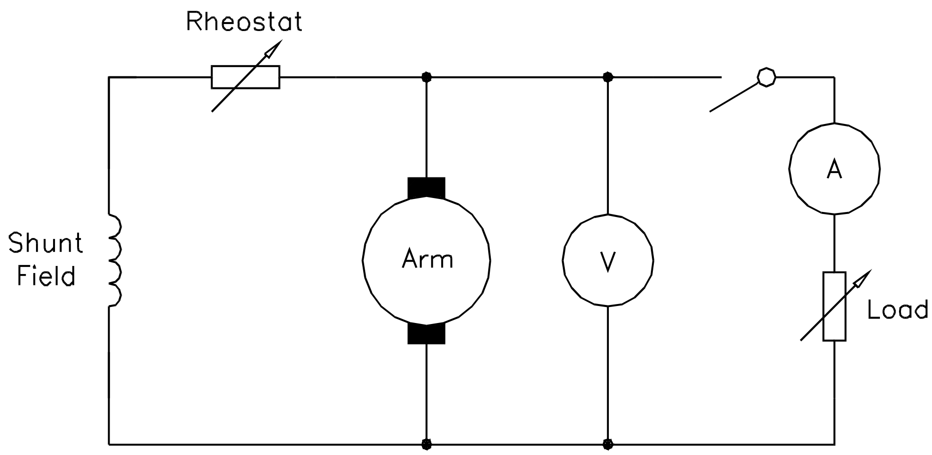


Figure 53. Shunt excited generator

21. Figure 54 shows the shunt field connected in parallel with the armature. The output voltage is controlled by a variable resistor, rheostat, in series with the shunt field.

22. The shunt machine relies on the existence of **RESIDUAL MAGNETISM** in the frame and pole pieces. Without residual magnetism the machine will not start to generate an e.m.f.

23. Residual magnetism is the amount of flux which remains in a ferromagnetic material when the magnetising force is removed.

24. When residual magnetism is present, the armature develops a small e.m.f as soon as it begins to rotate even with no current flowing in the field winding. This small e.m.f will cause a current to flow in the field winding thereby increasing the field flux.

25. As the field flux increases, the armature's e.m.f increases which causes more current to flow in the field. The process will continue until normal field current is achieved.

26. If the machine fails to generate when rotating, the field connection may be connected so that the generated e.m.f is opposing the residual. To rectify the problem either the rotation should be reversed or if this is not practical, the field to armature connection should be interchanged.

Applications for Shunt Wound Generators

27. Shunt wound generators were widely used by the automotive industry to charge batteries. To a large extent, the alternator has replaced the shunt wound generator. Static battery charging sets and small electroplating plants still use shunt wound generators.

DC Shunt Motor

28. A shunt motor is similar to a shunt generator in that its field winding is in parallel with the armature. The supply is connected to the leads which were the output leads on the generator as shown if Figure 55.

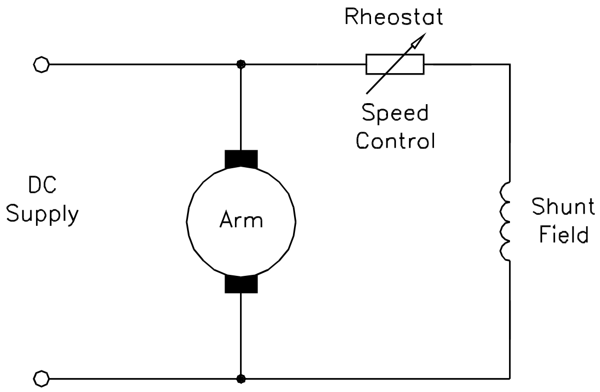


Figure 54. Shunt motor

29. Shunt motors are usually run without field rheostats, only being fitted when speed change is required. Decreasing the rheostat resistance increases the field current which therefore increases the field strength and slows the motor. Increasing the rheostat resistance therefore causes an increase in speed.

30. If the shunt field were to be open circuited the motor could accelerate to dangerously high speed due to the absence of the field. For this reason precautions must be taken to ensure that the shunt field is never 'open-circuited'.

31. The speed of a shunt motor may also be changed by means of an adjustable resistance, rheostat, in series with the armature. This method has two major disadvantages,

    a. Excessive power wastage
    b. Very poor speed regulation with changes of load.

32. Although the speed characteristic shows a slight drop, the shunt motor is generally regarded as a constant speed machine. Shunt motors are suitable for driving light machine tools and for all applications where an approximately constant speed is required and when the chance of overload is unlikely.

33. To reverse direction of rotation the armature lead connections should be changed in relation to the field connections.

DC Series Generator

34. The series generator has, as the name suggests, the armature connected in series with the field as shown in Figure 56.

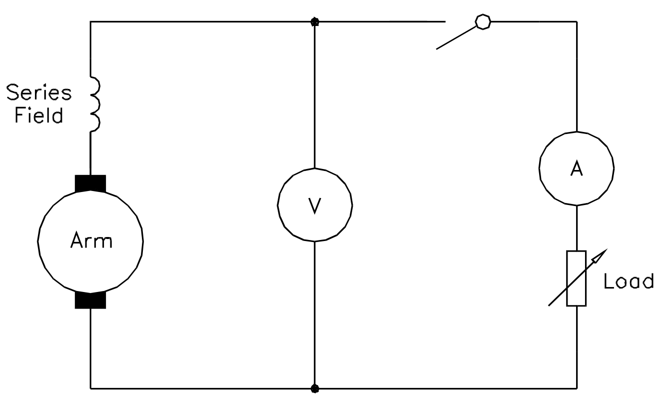


Figure 55. Series generator

35. The series generator has no practical application because the voltage rises significantly as the load is applied.

DC Series Motor

36. As Figure 57 shows, the connections for the series motor are the same as for the series generator. The field and armature being connected in series.

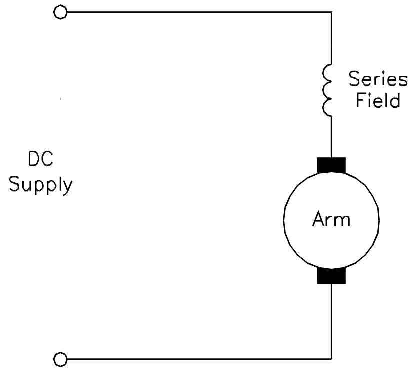


Figure 56. Series motor

37. Unlike the series generator, the series motor has wide applications, especially within the traction industry.

38. Because the current flowing in the field and the armature is the same, the field windings have comparatively few turns of heavy gauge wire. The field winding has to carry all the armature current.

39. A series motor should never be operated in the 'NO LOAD' condition or fitted to belt drive machines with a wattage greater than 180 watts. Under 'no-load' conditions the armature/field current is low therefore the field is weak and the motor can accelerate to destruction. The high speeds can physically throw the windings out of their slots.

40. Series motors are capable of delivering very high torque at low speeds which makes them suitable for traction motors in locomotives, haulpaks, winches and automotive starter motors.

41. To reverse a series motor, reverse the connections to the armature.

Compound Generators

42. The compound generator combines the characteristics of the shunt and series generators. The field windings consist of a shunt field and a series field, wound on the same pole piece as shown in Figure 58.

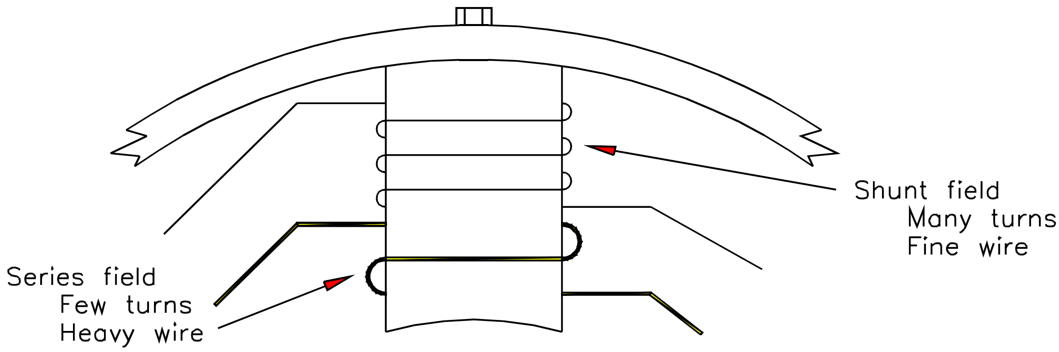


Figure 57

Field Connections

43. **Cumulatively Compounded** - If the two windings are connected to give the same polarity, shunt and series assisting each other, the machine is said to be cumulatively compounded.

