INDUSTERIAL ELECTRICAL MACHINES AND DRIVES SERVICING

Level II

LEARNING GUIDE #30

Unit of competence:-Industrial Electrical Machines and Drives Servicing Level II

Module Title: Maintaining and repairing industrial electrical machines and drives

LG Code: EEL EMD2 M08LO1 –LG 30

TTLM Code: EEL EMD2 TTLM081019V1

LO1: Plan, prepare and coordinate maintenance works

Instruction Sheet :1	Learning Guide 30

This learning guide is developed to provide you the necessary information regarding the following learning outcome and content coverage

- Secure Safety permit/Hot work permit
  - Identify potential hazards
  - Electromagnetic principles
  - Preparing Maintenance work schedule
  - Identify and request/obtain Materials, tools, equipment, testing devices and PPE
  - Preparing Work instructions according to machine's manual
  - Informing the schedule of work for concerned department/personnel

This guide will also assist you to attain the learning outcome and contents stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Secure Safety permit/Hot work permit
  - Identify potential hazards
  - Apply Electromagnetic principles
  - Prepare Maintenance work schedule
  - Identify and request/obtain Materials, tools, equipment, testing devices
  - Prepare Work instructions according to machine's manual
  - Inform the schedule of work for concerned department/personnel

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below 3 to 6.
3. Read the information written in the "Information Sheet 1, Sheet 2, Sheet 3, Sheet 4, Sheet 5, Sheet 6 and Sheet 7" in page 3, 5,9,14,18,79 and 82 respectively".
4. Accomplish the "Self-check 1, Self-check 2, Self-check 3 , Self-check 4 , Self-check 5 , Self-check 6 and Self-check 7" in page 4, 8,13,17,76,81and 83 respectively".
5. If you earned a satisfactory evaluation from the "Self-check" proceed to "Operation Sheet 1 and Operation Sheet 2" in page 84and 85 respectively.
6. Do the "LAP test" in page 86

Information Sheet :1	Secure Safety permit/Hot work permit

1.1. Introduction

Safety is the number one priority in any job. Every year, electrical accidents cause serious injury or death. Many of these casualties are young people just entering the workplace. They are involved in accidents that result from carelessness, from the pressures and distractions of a new job, or from a lack of understanding about electricity. This chapter is designed to develop an awareness of the dangers associated with electrical power and the potential dangers that can exist on the job or at a training facility.

1.2. Personal Protective Equipment (PPE)

Construction and manufacturing worksites, by nature, are potentially hazardous places. For this reason, safety has become an increasingly large factor in the working environment. The electrical industry, in particular, regards safety to be unquestionably the most single important priority because of the hazardous nature of the business. A safe operation depends largely upon all personnel being informed and aware of potential hazards. Safety signs and tags indicate areas or tasks that can pose a hazardto personnel and/or equipment. Signs and tags may provide warnings specific to the hazard, or they may provide safety instructions (Figure 1-2).To perform a job safely, the proper protective clothing must be used. Appropriate attire should be worn for each particular job site and work activity.

The following points should be observed:

i. Hard hats, safety shoes, and goggles must be worn in areas where they are specified. In addition, hard hats shall be approved for the purpose of the electrical work being performed but metal hats are not acceptable!
ii. Safety earmuffs or earplugs must be worn in noisy areas.
iii. Clothing should fit snugly to avoid the danger of becoming entangled in moving machinery. Avoid wearing synthetic-fiber clothing such as polyester material as these types of materials may melt or ignite when exposed to high temperatures and may hard hat Goggles Cotton only, no polyester Tight sleeves and trouser legs No rings on fingers Safety shoe.

Self-Check -1	Written Test

Directions: Choose the best answer.

1. Which one of the following safety equipment?
   A. Measuring instrument
   B. Hand tool
   C. Glave
   D. All of the above
2. ________ must be worn in noisy areas.
   A. Safety shoose
   B. Ear plag
   C. Hat
   D. All of the above

***Note:* Satisfactory rating - 1 points** **Unsatisfactory - below 1 points**

Score = ___________

Rating: ____________

Name: ___________________________ Date: _______________

Information Sheet :2	Identify potential hazards

2.1. Electrical Shock

The human body conducts electricity. Even low currents may cause severe health effects. Spasms, burns, muscle paralysis, or death can result, depending on the amount of the current flowing through the body, the route it takes, and the duration of exposure. The main factor for determining the severity of an electric shock is the amount of electric current that passes through the body. This current is dependent upon the voltage and the resistance of the path it follows through the body. Electrical resistance (*R*) is the opposition to the flow of current in a circuit and is measured in ohms (Ω).The lower the body resistance, the greater the current flow and potential electric shock hazard. Body resistance can be divided into external (skin resistance) and internal (body tissues and blood stream resistance). Dry skin is a good insulator; moisture lowers the resistance of skin, which explains why shock intensity is greater when the hands are wet. Internal resistance is low owing to the salt and moisture content of the blood. There is a wide degree of variation in body resistance. A shock that may be fatal to one person may cause only brief discomfort to another.

Typical body resistance values are:

Dry skin—100,000 to 600,000 Ω

- Wet skin—1,000 Ω
- Internal body (hand to foot)—400 to 600 Ω
- Ear to ear—100 Ω

Thin or wet skin is much less resistant than thickor dry skin. When skin resistance is low, the current may cause little or no skin damage but severely burn internal organs and tissues. Conversely, high skin resistance can produce severe skin burns but prevent the current from entering the body.

2.2. Rubber Protective Equipment

Rubber gloves are used to prevent the skin from coming into contact with energized circuits. A separate outer leather cover is used to protect the rubber glove from punctures and other damage. Rubber blankets are used to prevent contact with energized conductors or circuit parts when working near exposed energized circuits. All rubber protective equipment must be marked with the appropriate voltage rating and the last inspection date. It is important that the insulating value of both rubber gloves and blankets have a voltage rating that matches that of the circuit or equipment they are to be used with. Insulating gloves must be given an air test, along with inspection. Twirl the glove around quickly or roll it down to trap air inside. Squeeze the palm, fingers, and thumb to detect any escaping air. If the glove does not pass this inspection it must be disposed of.