44. Figure 59 shows the circuit diagram of a compound generator.

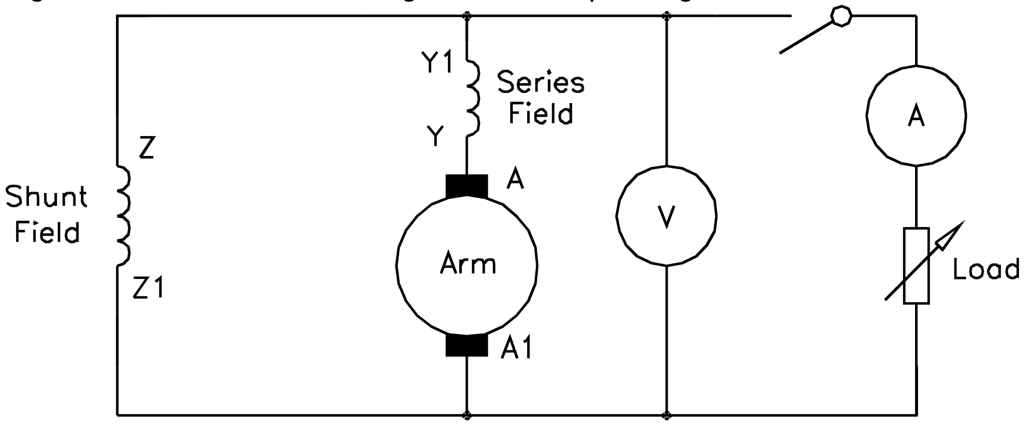


Figure 58

45. Figure 59 shows the series winding, Y1 and Y, in series with the armature, A and A1, therefore both are affected by the load current. As the load current increases so does the series field current which increases the field flux. This increase compensates for the drop in revolutions when the generator is under load and maintains the output through the increase in the field flux density.

46. There are three methods of connecting the series field,

a. **Under Compounded** - the series winding has only a few turns, it may not be able to maintain a constant e.m.f at full load.

b. **Level Compounded** - the series winding has sufficient windings to maintain a constant voltage at all load conditions.

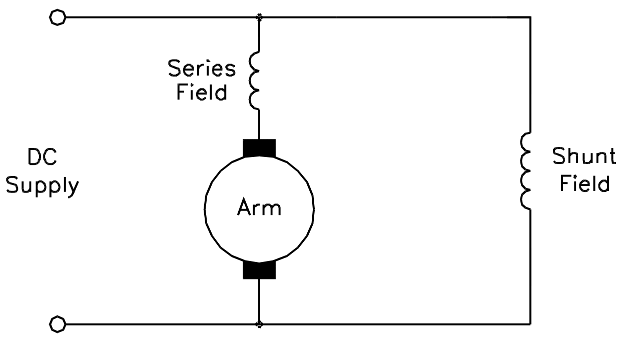
c. **Over Compounded** - the series winding has that many turns that a higher voltage is produced at full load.

47. **Differentially Compounded** - the term 'differentially compounded', is used to describe the field connection where the series field is connected to create a polarity which opposes that of the main field. As the load current increases, the voltage drops off in value.

48. The differentially compounded generator is limited in its use. One application being in a rotary arc welding generators. In this application the higher voltage is needed to strike an arc and a lower voltage is required to maintain the weld.

Compound Motors

49. The circuit diagram in Figure 60 shows that the windings in the compound motor are the same as those in the compound generator.



50. By using various proportions of the series and shunt fields, the compound motor can be made to display any of the torque/speed characteristics between those of a shunt and series motor.

51. The main advantage of this type of motor is, the motor can be made to operate in a similar manner to the series motor but with the shunt field preventing over speeding at 'no load'.

Long Shunt and Short Shunt

52. DC compound machines can be connected long shunt or short shunt as shown in Figure 61.

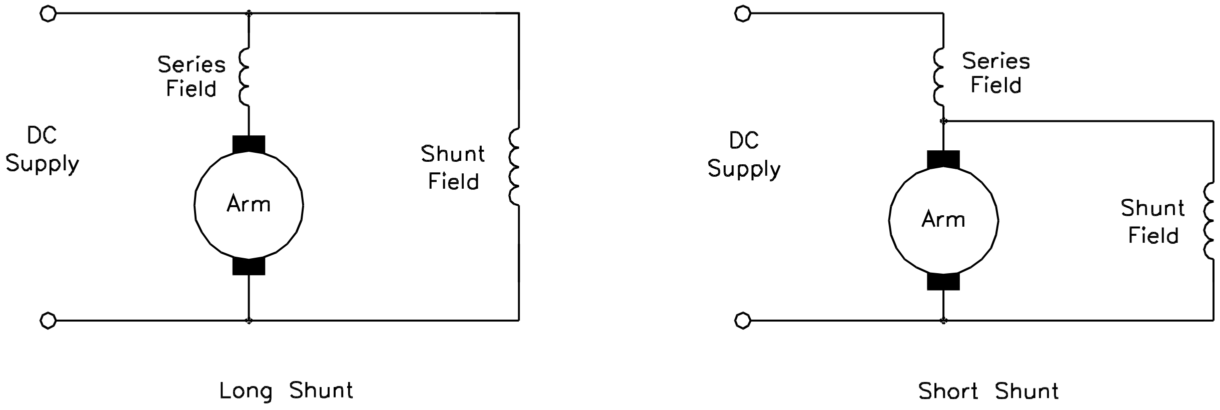


Figure 60

53. There is no operational difference between the two connections. However, the general rule is that if a machine is originally connected a specific way then the machine should be left connected that way.

54. To reverse direction the armature connections should be reversed.

55. Machines fitted with interpoles require that both the armature and the interpoles are reversed together otherwise bad commutation will occur.

56. Figure 62 shows a d.c compound machine with interpoles.

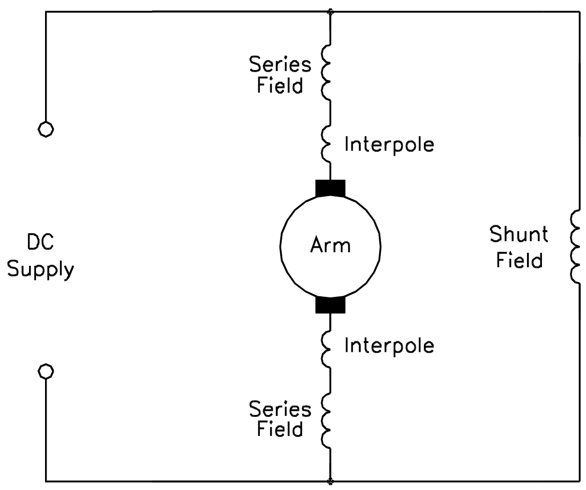


Figure 61

57. Simply reversing the supply connections will not change the direction of rotation as the armature to field current relationship remains the same.

Self-Excited Generator Characteristics

58. In a self-excited generator the voltage does not build up immediately. The voltage builds along a line governed by:

    A. the speed and,
    B. the resistance of the field winding.

59. Figure 63 shows the Voltage/Excitation graph of a self-excited generator.

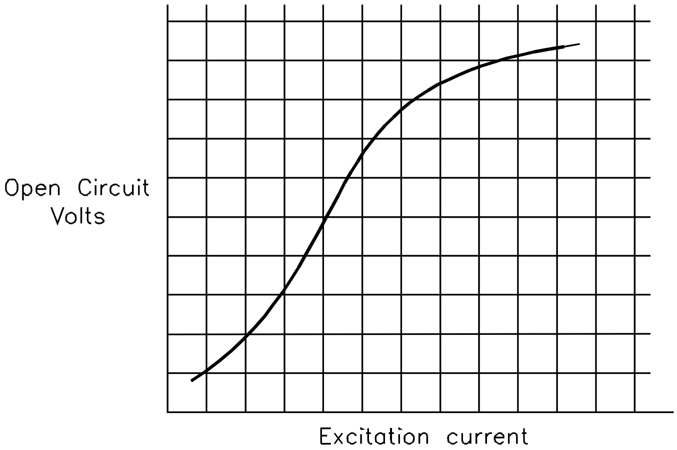


Figure 62

Effects of Speed on Voltage Output

60. As a load is applied to the output terminals, the increased current causes the speed of the prime mover to drop. As the speed is one of the factors governing the generated e.m.f, the voltage will also drop as shown in Figure 64.

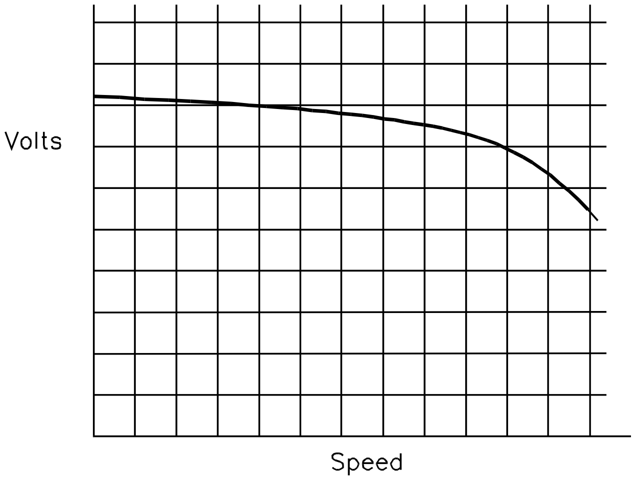


Figure 63

Effect of Load on Voltage Output

61. In Figure 64 it was shown that the load affected the voltage because of speed loss. The load is supplied by current from the generator therefore it can be expected that an increase in load current will cause a drop in voltage.