2.3. Protection Apparel

Special protective equipment available for high-voltage applications include highvoltage sleeves, high-voltage boots, nonconductive protective helmets, nonconductive eyewear and face protection, switchboard blankets, and flash suits.

2.4. Hot Sticks

hot sticks are insulated tools designed for the manual operation of high-voltage disconnecting switches, high-voltage fuse removal and insertion, as well as the connection and removal of temporary grounds on high-voltage circuits. A hot stick is made up of two parts, the head, or hood, and the insulating rod. The head can be made of metal or hardened plastic, while the insulating section may be wood, plastic, or other effective insulating materials.

2.5. Shorting Probes

Shorting probes are used on de energized circuits to discharge any charged capacitors or built-up static charges that may be present when power to the circuit is disconnected. Also, when working on or near any high-voltage circuits, shorting probes should be connected and left attached as an extra safety precaution in the event of any accidental application of voltage to the circuit. When installing a shorting probe, first connect the test clip to a good ground contact. Next, hold the shorting probe by the handle and hook the probe end over the part or terminal to be grounded. Never touch any metal part of the shorting probe while grounding circuits or components.

2.6. Face Shields

listed face shields should be worn during all switching operations where there is a possibility of injury to the eyes or face from electrical arcs or flashes, or from flying or falling objects that may result from an electrical explosion. With proper precautions, there is no reason for you to ever receive a serious electrical shock. Receiving an electrical shock is a clear warning that proper safety measures have not been followed. To maintain a high level of electrical safety while you work, there are a number of precautions you should follow. Your individual job will have its own unique safety requirements. However, the following are given as essential basics.

i. Do not close any switch unless you are familiar with the circuit that it controls and know the reason for its being open.
ii. When working on any circuit, take steps to ensure that the controlling switch is not operated in your absence. Switches should be padlocked open and warning notices should be displayed (**lockout/tag out**).
iii. Avoid working on "live" circuits as much as possible.
iv. When installing new machinery, ensure that the framework is efficiently and permanently grounded.
v. Always treat circuits as "live" until you have proven them to be "dead." Presumption at this point can kill you. It is a good practice to take a meter reading before starting work on a dead circuit.
vi. Avoid touching any grounded objects while working on electrical equipment.
vii. When working on live equipment containing voltages over approximately 30-V, work with only one hand. Keeping one hand out of the way greatly reduces the possibility of passing a current through the chest.
viii. Safely discharge capacitors before handling them. Capacitors connected in live motor control circuits can store a lethal charge for a considerable time after the voltage to the circuits has been switched off. Although Article 460 of the National Electric Code (NEC) requires an automatic discharge within 1 minute, never assume that the discharge is working! Always verify that there is no voltage present. Confined spaces can be found in almost any workplace

Self-Check -2	Written Test

Directions: Answer all the questions listed below. Choose the best answer.

1. _______ are insulated tools designed for the manual operation of high-voltage disconnecting switches, high-voltage fuse removal and insertion.
   A. Hot Sticks
   B. Shorting probes
   C. face shields
   D. None of the above
3. _______ are used on de energized circuits to discharge any charged capacitors
   A. Hot Sticks
   B. Shorting probes
   C. face shields
   D. None of the above

***Note:* Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ____________

Rating: _____________

Name: _________________________ Date: _______________

Information Sheet :3	Electromagnetic principles

3.1. Introduction

A magnetic field is a change in energy within a volume of space. The magnetic field surrounding a bar magnet can be seen in the magnetograph shown in fig 3.1. A magnetograph can be created by placing a piece of paper over a magnet and sprinklingt he paper with iron filings. The particles align themselves with the lines of magneticforce produced by the magnet. The magnetic lines of force show where the magneticfield exits the material at one pole and reenters the material at another pole along thelength of the magnet. It should be noted that the magnetic lines of force exist in three-dimensions but are only seen in two dimensions in the image.

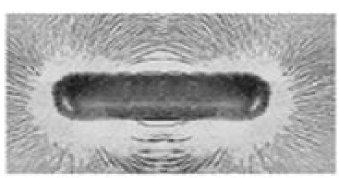


Fig.3.1. Horseshoe magnet

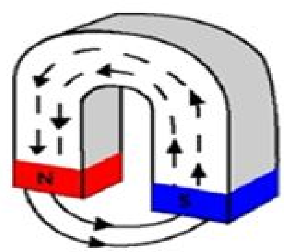


Fig3.2 the magnetic field surrounding a bar magnet

It can be seen in the magnetograph that there are poles all along the length of the magnet but that the poles are concentrated at the ends of the magnet. The area where the exit poles are concentrated is called the magnet's north pole and the area where the entrance poles are concentrated is called the magnet's south pol.Magnets come in a varity of shapes and one of then more common is the horseshoe (U) magnet. Then horse shoe magnet has north and south poles just like a barmagnet but the magnet is curved so the poles lie in the poles as shown in fig. (3.2). Same plane, the magnetic field is concentrated between the number of magnetic lines of force is known as magnetic flux. The flux has the weber (wb) as its unit, The number of magnetic lines of force cutting through a plane of a given area at a right angle is known as the magnetic flux density B. The flux density or magnetic induction has the tesla as its unit. One tesla is equal to one Newton/(A/m). From these units it can be flux density is a measure of the force applide to a particle by the magnetic field.

3.2. Types of magnets

There are two kinds of magnets permanent and temporary magnets.

- ✓ **Permanent magnet**

Permanent magnet will retain or keep their magnetic properties for a very long time. Permanen magnets are by placing pieces of iron cobalt, and nickel into strong magnetic fields. Permanent magnets are mixtures of iron , nickel, or cobalt with other elements. These are known as hard magnetic materials. The natural form of a magnet is called a load stone, it contains iron. When man mixed the pure metals together (ie. iron, nickel and cobalt) we created an even stronger magnet which a.e the ones we use most today

- ✓ **Temporary magnets**

Temporary magnets will loose all or most of their magnetic properties. Temporary magnets are made of shuch materials as iron and nickel. There are two essential methods for generating a magnetic field . Those two following methods

(a) Electromagnetic Fields

Magnets are not the only source of magnetic fields. In 1820, Hans Christian oersterd discovered that the current in the wire was generating a magnetic field. He found that the magneticfield existed in circular form around the wire and that the intensity of the field was directly proportional to the amount of current carried by the wire as shown in the fig.3.3.