62. Figure 65 shows the curves for the separately excited and the shunt excited generators.

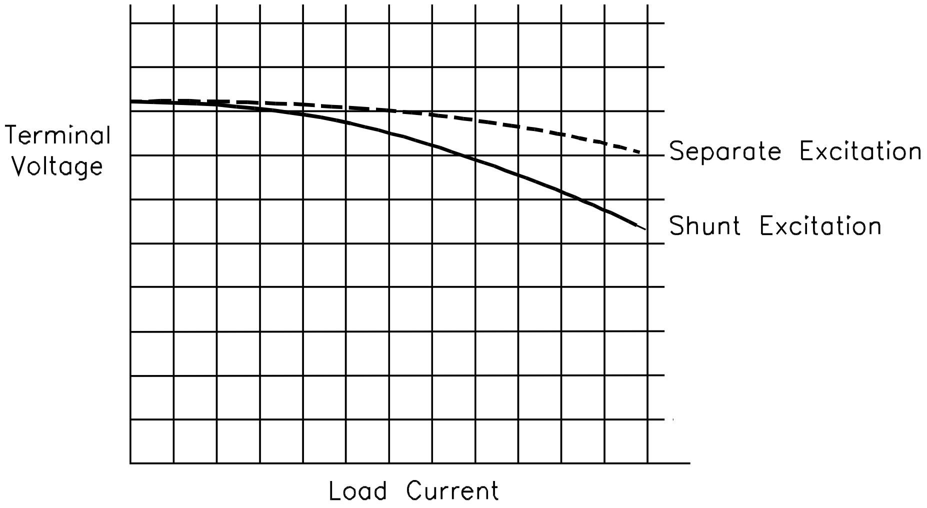


Figure 64

63. It can be seen that the separately excited output does not fall as much as the shunt excited generator. The shunt excited generator output falls because the excitation current decreases as the voltage drops due to loss of speed.

64. The separately excited field current is constant. The voltage drop occurs because of the fall in flux at the poles due to armature reaction.

Compound Generators

65. Figure 66 shows quite clearly the difference between the output curves of the three types of compounding.

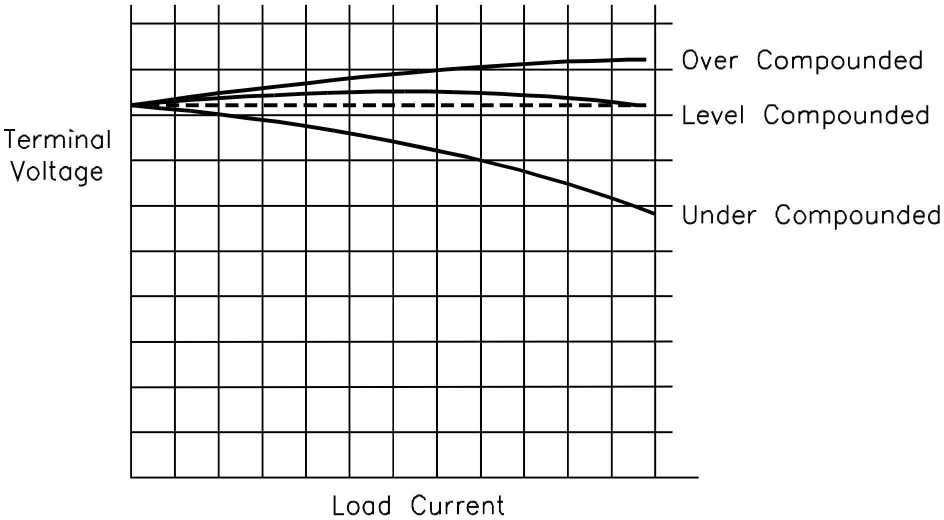


Figure 65

66. Most generators are constructed to be either level or slightly over compounded to maintain voltage levels over a range of voltage conditions.

67. The compound generator is widely used for most power supply applications, for example, traction generation.

Shunt Motor Characteristics

68. **Speed to Load Current** The shunt motor is generally regarded as a constant speed motor.

69. The effect of armature reaction on the flux of the field as the load current increases, enables the motor to maintain a slightly drooping characteristic as shown in Figure 67.

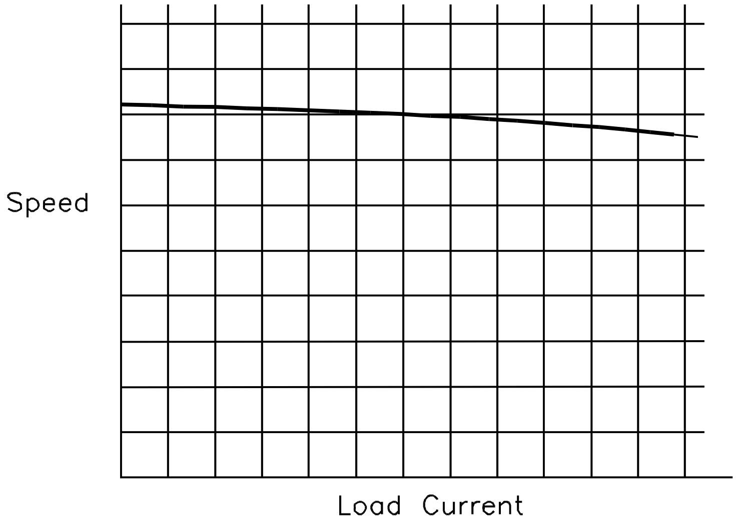


Figure 66

70. **Torque to Load Current** Figure 68 shows that as the load current is increased the torque increases.

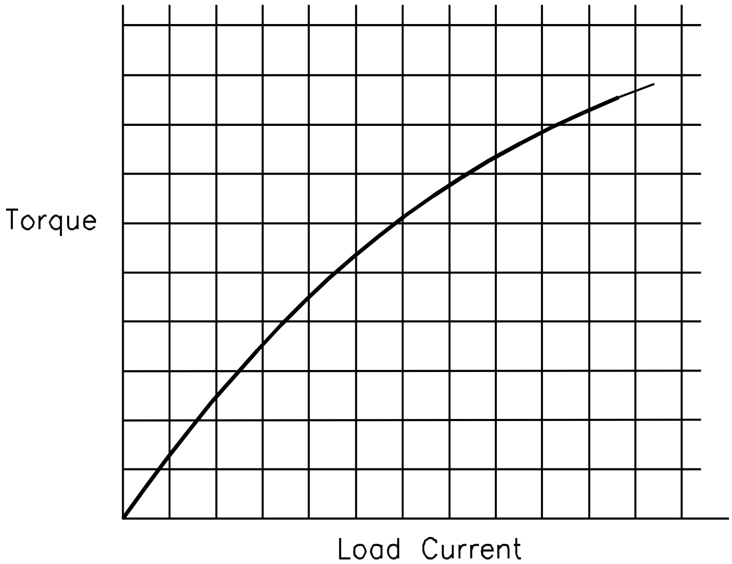


Figure 67

Series Motor Characteristics

71. The Speed Torque Curve as shown in Figure 69, shows that as the speed is reduced the torque increases. The increase in torque is due to the drop in speed reducing the back e.m.f thereby increasing the flux and hence the torque.

72. The Current Torque Curve as shown in Figure 69, shows that as the current increases in the motor the torque also increases. This characteristic of high torque at low speeds makes the series motor ideal for traction applications.

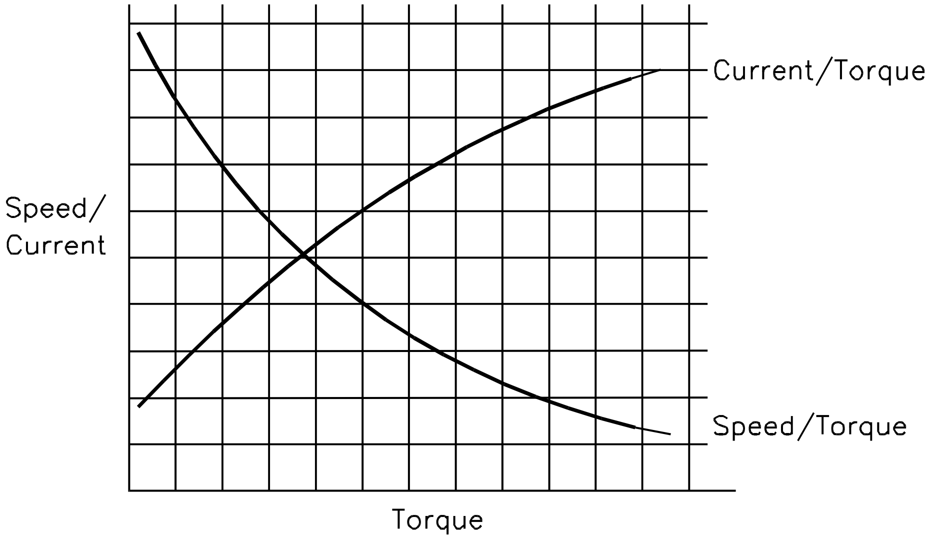


Figure 68

Compound Motor Characteristics (Figure 70)

73. Curve A represents a compound motor with a small series field displaying a characteristic similar to a shunt motor but with a slightly more drooping characteristic.

74. Curve B shows the effect of a large series field displaying the characteristic of a series motor with the added advantage of a shunt field which prevents over speed at no load.