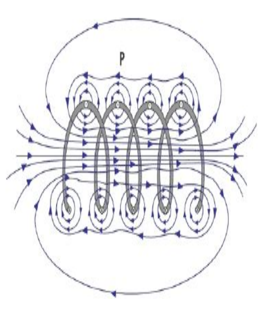


Fig.3.3: *Magnetic field around the wire carried current*

There is a simple rule for remembering the direction of the magnetic field around a conductor. It is called the ***right-hand rule.*** If a person grasps a conductor in ones right hand with the thumb pointing in the direction of the current, the fingers will circle the conductor in the direction of the magnetic field as shown in fig.3.4.

Figure 3.4 : Right-hand rule

(b) Magnetic Field Produced by a Coil

Themagnetic field is essentially uniform down the length of the coil when it is wound The strength of a coil's magnetic field increases not only with increasing current but also with each loop that is added to the coil. Coiling a current-carrying conductor around a core material that can be easily magnetized, such as iron, can form an electro magnetism. The magnetic field will be concentrated in the core. This arrangement is called a **solenoid.**

- ✓ **Induction**

Faraday noticed that the rate at which themagnetic field changed also had an ef fect on the amountof current or voltage that was induced. Faraday's Law for an uncoiled conductor state that the amount of induced voltage is proportional to the rate of change of flux lines cutting the conductor. Faraday's Law for a straight wire is shown below.

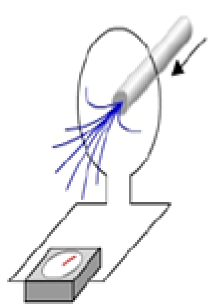


Figure 3.5. Induction in wire

Induction is measured in unit of Henries (H) which reflects this dependence on the rate of change of the magnetic field. One henry is the amount of inductance that is required to generate one volt of induced voltage when the current is changing at the rate of one ampere per second. Note that current is used in the definition rather than magnetic field

- ✓ **Self-inductance**

When induction occurs in an electrical circuit and affects the flow of electricity it is called inductance (L) Self-inductance, or simply inductance is the property of a circuit where by a change in current causes a change in voltage in the same circuit as shown in fig 3.6.

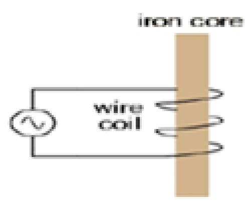


fig 3.6: Self inductance

The mmf required to produce the changing magnetic flux (Φ) must be supplid by a changing current through the coil.Magnetomotive force generated by an electromag oil is equal to the amount of current through that coil (in amps) multiplie by the number of turns of that coil around the core (the unit for mmf is the amp-turn). Because the mathematical relationship between magnetic flux and mmf is directly Proportional, and because the mathematical relationship between mmf and current is also directly proportional (no rates-of-change present in either equation), the current through the coil will be in-phase with the flux waveform as shown in fig 3.7:

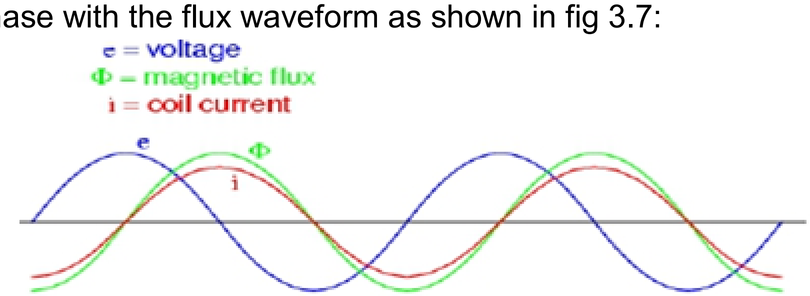


fig 3.7: Current, flux and voltage waveform

- ✓ **Mutual-inductance**

When one circuit induces current flow in a second nearby circuit, it is known as mutual-inductance. The image to the right shows an example of mutual-inductance as shown in fig 3.8. When an AC current is flowing through a piece of wire in a circuit, an electromagnetic field is produced that is constantly growing and shrinking and changing direction due to the constantly changing current in the wire. This changing magnetic field will induce electrical current in another wire or circuit that is brought close to the wire in the primary circuit. The current in the second wire will also be AC and in fact will

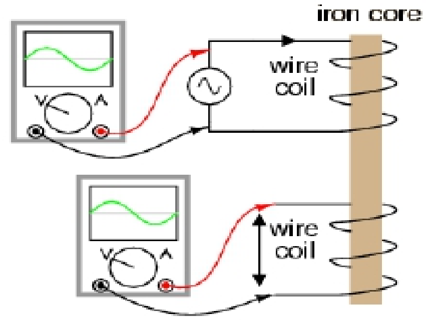


fig 3.8. Mutual inductance

Self-Check -3	Written Test

Directions: Choose the best answer.

- ✓ ______ is measured in units of henneries (H)
  A. Magnetic field C. Iduction
  B. Electromagnet D. A and B
- ✓ The SI unit of magnetic flux is _____?
  A. Magnet C. Electromagnet
  B. Weber D. None of the above
- ✓ ________ is a change in energy with in a volume of space
  A. Permanent magnet C. Magnetic Filed
  B. Temporary Magenet D. All
- ✓ Magnet will return or keep their magnetic properties for a very long time?
  A. Permanent magnet C. Magnetic Filed
  B. Temporary Magenet D. All
- ✓ The number of magnetic lines of forces cutting through a plane of a given area at a right angle is ________?
  A. Flux C. magnetic filled
  B. Magnetic flux density D. All

Note: **Satisfactory rating - 3 and 5 points** **Unsatisfactory - below 3 and 5 points**

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

4.1. Types of Maintenance

4.1.1. Breakdown maintenance

Breakdown maintenance is basically the **"run it till it breaks"** type of maintenance mode. No actions or efforts are taken to maintain the equipment till its design life is reached. Advantages are, Low cost, less staff. Disadvantages are: Increased cost due to unplanned downtime of equipment. Increased labor cost, especially if overtime is needed. Cost involved in repair or replacement of equipment. Possible secondary equipment or process, damage from equipment failure, inefficient use of staff.

4.1.2. Preventive maintenance:

It is a daily maintenance procedure (cleaning, inspection, oiling and re-tightening), designed to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis by measuring deterioration. Just like human life is extended by preventive medicine, the equipment service life can be prolonged by doing preventive maintenance.

It is further divided into Periodic maintenance and Predictive maintenance.

a) Periodic maintenance (Time based maintenance - TBM):

Time based maintenance consists of periodically (at pre-determined intervals) inspecting, servicing and cleaning equipment and replacing parts to prevent sudden failure and process problems.

b) Predictive maintenance:

This is a method in which the service life of important part is predicted based on inspection or diagnosis, (for Ex., by testing the condition of the lubricating oil in a vehicle for its actual condition and lubrication properties in a good testing centre instead of changing every 5000kM), This type of maintenance allows us to use the parts/equipment to the limit of their service life. Compared to periodic maintenance, predictive maintenance is condition based maintenance. Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule. It is possible to schedule maintenance activities to minimize or delete overtime cost. Also, inventory and order parts can be minimized as required, well ahead of time to support the downstream maintenance needs. It helps to optimize the operation of the equipment, saving energy cost and increasing plant reliability.

4.1.3. Corrective maintenance:

It improves equipment and its components so that preventive maintenance can be carried out reliably. Equipment with design weakness must be redesigned to improve reliability or improving maintainability

4.1.4. Maintenance prevention:

It indicates the design of a new equipment. Weakness of current machines are sufficiently studied (on site information leading to failure prevention, easier maintenance and prevents of defects, safety and ease of manufacturing) and are incorporated before commissioning a new equipment.

4.2. Preventive Maintenance of Electrical Equipments

Maintenance usually consists of regularly scheduled inspection, greasing, oiling and possibly Minor repairs. Most causes of failure of alternator and electrical equipment are poor maintenance procedure, which involves flushing out oil wells, greases cups, and checking of rotor and slip rings for concentricity. Shop overhaul is essential for all electrical equipment at least once in five years.

To avoid major repairs:

- Check all connections and wiring.
- Make sure that moisture does not penetrate the winding insulation. Presence of moisture lowers insulation resistance. Test insulation using a megger.
- Remove the moisture by heating the windings using hot bulbs or applying low voltage to winding to develop heat and dry. Do not allow the temperature to rise above 90^0C, which may damage the insulation.
- Dust in the machine should be removed by using a blower with low pressure of air.
- Remove grease and oil using carbon tetrachloride (CTC). While using CTC the

area should be well ventilated to avoid fumes and toxics.

Check voltage of alternator at terminals and panel boards. If the generator is operating satisfactory, load the alternator gradually for 2 to 4 hours to evaporate remaining moisture. While testing it should be within 5% of rated voltage and 3 phases load should be well balanced.

- Always open bus bar switches and then stop the alternator. Be sure that all the switches are in 'off' condition before working on the equipment.
- Reversed coil connections of pole windings can be detected by passing Direct current through winding and testing poles by soft iron strip or bar. If polarity is correct soft iron piece will be held tightly. If not the bar will not be held in its place. Great care is to be taken if D.C. exciter is to be removed for check up of main alternator itself.
- Slip rings on rotor are made of Bronze or non ferrous metal which are polished by fine sand paper or polishing stone. If the rings are worn-out excessively, the rotor should be removed and the rings be reduced down in diameter on the lathe machine. Insulation resistance is then measured by Megger, ring to ring and ring to shaft. Accumulation of carbon or metal dust in the vicinity of rings should be cleaned thoroughly.
- Before starting the motor or alternator – clean the motor/alternator surrounding area to make sure that there is sufficient open space for air movement, also be sure of dry windings.

Make sure from name plate data that type, design of the motor for that work and load.

- Check that operating speed reaches in minimum time, if not there may be overload or centrifugal switch or starting coil is defective. If motor is running in improper direction check for the proper connections as per manufacturing data.
- Check for unusual noises. Poor alignment of end plates, which causes the rotor core to strike against the stator core. Bearing may be defective. If motor becomes overloaded and begins smoking, there may be over loading or defective starting winding or switch. Clean the commutator or reset brushes or adjust spring tension of brushes, if there is sparking at brushes.

Self-Check -4	Written Test

Directions: Answer all the questions listed below. **Choose the best answer**

1. The maintenance work carried out on the machine after it has failed to work is called

A) Breakdown maintenance B) Preventive maintenance
C) Periodic maintenance D) Predictive maintenance.

2. Moisture is the air is prevented from absorption in motor insulation by

A) laminating the windings B) applying varnish
C) Covering with plastic sheets D) vacuum sealing

Note: **Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ____________

Rating: _____________

Name: ___________________________ Date: ________________

Information Sheet :5	Identify and request/obtain Materials, tools, equipment, testing devices and PPE

1. Introduction to Transformer

Transformer is a static device that transfers electrical energy from one electrical circuit to another electrical circuit through the medium of magnetic field and withouta change in the frequency. The electric circuit which receives energy from the supplymains is called ***primary winding*** and the other circuit which delivers electricalenerg y to the load is called ***secondary winding.***Actually the transformer is an electric energ y conversion device, since the energyreceived by the primary is converted to usef ul electrical energy in the other circuits(secondary winding circuit).If the secondary winding has more turns than the primary winding, then thesecondary voltag e is higher than the primary voltage and the transformer is called a ***step-up transformer***. When the secondary winding has less turns than the primary windings then the secondary voltage is lower than the primary voltage and the transformer is called ***step down transformer.***

The most important tasks performed by transformers are

i) Changing voltage and current levels in electrical power systems
ii) Matching source and load impedances for maximum powertransfer in electronic and control circuit an
iii) Electrical isolation (isolating one circuit from another

Transformers are used extensively in ac power systems. AC electrical power can be generated at one central location, its voltage stepped up for transmission very long distances at very low losses and its voltage stepped down again for final use.

1.1. Principles of transformer

Faraday summed up the results of the experiments in the form of following two laws, *known as Faraday's laws of electromagnetic induction.* Faraday's first law states that whenever the magnetic flux associated or linked with a closed circuit is changed, or alternatively, when a conductor cuts or is cut by the magnetic flux, an emf is induced in the circuit resulting in an induced current. This emf is induced so long as the magnetic flux changes.