75. Compound motors were widely used on presses and similar applications where intermittent loads were experienced.

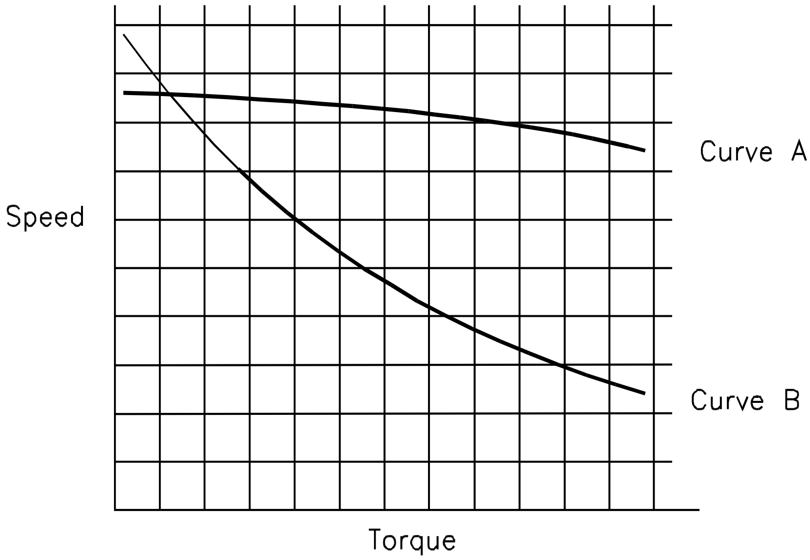
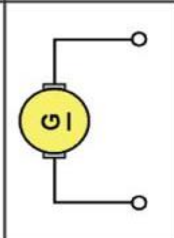
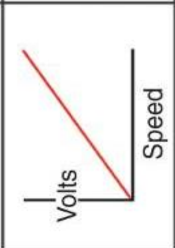
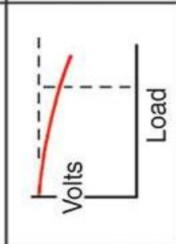
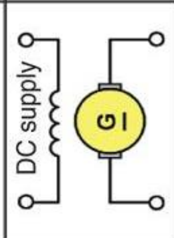
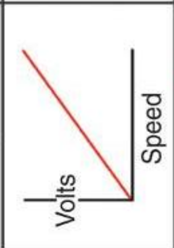
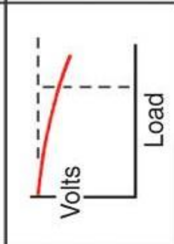
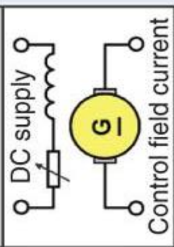
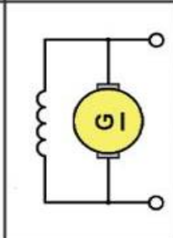
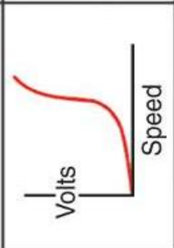
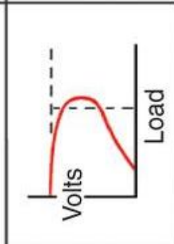
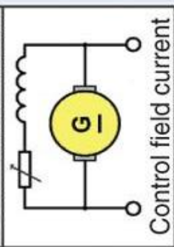
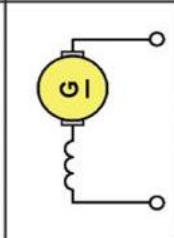
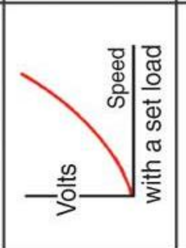
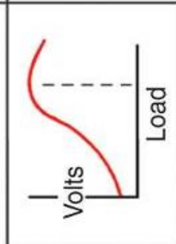
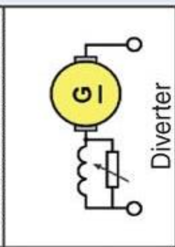
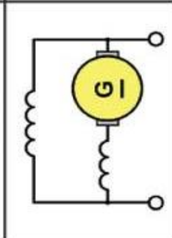
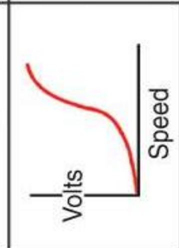
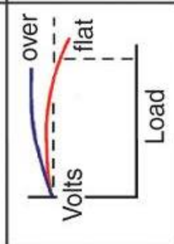
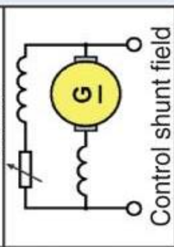
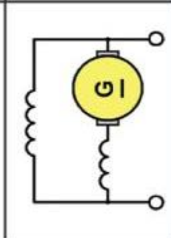
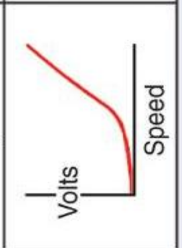
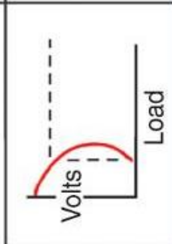
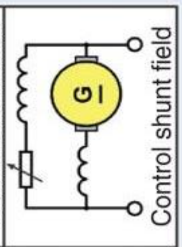


Figure 69

Summary

Type	*Field winding*	*Circuit diagram*	*Voltage / speed*	*Voltage / load*	*Characteristics*	*Voltage control*
Permanent magnet	—				1. Volts directly proportional to speed 2. Output drops slightly on load	Use magnetic shunts on field system
Separately excited	Many turns fine wire				1. Volts directly proportional to speed 2. Output drops slightly on load	
Shunt generator	Many turns fine wire				1. Volts is not linear with speed 2. Voltage drops more than permanent magnet on load	
Series generator	Few turns heavy wire				Rising voltage characteristics	
Cumulative compounding	Series assists shunt				Voltage characteristic can be made flat or increase with load, depending on compounding	
Differential compounding	Series demagnetises shunt				Voltage drops quickly on load	

Type	*Field winding*	*Circuit diagram*	*Speed/load*	*Torque/load*	*Characteristics*	*Speeds below normal*	*Speeds above normal*	*Methods for reversing*
Permanent magnet	—	M	Speed / Load	Torque / Load	Speed drops slightly on load Torque proportional to load	M	Weaken permanent magnet fields with magnetic shunts	Change supply polarity
Shunt	Many turns fine wire	M	Speed / Load	Torque / Load	Speed drops slightly on load Torque approx. proportional to load	M	M	M Change armature or field
Series	Few turns heavy wire	M	Speed / Load	Torque / Load	Speed decreases and torque increases with increase of load	M	M	M Change armature or field
Cumulative compound	Series assists shunt	M	Speed / Load	Torque / Load	1. Speed drops more than shunt 2. Torque increases more than shunt	M	M	M Change armature or both fields
d.c. motors with interpoles	Few turns heavy wire	M	—	—	Gives better commutation under all loads	—		Interpoles and armature must always be changed together M Change these two leads

Worksheet T7 Motors and Generators Questions

1. List three types of Prime Mover used to drive DC generators and explain the source of energy used in each. (T10.3)

2. Explain how energy flows from a prime mover (the source of energy) to the generator to produce electricity. (T10.3, 10.1)

Permanent Magnet, Separately Excited and Self Excited DC Machines

3. List the five types of DC machine. (T10.4, 11.4)

4. Explain what is meant by the term 'EXCITATION CURRENT'. (T10.5, 10.1)

5. Explain what is meant by the term 'Separately Excited' when applied to DC generators. (T10.5, 10.1)

6. Explain what is meant by the term 'Self Excited' when applied to DC generators. (T10.5, 10.1)

7. List three types of self-excited generators. (T10.5, 10.1)

8. List two applications where permanent magnet motors would be used. (T11.4)

9. How may the direction of rotation of a permanent magnet motor be reversed? (T11.10)

10. List two examples of how the DC source may be obtained for the excitation current in a separately excited generator. (T10.5, 10.1)

11. Give an application where a separately excited generator would be used. (T10.4)

12. Sketch the circuit diagram for a separately excited generator, label all component parts. (T10.4)

13. How may the direction of rotation of a separately excited motor be reversed? (T11.10)

14. What is the major disadvantage of a separately excited generator? (T10.4)

Shunt Machines

15. Draw the circuit diagram for a shunt excited DC generator, identify all component parts. (T10.4)

16. State how the output voltage of a DC generator may be controlled. (T10.5, 10.1)

17. Explain what is meant by the term residual magnetism. (T10.7)

18. If a DC generator fails to generate a voltage when rotated, what is the most likely cause of the problem? (T10.7, 10.1)

19. State two applications for shunt wound generators. (T10.4)

20. Draw the circuit diagram for a DC shunt motor, identify all component parts. (T11.5)

21. Explain the purpose of a field rheostat on a shunt motor. (T10.1)

22. What effect will it have on the speed of a shunt motor if the field connections were open circuited? (T11.11)

23. List two major disadvantages of having a speed control rheostat connected in series with the armature of a shunt motor. (T11.8)

24. Explain how you would reverse the direction of rotation of a shunt DC motor. (T10.10)

Series Machines

25. Explain why there is no real practical application for the DC series generator. (T10.4, 10.12)

26. Sketch the circuit diagram for a DC series generator, label all component parts. (T10.4)

27. Sketch the circuit diagram for a DC series motor, label all component parts. (T11.5)

28. Briefly explain why the armature of a DC series motor must be constructed using heavy gauge wire. (T11.8)

29. Briefly explain why a series motor should not be operated under 'no-load' conditions. (T11.11)

30. State how the direction of rotation of a DC series motor should be reversed. (T11.10)

Compound Machines

31. Briefly explain what is meant by the term cumulatively compounded. (T10.4, 11.4)

32. Briefly explain what is meant by the term differentially compounded. (T10.4, 11.4)

33. Sketch the circuit diagram for a DC compound generator, label all component parts. (T10.4)

34. Give an application where a differentially compounded generator would be used. (T10.4)

35. Explain the following DC generator terms: (T10.9)

    - Under Compounded
    - Level Compounded
    - Over Compounded

36. Sketch the circuit diagram for a DC compound motor, label all component parts. (T11.5)

37. State the main advantage of a compound DC motor when compared to a series motor. (T11.4, 11.8)

38. Sketch the circuit diagrams for both long and short shunt connected DC compound machines. (T10.4, 11.5)

39. Explain how you would reverse the direction of rotation of a compound DC motor. (T11.10)

40. Explain why reversing the supply polarity to a DC compound motor will not result in reversal of direction of rotation. (T11.10)