Faraday's second law states that the magnitude of the induced emf generated in a coil is directly proportional to the rate of change of magnetic flux. These two basic laws discovered by Faraday changed the course of electrical engineering and led to the development of generators, transformers, etc. The change of flux as discussed in the

Faraday's laws can be produced in two different ways:

(i) by the motion of the conductor or the coil in a magnetic field, i.e. the magnetic field is stationary and the moving conductors cut across it. The emf generated in this way is normally called dynamically induced emf;

(ii) by changing the current (either increasing or decreasing) in a circuit. There by changing the flux linked with stationary conductors, i.e. the conductors or coils remain stationary and the flux linking these conductors is changed. The emf is termed statically induced emf. *Statically induced* emf can be further subdivided into:

(a) Self-induced emf and

(b) Mutually induced emf.

The concept of dynamically induced emf gave rise to the development of generators, whereas statically induced emf was helpful in developing transformers.

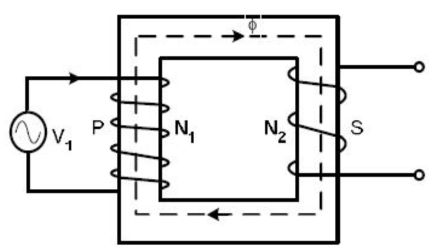


Figure 5.1.. Schematic diagram of a two-winding transformer

The primary winding P is connected to an alternating voltage source, therefore, an alternating current I_m starts flowing through N_1 turns. The alternating mmf N_1I_m sets up an alternating flux ϕ which is confined to the high permeability iron path as indicated in Figure 5.1. The alternating flux induces voltage E1 in the primary (P) and E2 in secondary (S). If a load is connected across the secondary, load current starts flowing.

1.2. Ideal Two-Winding Transformer

For a transformer to be an ideal one, the various assumptions are as follows

1. Winding resistances are negligible.
2. All the flux set up by the primary links the secondary windings i.e. all of the flux is confined to the magnetic core.
3. The core losses (hysteresis and eddy current losses) are negligible. Therefore, volt-amperes input to the primary are equal to the output volt-amperes i.e.

$$V_1 I_1 = V_2 I_2$$

Input VA= Output VA

4. The core has constant permeability, i.e. the magnetization curve for the core is linear.

1.2.1. Voltage Transformation Ratio

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = k \qquad \frac{I_1}{I_2} = \frac{V_2}{V_1} = \frac{1}{k}$$

Where : - E_1 & I_1 – for primery voltage & current respectively
N_1 - for primery turn
E_2 - for secondery voltage
N_2 - for secondery turn
K – transformer ratio

Hence, the currents are in the inverse ratio of the (voltage) transformation ratio.

The ratio is known as voltage transformation ratio.
i) If N2 > N1 i.e., K<1, then the transformer is called a ***step-up transformer.***
ii) If N2 < N1 i.e., K>1, then the transformer is known as a ***step-down transformer***.

1.2.2. Type of transformer

Depending upon the manner in which the primary and secondary are wound on the core, transformers are of two types viz., (i) core-type transformer and (ii) shell-type transformer.

(i) Core-type transformer.

In a core-type transformer, half of the primary winding and half of the secondary winding are placed round each limb as shown in Fig. 5.2.This reduces the leakage flux. It is a usual practice to place the low-voltage winding below the high-voltage winding for mechanical considerations.

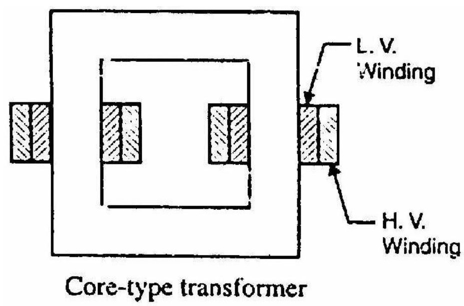


Fig .5.2. Core-type transformer

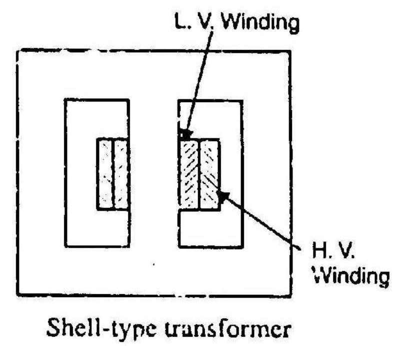


Fig .5.3. Shell-type transformer

(iii) Shell-type transformer.

This method of construction involves the use of a double magnetic circuit. Both the windings are placed round the central limb (See Fig. 5.3), the other two limbs acting simply as a low-reluctance flux path.

The choice of type (whether core or shell) will not greatly affect the efficiency of the transformer. The core type is generally more suitable for high voltage and small output while the shell-type is generally more suitable for low voltage and high output.

1.3. Autotransformer

An autotransformer has a single winding on an iron core and a part of winding is common to both the primary and secondary circuits. Fig.(Fig.5.4 (i)) shows the connections of a step-down autotransformer whereas Fig. (Fig.5.4 (ii)) shows the connections of a step-up autotransformer. In either case, the winding ab having N_1 turns is the primary winding and winding be having N_2 turns is the secondary winding. Note that the primary and secondary windings are connected electrically as well as magnetically. Therefore, power from the primary is transferred to the secondary conductively as well as inductively (transformer action).

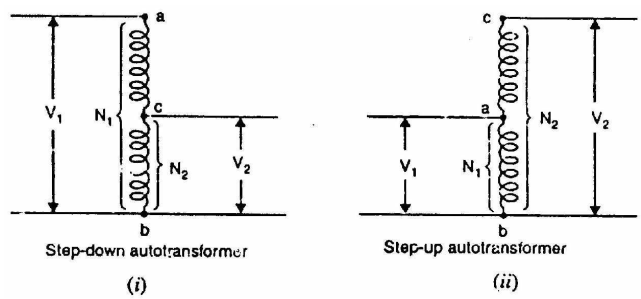


Fig. 5.4. Autotransformer

1.3.1. Welding Machine

Welding is a fabrication process that joins materials usually metals or thermoplastics, by causing coalescence. Generally, most of the weldable common steels are preferred to be join by welding method. The most popular of the welding machines uses the arc welding methods, which include the (i) SMAW – The stick welding or shielded metal arc welding (ii) GMAM – The tig welding gas metal arc welding (iii) GTAM – The tig welding or gas tungsten arc welding. Others are brazing, soldering and oxyacetylene welding. In the automobile industry the resistance spot welding (RSM) is one of the most efficient material-joining processes, it utilizes currents in the range of 1 – 200KA with durations ranging from a few cycles to one second to generate joule heating. RSM transformers operates within a middle frequency range of around 1kHz.

The welding system constructed uses low frequency transformer that operate at the utility mains frequency of 50 or 60 Hz with variable current selectors to avoid power quality problem. Power quality problem refers to voltage current and frequency deviation from nominal value in electrical distribution and utilization system.

Any significant deviation in the waveform magnitude, frequency or purity is a potential power quality problem which may result in failure or malfunctioning of equipment. The current selector introduced in this transformer help to maximize the power quality problem association with a.c electric power systems, that operates at a sinusoidal waveform of 50 or 60 Hz and rated voltage magnitude. The deviations depends on the duration and magnitude which help to categorize the voltage deviation as voltage sags, interruption, over voltage, under voltage, transients, voltage imbalance and voltage

In many electric welding systems, a potential difference of 50-70 volts is required to strike an electric arc. After the arc is struck, an essentially constant current supply is desired .The welding transformer converts the high voltage and low current from the utility mains into low voltage and high current, usually in the range of 55 –590 amperes. In this transformer the variable current selector help to maintain the constant current supply desired.

1.3.2. Construction

The a.c welding machine design is a two pole circuit, with the first pole been the primary circuit and the second pole is the secondary circuit.

i. The Primary Circuit (pole 1)

The primary circuit was design to vary in current selection without tempering with the coil itself; it has a four step coil with three looping for the selection of current capacity.

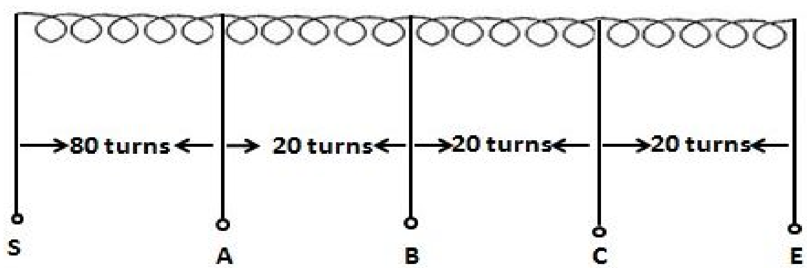


Fig 5.5: A circuit showing the four step circuit and the looping for the current selection

In the primary circuit the winding begins at the start point S and was given 80 turns with a copper wire of size gauge 13. The first looping was introduced after the first winding and was labeled A, the winding continues with same size gauge for another 20 turns before the second looping labeled B. The third looping C and the last winding labeled E was given 20 turns each with same size wire gauge 13. The beginning of the wire marks the starting point „ S‟ and the end of the wire marks the ending point „ E‟, both point are use for connection purposes.

ii. The Secondary Circuit (Pole 2)

The second circuit was design to consist of two coils over lapping each other. The first coil is the primary coil wound with 114 turn's size wire gauge 13 while the secondary coil was 40 turn of tick size wire gauge 8 as shown in figure 5.6.The starting point and ending point of the secondary coil serve as the welding terminals.

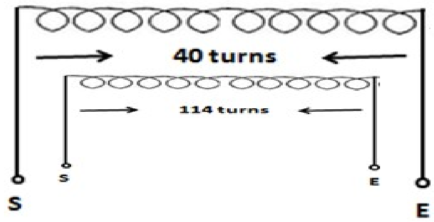


Fig 5.6: A circuit showing the secondary circuit with the over lapped primary circuit

The core is made of laminations assembled to provide a continuous magnetic path with a minimum of air gap included. The lamination steel help to minimize eddy current loss and the thickness of the lamination varies from 0.35mm for a frequency of 50Hz 0.5mm for a frequency of 25Hz. The cores are cut in the form of long strips. L"s, E"s and I" shapes as shown below.

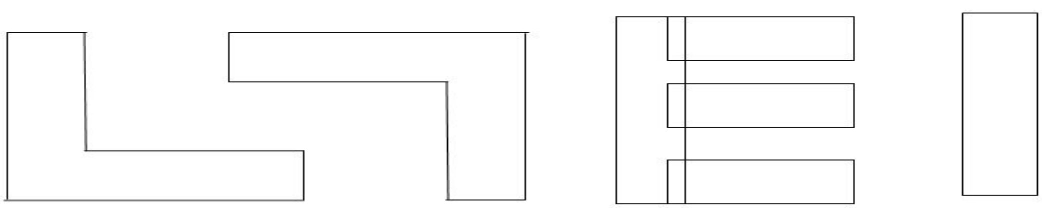


Fig. 5.7: Diagrams showing the shapes of lamination

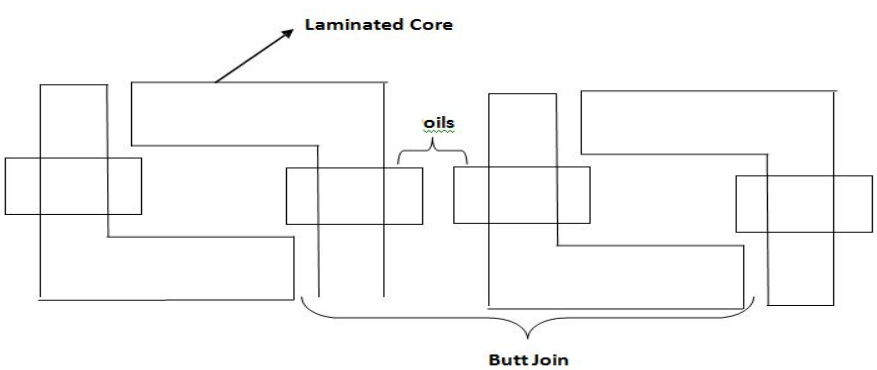


Fig. 5.8: Diagrams showing the arrangement of a laminated core on the coil

In other to avoid reluctance at the joins where the laminated cores are butted against each other, the alternate layers are stacked differently with the shape I to eliminated joins as shown below.