DC Machine Characteristics and Applications

41. State the two factors which govern the build-up of voltage in a self-excited DC generator. (T10.8, 10.1)

42. Explain what happen to current, speed and output voltage when load is applied to a DC generator. (T10.9)

43. Explain the difference in effect of load current on output voltage in a separately excited and shunt excited generator. (T10.9)

44. What causes the fall in output voltage in a shunt excited generator? (T10.9)

45. Explain the difference in output voltage for the following types of compounding as load is applied to a compound generator. (T10.9)

    - Under Compounded
    - Level Compounded
    - Over Compounded

46. State one application for a cumulatively compounded DC generator. (T10.4)

47. A shunt DC motor is generally regarded as a __________ _________ Motor. (T11.8)

48. What major factor enables a shunt DC motor to maintain a slightly drooping characteristic? (T11.8)

49. Explain what happens to torque and speed as load current increases in a series DC motor. (T11.8)

50. State one application for a series DC motor. (T11.4)

51. State one application for a cumulatively compounded DC motor. (T11.4)

52. What characteristic does a compound motor having a small series winding display? (T11.8)

53. What characteristic does a compound motor having a large series winding display? (T11.8)

Motors and Generators Practical 1

Task:

To connect both a shunt motor and a compound motor with to a d.c supply. Both motors must be made to correctly operate in both directions.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:

Shunt motor
Compound motor with interpoles.
Suitable load.

Method:

Part a - Shunt Motor

1. Draw a circuit diagram for a shunt connected motor. Label all component parts and identify all connections. Have the diagram checked by your Lecturer.

CIRCUIT DIAGRAM

2. Connect the motor according to your diagram. DO NOT TURN ON THE SUPPLY.

3. Have your wiring checked by your Lecturer.

4. Connect the motor to the 220 volt d.c supply. Check the direction of rotation of the motor, then switch off and disconnect from the supply, attach your DANGER TAG.

5. Reconnect the motor to give reverse direction of rotation. Have your wiring checked by your Lecturer.

6 Connect the motor to the 220 volt d.c supply. Confirm that the motor is running in the reverse direction of rotation.

7. Switch off, disconnect the supply, and attach your DANGER TAG.

Part B - Compound Motor

1. Draw a circuit diagram for a compound d.c motor. Label all component parts and identify all connections. Have your diagram checked by your Lecturer.

CIRCUIT DIAGRAM

2. Connect the motor according to your diagram.

3. Have your wiring checked by your Lecturer.

4. Connect the motor to the 220 volt d.c supply and apply load to the motor up to its rated value.

5. Note the direction of rotation and commutation of the motor.

6. Switch off, disconnect the supply, and attach your DANGER TAG.

7. Reconnect the motor for reverse direction of rotation. Have your wiring checked by your Lecturer.

8. Connect the motor to the 220 volt d.c supply. Check for reversed direction of rotation, apply load and check commutation. If arcing is occurring, switch off, disconnect the supply and attach your DANGER TAG.

9. Check the connections of the interpoles for correct polarity.

10. Have your wiring checked by your Lecturer.

11. Reconnect to 220 volt d.c supply, recheck direction of rotation and commutation.

12. Switch off, disconnect the supply and attach your DANGER TAG.

Feedback and Recommendations:

Student's Signature: ______________________________ **Date:** ____________

Assessor's Signature: ______________________________ **Date:** ____________

Motors and Generators Practical 2

Task:

To test a shunt connected d.c generator and determine its load/voltage characteristics.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:

Shunt Generator test bench complete with load bank.
DC Voltmeter to suit generator and load.
DC Ammeter to suit generator and load.
Graph paper — 5 mm squares

Method:

1. Draw a circuit diagram for a shunt generator connected to a load.
   Label:
   a. The field connections F1 and F2.
   b. The armature connections - Al and A2.
   c. Voltage control rheostat - RI and R2.
   d. Output terminals - L+ and L-.
   Include meters suitable for measuring line voltage and line current.

CIRCUIT DIAGRAM

2. Have your circuit diagram checked by your Lecturer.

3. Connect the generator to the load according to your diagram. Have your wiring checked by your Lecturer.

4. Set the field control rheostat to its maximum resistance and start the prime mover.

5. Use the field control rheostat to adjust the output voltage to the rating of the generator.

6. Apply the load in steps by switching in one section of the load bank at a time. Record the voltage and current readings for each step in Table 1.

Table 1.

Step	Voltage	Current
0		
1		
2		
3		
4		
5		
6		

7. Switch the load off and stop the prime mover.

8. Short circuit the load terminals with a jumper lead.

9. Start the prime mover again and record the voltage and current readings in the table below.

10. Stop the prime mover and remove the bridge across the load terminals. Open circuit the FIELD circuit. Start the prime mover again.

11. Record the voltage and current readings, (if any) in Table 2.

Table 2

	Voltage	Current
Load short circuited		
Field open circuited		

7. Have your results checked by your Lecturer.

8. Switch the test bench circuit breaker off, attach your DANGER TAG.

9. Disconnect your circuit wiring and return all of the equipment to its correct place.

10. Use your readings from Step 7 and plot a graph of the generator load/voltage characteristic.

    Plot voltage on the Y (vertical) axis.

    Plot load current on the X axis.

Questions:

1. What percentage of the no load voltage was obtained on full load?

2. What caused the voltage reading to occur when the field system was open circuited?

Feedback and Recommendations:

Student's Signature: ______________________________ **Date:** ____________

Assessor's Signature: ______________________________ **Date:** ____________

Motors and Generators Practical 3

Task:

To connect a d.c generator for differential and cumulative compounding and plot the characteristic curve for each connection.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:

Compound wound d.c generator (approximately 2 kW).
Load bank.
Voltmeter to suit generator rating. Ammeter to suit generator rating.

Method:

1. Draw a diagram of the terminal markings on the compound d.c generator.

TERMINAL MARKINGS

2. Draw a circuit diagram showing how the generator should be connected to give cumulative compounding. Long or short shunt connection may be used. Include the load and the voltage control rheostat on your diagram.

CIRCUIT DIAGRAM

3. Connect the generator according to your diagram, check your connections.

4. Have your wiring checked by your Lecturer.

5. Start the prime mover and run up to full speed. Set the no load generator voltage to the rated value of the generator, as shown on the generator nameplate.

6. Switch in the load bank one step at a time until maximum permissible current is reached, as shown on the generator nameplate. Record the speed, voltage and current for each step of the load bank, enter the results in Table 1.

7. Stop the prime mover and have your results checked by your Lecturer.

8. Calculate the generator output power using the readings in Table 1 .

9. Repeat steps 1 to 8 with the generator connected differentially compounded. Record your results in Table 2.

10. Have all your results checked by your Lecturer.

11. Switch the test bench circuit breaker off, attach your DANGER TAG.

12. Disconnect your wiring and return all of the equipment to its proper place.

13. Draw a graph of the results obtained in the voltage and current columns of Tables 1 and 2. Plot both curves on the same graph using different colours. Plot the voltage on the vertical axis (Y) and the current on the horizontal axis (X).

Table 1 - Cumulatively Compounded

Load Step No	Speed	Voltage	Current	Power (Calculate)
No Load				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Table 2 - Differentially Compounded

Load Step No	Speed	Voltage	Current	Power (Calculate)
No load				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Questions:

1. State an application for each type of generator considered in this project.

2. Could the generator used for this project be described as over, level or under compounded when it was connected cumulatively?

Feedback and Recommendations:

Student's Signature: ______________________________ **Date:** __________

Assessor's Signature: ______________________________ **Date:** __________

Motors and Generators Advanced

Equivalent Circuit for Generators

1. A simple generator circuit diagram is shown below in Figure 71.

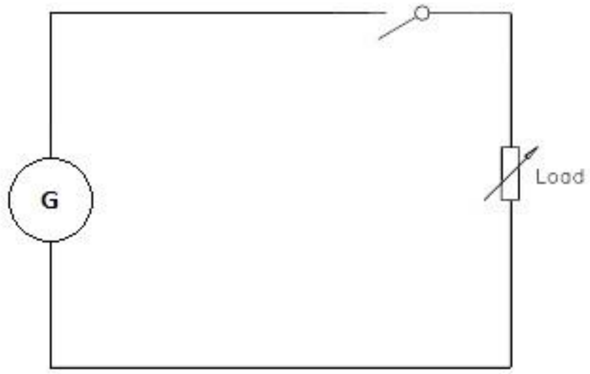


Figure 70

2. This generator can be modelled as an ideal power source in series with a resistor. As shown below in Figure 72. It can be helpful to keep this model in mind when testing and fault-finding.