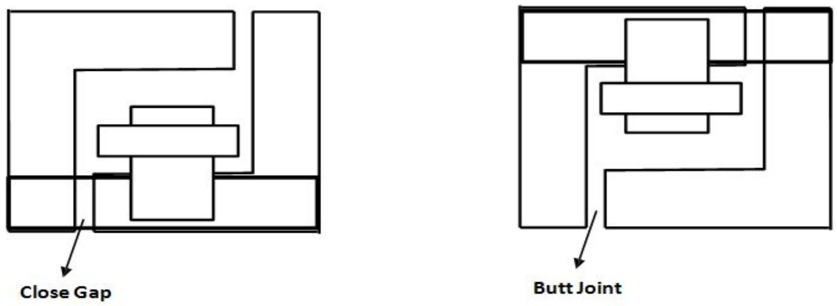


Fig 5.9: Diagrams showing the arrangement of the I lamination covering the butted joint.

✓ **Copper as my coil**

Copper wire is of more advantage in winding process than that of aluminum. Copper wire has more capacity and strong enough to resist the function of any kind of winding for a longer time. It has different type of gauge and is coated with insulator to prevent contact of wires when winding.

For the aluminum wire its very effective when used than the copper wire, it produces stronger magnetic flux which makes the machine more powerful. The disadvantage of an aluminum wire is that they are not insulated thereby need proper insulation before it can be used for winding.

✓ **Insulators**

Insulators are materials that do not conduct electricity in any form. They are used to separate two wires to avoid partial contact of any form.

✓ **Connection**

The major kinds of connections that can be given to this construction include:

a) Star-delta connection or End to start connection
b) Star – star connection or start to start connection
c) Delta-Delta connection or End to End connection

The type of connection use in this work is the start to start connection; it involves the starting wire hand of the primary circuit connected to the secondary circuit as shown in figure below.

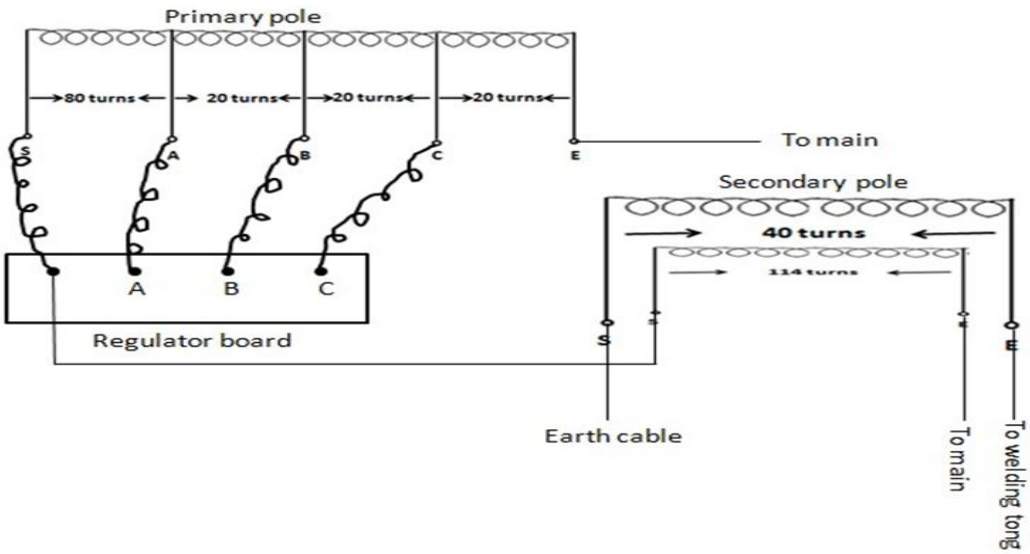


Fig 5.10: The detail connection of the primary circuit diagram

Owing to the connection between the primary pole and the secondary pole, the primary turns will toggle with respect to the variation of the current thus, 254 turns from S to A, 174 turn from A to B, 154 turns from B to C and 114 turns from C to E. At the secondary circuit, the starting hand is connected to the earth of the welding side and the end hand connected to the tong bearing the electrode.

- ✓ **Testing**

The testing of the machine confirmed the success of the design, construction and connection of the work, as there was no spark or shock from the laminated core and when connected to the welding apparatus, it was used for joning metals without any problem. In the testing, the voltages at zero load and when in operation was measured and recorded as shown in the result below.

1.3.3. Three-phase transformer

A three-phase system in used to generate and transmit electric power. Three- phase voltages are raised or lowered by means of three-phase transformers. A three-phase transformer can be built in two ways viz. (i) by suitably connecting a bank of three single-phase transformers or (ii) by constructing a three-phase transformer on a common magnetic structure. In either case, the windings may be connected in Y-Y, ∆-∆ , Y-∆ or ∆-Y.

(i) Bank of three single-phase transformers

Three similar single-phase transformers can be connected to form a three-phase transformer. The primary and secondary windings may be connected in star (Y) or delta (Δ) arrangement. Fig. (5.11.(ii)) shows a Y – Δ connection of a three-phase transformer.

The primary windings are connected in star and the secondary windings are connected in delta. A more convenient way of showing this connection is illustrated in Fig. (5.11.(i)). The primary and secondary windings shown parallel to each other belong to the same single-phase transformer. The ratio of secondary phase voltage to primary phase voltage is the phase transformation ratio K.

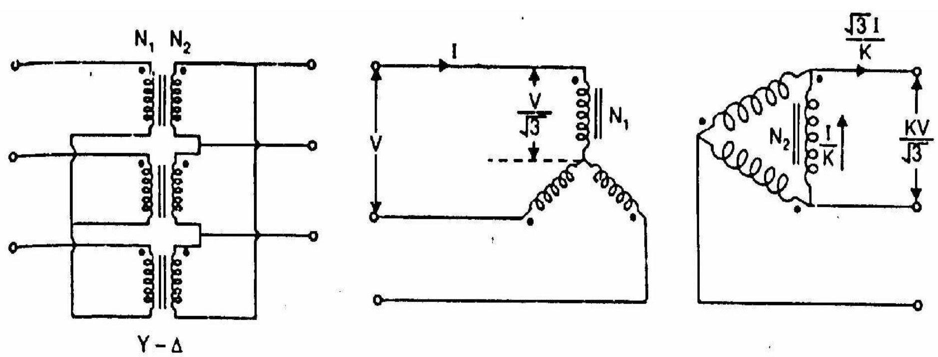


Fig. 5.11: connection of a three-phase transformer.