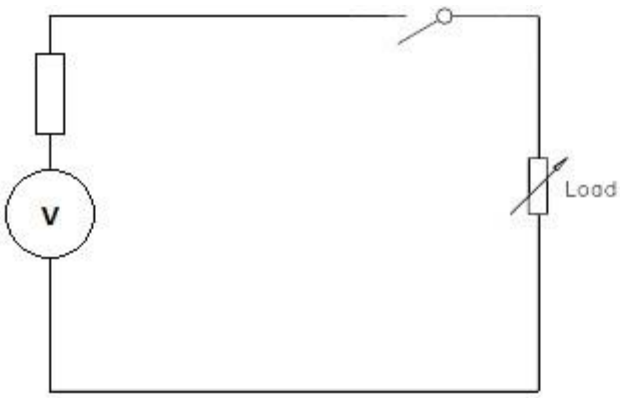


Figure 71

Safety Risks Associated with d.c. Machines

3. There are many dangers with working with d.c. machines that must be considered when working nearby or on them.

   a. D.c machinery and parts of are designed to move and the machine may be remote started causing persons to be struck.

   b. D.C. machines produce high voltages and may have residual energy in the machine even when it's turned off.

   c. D.C. machines are heavy and often awkward shapes resulting in manual handling techniques to be applied.

   d. If the generator is a hydrocarbon power source the burning of the petrol or diesel will create hazardous fumes.

   e. Series d.c. motors are known to spin destruction if unloaded. This can also occur if a parallel or compound motor has its field windings open circuited.

Equivalent Circuit for Motors

4. A simple motor circuit diagram is shown in Figure 73.

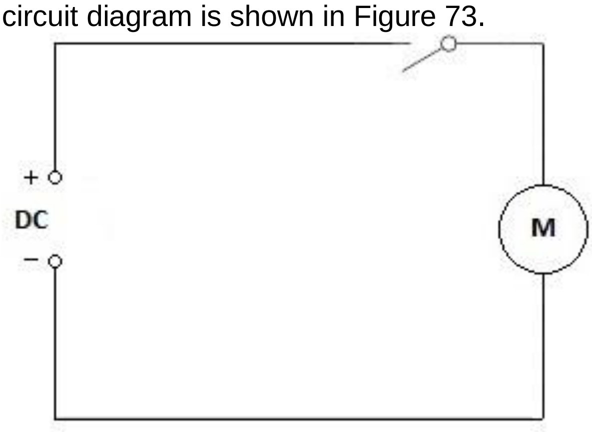


Figure 72

5. This motor can be modelled as a resistor in series with an inductor and an ideal power source. As shown below in Figure 74. The resistor acting as the internal resistance of the motor, the inductor acting as the induction due to the windings and the power source as the back e.m.f. It can be helpful to keep this model in mind when testing and fault-finding.

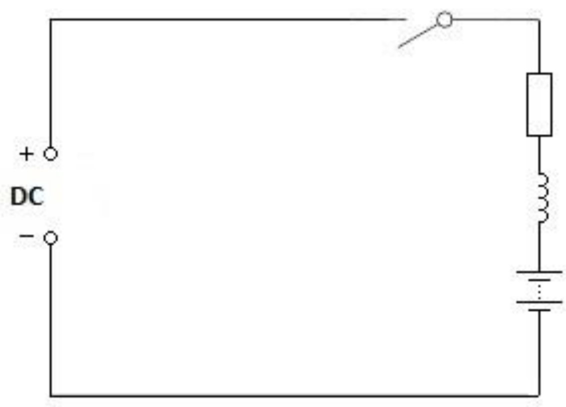


Figure 73

Efficiency of D.C. Machines

6. As mentioned previously motors and generators differ on the flow and conversion of energy. Generator convert mechanical energy to electrical while motors convert electrical energy to mechanical. As this occurs some of the energy is lost to heat and sound.

7. The losses that occur in a machine include but are not limited to:

1) Friction – where energy is required to move an object past another
2) Wind age – where energy is required to overcome wind resistance
3) Iron losses - where energy is lost to producing eddy currents
4) Field losses - where energy is lost due to the hysteresis effect
5) I^2R (copper) losses - where energy is lost due to electrical resistance

8. The nature and extent of the losses in a D.C. machine can be determined by either the use of measuring implements like dynameters, wattmeters, and thermal cameras or

the indirect calculation of efficiency using the Swinburne method. Using the information measured directly the efficiency of the machine can be calculated using the flowing formula:

$$\eta\ \% = \frac{output\ power}{input\ power} \times 100\ \%$$

Where: $\eta\ \%$ = efficiency as a percent
Output power = the power the machine produces
Input power = the power put into a machine

9. **Example** A generator is connected to a 10kW disel motor acting as the prime mover. The generator produces 9.3kW. What is the efficiency of the generator?

Solution

$$\eta\ \% = \frac{output\ power}{input\ power} \times 100\ \%$$

$$\eta\ \% = \frac{9\ 300}{10\ 000} \times 100\ \%$$

$$\eta\ \% = 93\ \%$$

Swinburne Method for Calculating the Efficiency and Losses of d.c. Machines

10. The Swinburne method involves measuring the resistance of the windings of a machine, measuring the supply voltage, the supply current and the current in the shunt winding. A series machine is not able to be used in this method as it is a no load test. The test is arranged like shown in the diagram below.

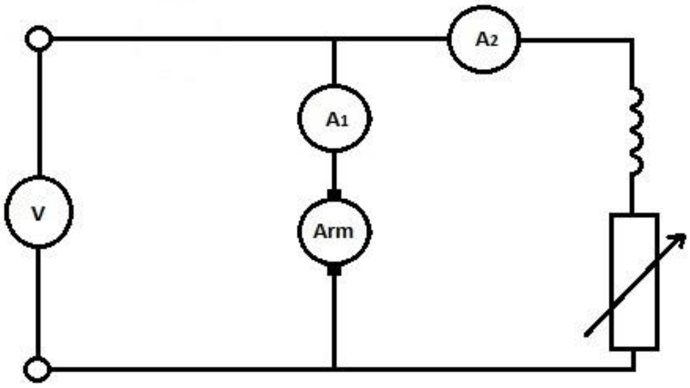


Figure 74

11. Methodology of the Swinburne method:
   1) measure and record the resistance of the armature (R_a)
   2) connect up the machine as in Figure 75
   3) set the voltage supply to the machines rated voltage (V_T)
   4) adjust the speed of the machine using the rheostat to be the same as the machines rated speed
   5) record the armature current measured by Ammeter 1 ($I_{A,\ measured}$)
   6) record the shunt current measured by Ammeter 2 (I_{sh})

12. From these measurements and the following formula the losses of the machine can be calculated.

Motor

Power Input

$P = V_T I_T = V_T(I_{a,\text{measured}} + I_{sh})\ Watts$

Copper losses

$Cu\ Field\ losses\ (W_F) = V_T \times I_{sh}$

$Cu\ Armature\ losses = I^2_{a,\text{measured}} \times R_a = (I_T - I_{sh})^2 \times R_a$

Stray losses – losses due to iron, friction and windage

$Stray\ losses = Input\ to\ machine - Cu\ losses$

$W_a = V_T I_T - I^2_{a,\text{measured}} \times R_a - V_T \times I_{sh}$

Constant losses – losses due to iron, friction, windage, and field copper losses

$Constant\ losses = No\ load\ input - No\ load\ Armature\ Cu\ loss$

$W = V_T I_T - I^2_{a,\text{measured}} \times R_a$

Full load Armature Cu losses

$Cu\ Armature\ losses = I^2_{a,line} \times R_a$ Where $I_{a,line} = I_{rated} - I_{sh}$

Total losses

$Total\ losses = Full\ load\ Armature\ Cu\ loss + Constant\ losses$

Full Load Power Output

$P = V_T I_{rated} - total\ losses$

Generator

Power Output

$P = V_T I_T = V_T(I_{a,\text{measured}} + I_{sh})\ Watts$

Copper losses

$Cu\ Field\ losses\ (W_F) = V_T \times I_{sh}$

$Cu\ Armature\ losses = I^2_{a,\text{measured}} \times R_a = (I_T + I_{sh})^2 \times R_a$

Constant losses – losses due to iron, friction, windage, and field copper losses

$Constant\ losses = No\ load\ input - No\ load\ Armature\ Cu\ loss$

$W = V_T I_T - I^2_{a,\text{measured}} \times R_a$

Full load Armature Cu losses

$Cu\ Armature\ losses = I^2_{a,line} \times R_a$ Where $I_{a,line} = I_{rated} - I_{sh}$

Total losses

$Total\ losses = Full\ load\ Armature\ Cu\ loss + Constant\ losses$

13. **Example** A 440 V d.c. shunt motor takes a no load current of 2.5 A. The resistance of the shunt field and the armature are 550 Ω and 1.2 Ω respectively. The full line current is 32 A. Find the total losses of the motor.

Solution

No load current $I_T = 2.5\ A$

No load input $= V_T I_T = 440 \times 2.5 = 1\ 100\ W$

Shunt current $I_{sh} = \frac{V}{R_{sh}} = \frac{440}{550} = 0.8\ A$

Armature current = $Total\ current - Shunt\ current$

$$I_{a,\text{measured}} = I_T - I_{sh} = 2.5 - 0.8 = 1.7\ A$$

No load armature copper loss = $I^2_{a,\text{measured}} \times R_a = 1.7^2 \times 1.2 = 3.468\ W$

Constant losses = No load input – No load armature Copper loss

$$= 1100 - 3.468 = 1\ 096.532\ W$$

Now, full load line current $I_{rated} = 32\ A$

Full load armature current $I_{a,line} = I_{rated} - I_{sh} = 32 - 0.8 = 31.2\ A$

Full load armature copper loss $= I^2_{a,line} \times R_a = 31.2^2 \times 1.2$

$$= 1\ 168.128\ W$$

Total losses = Full load armature copper loss + Constant losses

$$= 1\ 168.128 + 1\ 096.532 = 2\ 264.66\ W$$

14. The efficiency of the machine can also be calculated using the information obtained in the Swinburne method.

15. **Example** Find the full load output and efficiency of the motor in paragraph 13.

Solution

Full load motor input = $V_T I_T = 440 \times 32 = 14\ 080\ W$

Full load motor output = $Input - Losses$

$$= 14080 - 2264.66 = 11\ 815.34\ W$$

% Efficiency at full load = $\frac{Full\ load\ Output}{Full\ load\ Input} \times 100$

$$= \frac{11\ 815.34}{14\ 080} \times 100 = 83.91\ \%$$

Torque produced by d.c. Machines

16. A force that acts on an object to rotate is called Torque and it is found in motors as both the mechanical force produced by the motor and also the force acting on conductors to rotate as part of the rotor. It is measured in Newton meters (Nm) where one Newton metre (Nm) is the torque developed by a shaft when a force of 1 Newton is applied at a radius of 1 metre. This force is proportional to the distance from the point that the force acts on, to the centre about which the point will rotate. In the case of the conductors in the motor the radius of the armature/rotor is one of the factors that will determine the amount of torque produced.

17. The mechanical power output of a machine can be measured using a Newton meter or a force gauge / scale with a pivot arm (see Figure 76). The force gauge will specify the amount of force and the pivot will provide the radius, using these two pieces of information and the following formula the torque of a motor can be determined.

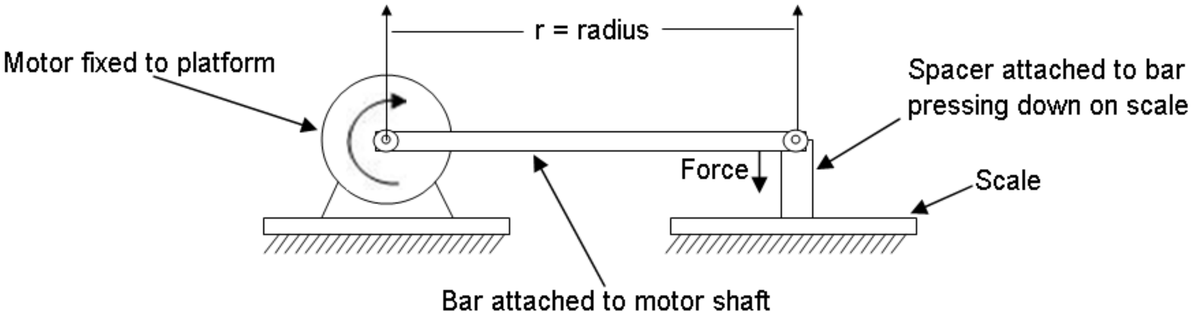


Figure 75

$\tau = F \times r$

Where: τ = torque (Nm)
F = force (N)
r = radius (m)

18. **Example** A motor is attached to a 600mm pivot arm pressing down on a scale measuring 20kg. What is the torque produced by the motor?

Solution

$Force \ = mass \times acceleration$

$F \ = 20 \times 9.81 \ (due\ to\ gravity - \ 9.81 m/s^2)$

$F = \ 196.2\ N$

$\tau = F \times r$

$= 196.2 \times 0.6$

$= 117.72\ Nm$

Calculation of Force & Torque Using Electrical Properties of d.c. Machines

19. The force experienced by the armature to rotate is the force on a conductor times the number of conductors in the armature divided by the number of parallel paths.

$$F \ = \frac{B \times I \times l \times Z}{a}$$

Where: F = the force exerted on the conductor in newtons.
B = the flux density in teslas.
I = the current in the conductor in amps.
ℓ = the length of the conductor in metres.
Z = number of armature conductors.
a = number of parallel paths in the armature

20. The torque experienced by the motor is given as:

$$\tau = \frac{P \times \Phi \times Z \times I}{2\pi \times a}$$

Where: τ = torque
P = number of poles
Ø = magnetic flux per pole in Webers
Z = number of effective conductors
I = current in armature
a = number of parallel current paths in the armature

21. **Example** A four-pole DC motor has a lap-wound armature of 30 coils, each with 20 conductors. If the flux per pole is 0.02 Wb and the armature current is 19 A, calculate the torque produced.

Solution

$$\tau = \frac{P \times \Phi \times Z \times I}{2\pi \times a}$$

$$\tau = \frac{4 \times 0.02 \times 30 \times 20 \times 19}{2\pi \times 4}$$

$$\tau = 36.3\ Nm$$

Efficiency Characteristics of D.C. Machines

22. Due to the nature of d.c. machines the efficiency of the machine follow the following graph Figure 77. The efficiency of the machine rises with load until it reaches maximum and begins to decline.

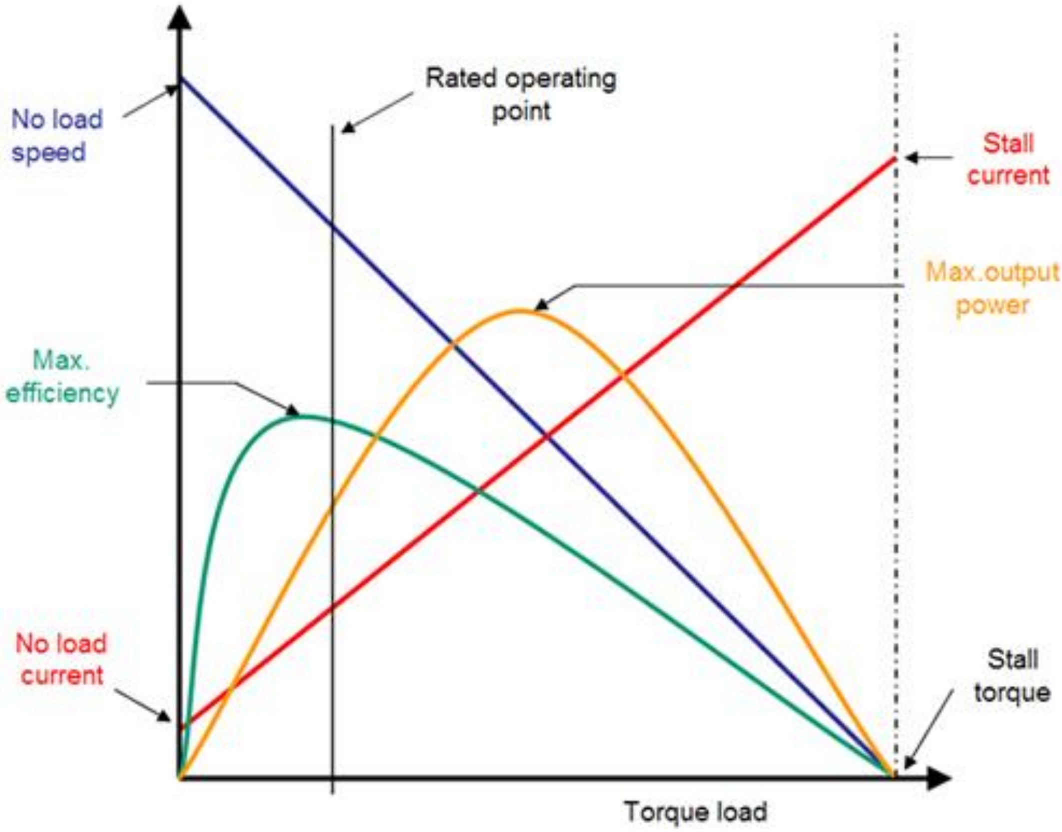


Figure 76

Methods Used To Maintain High Efficiency

23. Beyond motor losses, there are other factors that can impact electric motor efficiency. They include:

a. Proper sizing

b. Electrical power quality

c. Type of control

d. Distribution Losses

e. Type of transmission

f. Maintenance

g. Operating Temperature

h. Application (Mechanical efficiency of driven equipment)

Minimum Standards of Efficiency

23. Minimum Energy Performance standards (MEPS) are part of the Australian reduction in greenhouse gases commitment and are a regulatory tool used to ensure that Australians have more efficient appliances and equipment. Certain products containing magnetic and electromagnetic devices and machines must comply with specific standards for energy efficiency. MEPS programs have been made mandatory in Australia by state government legislation and regulations which give force to the relevant Australian standards.

24. Since 2001, 3 phase induction motors rating from 0.73kW to 185kW manufactured in or imported into Australia must comply with Minimum Energy Performance Standards (MEPS) requirements that are set out in Australia and New Zealand Standard AS/NZS 1359.5:2004

Worksheet T8 Motors and Generators Advanced Questions

1. Sketch the equivalent circuit for a DC generator and a DC motor. Label all parts. (T10.6, 11.6)

2. List five safety risks associated with DC machines. (T10.12, 11.11)

3. State the difference between a motor and a generator in terms of energy conversion. (T9.2)

4. List five losses that occur in a DC machine. (T12.1)

5. What methods can be used to determine the losses in a DC machine? (T12.2)

6. A generator is connected to a 10kW diesel motor acting as the prime mover. The generator produces 9kW. What is the efficiency of the generator? What percentage loss occurs in the generator? (T12.3)

7. A generator is connected to a 15kW diesel motor acting as the prime mover. The generator produces 13.65kW. What is the efficiency of the generator? What percentage loss occurs in the generator? (T12.3)

8. What is involved in using the Swinburne Method for Calculating the Efficiency and Losses of DC Machines? (T12.3)

9. A 400 V DC shunt motor takes a no load current of 2.5 A. The resistance of the shunt field and the armature are 500 Ω and 1.2 Ω respectively. The full line current is 35 A. Find the total losses of the motor. Find the full load output and efficiency of the motor. (T12.3)

10. Define the term Torque when applied to DC machines and give the unit of measurement. (T8.5, 11.3)

11. Define the term "One Newton Metre". (T8.5, 11.3)

12. A motor is attached to a 650mm pivot arm pressing down on a scale measuring 25kg. What is the torque produced by the motor? (T8.5, 11.3)

13. A motor is attached to a 500mm pivot arm pressing down on a scale measuring 30kg. What is the torque produced by the motor? (T8.5, 11.3)

14. Torque is the product of which two values? (T8.5, 11.3)

15. A four-pole DC motor has a lap-wound armature of 30 coils, each with 25 conductors. If the flux per pole is 0.03 Wb and the armature current is 20 A, calculate the torque produced. (T8.5)

16. A two-pole DC motor has a lap-wound armature of 30 coils, each with 30 conductors. If the flux per pole is 0.04 Wb and the armature current is 25 A, calculate the torque produced. (T8.5)

17. What impact does load have on efficiency of a DC Machine? (T12.4)

18. When is efficiency of a DC machine at its lowest? (T12.4)

19. When is efficiency of a DC machine at its highest? (T12.4)

20. List two methods used to maintain high motor efficiency. (T12.6)

21. What is the purpose of Minimum Energy Performance Standards (MEPS)? (T12.5)

22. Which products must comply with Minimum Energy Performance Standards (MEPS)? (T12.5)

Motors and Generators Advanced Practical 1

Task:

To graph the load/torque and load/speed characteristics for shunt and compound wound motors and to determine the efficiency of a d.c motor.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:

Wattmeter
0-20 amp d.c ammeter
DC motor test bench
Graph paper — 5 mm squares

Method:

Part a - Shunt Wound Motor

1. Record the motor nameplate details in the Table 1.

Table 1 - Nameplate Details

Speed	
Rating	
Type	
Voltage	
Power	
Current	

2. Connect the motor windings to give a shunt wound motor. Clearly label all connections on the attached circuit diagram.

3. Connect the motor via the ammeter, voltmeter and wattmeter. DO NOT TURN ON THE SUPPLY.

4. Have your wiring checked by your Lecturer.

5. Set the eddy brake unit to its minimum load position.

6. Apply 220 volts d.c to the motor.

7. Adjust the field rheostat to give the rated nameplate speed.

8. Record the readings as per Table 2 at six regular load steps.

Table 2 - Results

Load Step	Torque (N.m)	Current (A)	Power (W)	Speed (RPM)	Voltage
No load					
Load 1					
Load 2					
Load 3					
Load 4					
Load 5					
Full Load					

9. Return the motor to a no load condition and switch off the motor supply.

10. Switch off the test bench circuit breaker, ATTACH YOUR DANGER TAG.

11. Graph your results. Plot the load current along the horizontal axis (X) and the speed/torque along the vertical axis (Y).

Part B - Compound wound Motor

1. Connect the motor windings to give a cumulatively compound wound motor. Clearly label all connections on the attached circuit diagram.

2. Connect the motor via the ammeter, voltmeter and wattmeter. DO NOT TURN ON THE SUPPLY.

3. Have your wiring checked by your Lecturer.

4. Set the eddy brake unit to its minimum load position.

5. Apply 220 volts d.c to the motor.

6. Record the readings as per Table 3 at six regular load steps.

Table 3 - Results

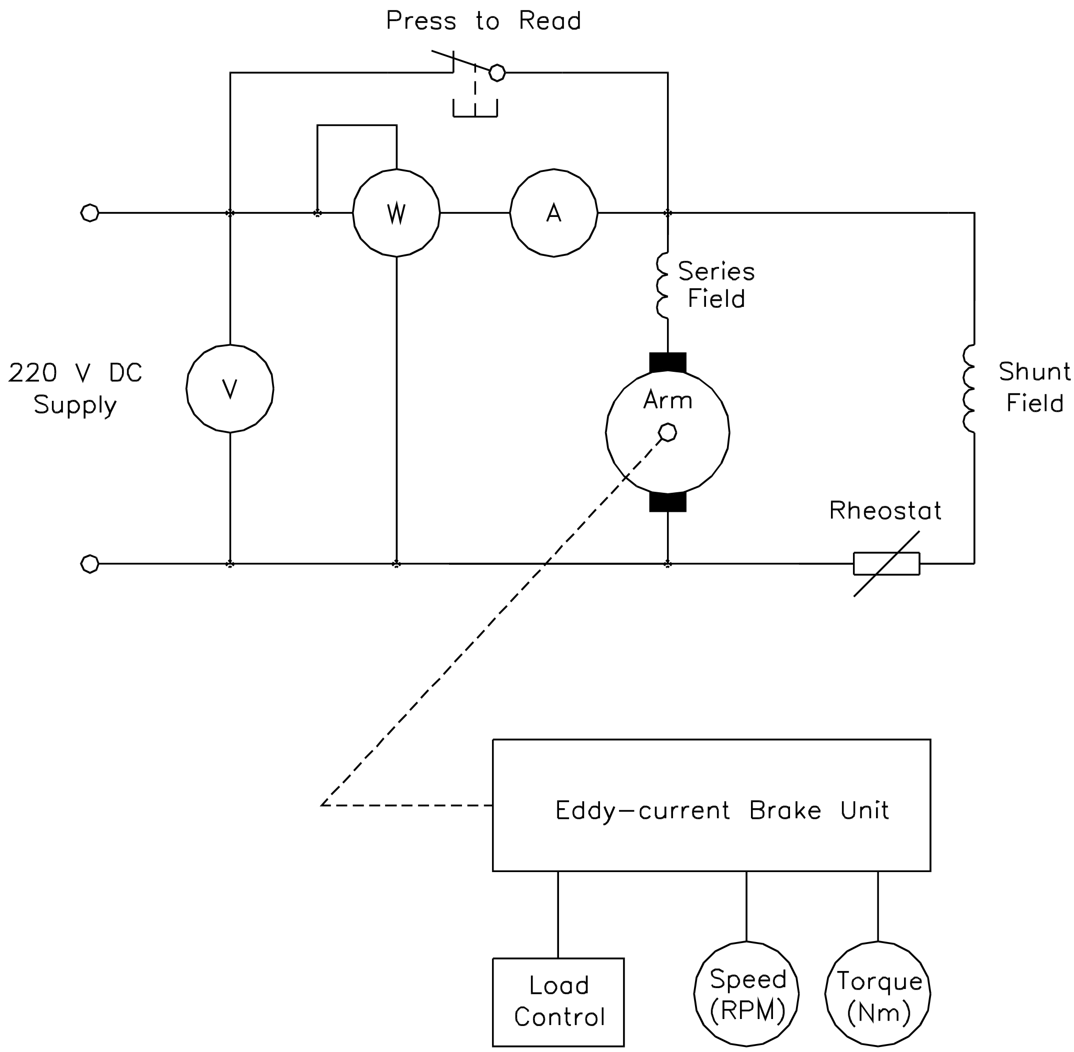
Load Step	Torque (N.m)	Current (A)	Power (W)	Speed (RPM)	Voltage
No load					
Load 1					
Load 2					
Load 3					
Load 4					
Load 5					
Full Load					

7. Return the motor to a no load condition and switch off the motor supply.

8. Switch off the test bench circuit breaker, ATTACH YOUR DANGER TAG.

9. Graph your results on the same graph paper as for Part A of this project. Use different colours for the different characteristics and clearly label each one.

DC Motor and Load Diagram



Questions:

1. From your results calculate the efficiency of the d.c motor.

2. Explain the difference in characteristics between the shunt and compound wound motor.

Feedback and Recommendations:

Student's Signature: ______________________________ **Date:** __________

Assessor's Signature: ______________________________ **Date:** __________

Motors and Generators Advanced Practical 2

Task:

To determine the efficiency of a d.c motor using the Swinburne method.

SAFE WORK PRACTISES MUST BE FOLLOWED

PPE MUST BE WORN

Equipment:

Multimeter
Voltmeter
2x d.c ammeter
DC motor test bench

Method:

1. Draw a circuit diagram for a shunt motor not connected to a load.
   Label:
   - b. The field connections F1 and F2.
   - c. The armature connections - Al and A2.
   - d. Voltage control rheostat - RI and R2.
   - e. Output terminals - L+ and L-.

   Include meters suitable for measuring as per the Swinburne method.

CIRCUIT DIAGRAM

3. Have your circuit diagram checked by your Lecturer.
4. Measure and record the resistance of the armature.
5. Connect up the motor and have your wiring checked by your lecturer.
6. Apply the rated supply voltage
7. Adjust the field rheostat to give the rated nameplate speed.
8. Record your results in Table 1.

Table 1 - Results

Rated Speed	
Rated Voltage	
Rated Current	
Armature Resistance	
Armature Current	
Shunt Current	

9. Switch off the motor supply.

10. Switch off the test bench circuit breaker, ATTACH YOUR DANGER TAG.

Questions:

1. From your results calculate the following for the d.c motor.

    a. Power Input

    b. Copper losses

    c. Stray losses

    d. Constant losses

e. **Full load** Armature - Cu losses

f. Total losses

g. Full Load Power Output

2. Calculate the full load output and efficiency of the motor.

Feedback and Recommendations:

Student's Signature: ____ **Date:** _____________

Assessor's Signature: ____ **Date:** _____________