(ii) Three-phase transformer

A three-phase transformer can be constructed by having three primary and three secondary windings on a common magnetic circuit. The basic principle of a 3- phase transformer is illustrated in Fig. (5.12.(i)).The three single-phase core- type transformers, each with windings (primary and secondary) on only one leg have their unwound legs combined to provide a path for the returning flux. The primaries as well as secondaries may be connected in star or delta. If the primary is energized from a 3-phase supply, the central limb (i.e., unwound limb) carries the fluxes produced by the 3-phase primary windings. Since the phasor sum of three primary currents at any instant is zero, the sum of three fluxes passing through the central limb must be zero. Hence no flux exists in the central limb and it may, therefore, be eliminated. This modification gives a three leg core- type 3-phase transformer. In this case, any two legs will act as a return path for the flux in the third leg. For example, if flux is in one leg at some instant, then flux is /2 in the opposite direction through the other two legs at the same instant. All the connections of a 3-phase transformer are made inside the case and for delta-connected winding three leads are brought out while for star- connected winding four leads are brought out.

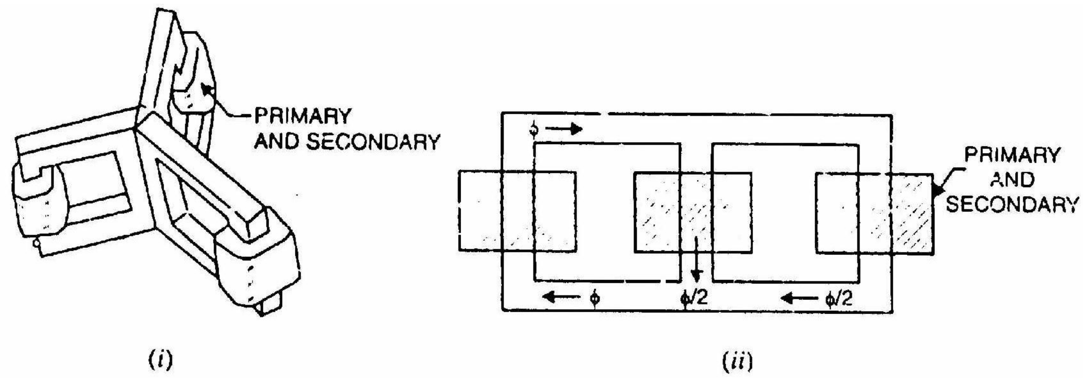


Fig.(5.12) construction of three phase transformer

For the same capacity, a 3-phase transformer weighs less, occupies less space and costs about 20% less than a bank of three single-phase transformers. Because of these advantages, 3-phase transformers are in common use, especially for large power transformations.

A disadvantage of the three-phase transformer lies in the fact that when one phase becomes defective, the entire three-phase unit must be removed from service. When one transformer in a bank of three single-phase transformers becomes defective, it may be removed from service and the other two transformers may be reconnected to supply service on an emergency basis until repairs can be made.

1.3.4. Three-Phase Transformer Connections

A three-phase transformer can be built by suitably connecting a bank of three single-phase transformers or by one three-phase transformer. The primary or secondary windings may be connected in either star (Y) or delta (∆) arrangement. The four most common connections are (i) Y-Y (ii) ∆-∆ (iii) Y- ∆ and (iv) ∆ -Y. These four connections are shown in Fig. (5.13).In this figure, the windings at the left are the primaries and those at the right are the secondary's. The primary and secondary voltages and currents are also shown. The primary line voltage is V and the primary line current is I. The phase transformation ratio K is given by;

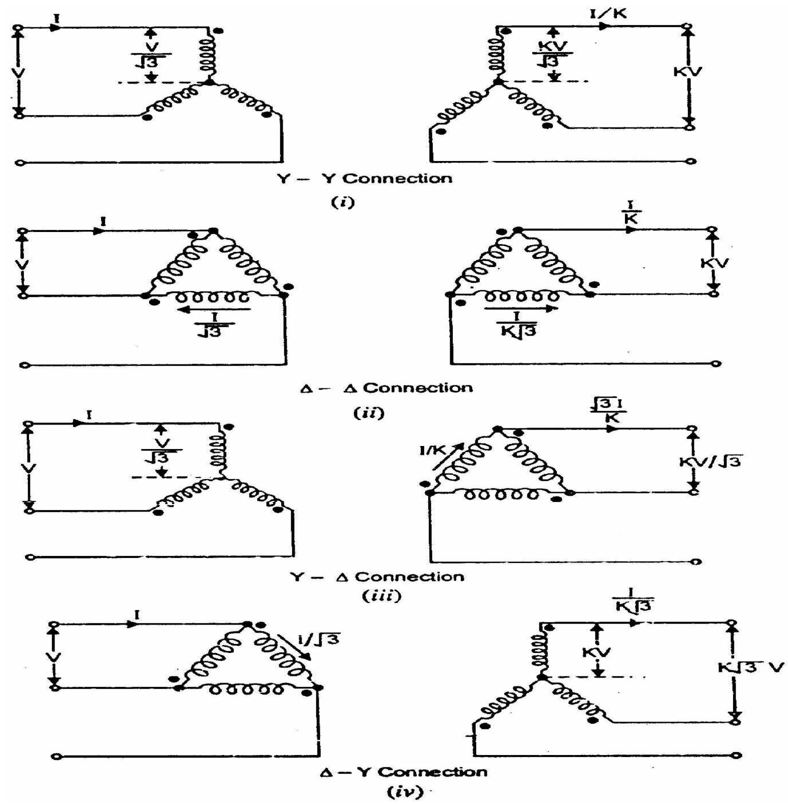


Fig.(5.13) three-phase transformer connection

$$K = \frac{\text{Secondary phase voltage}}{\text{Primary phase voltage}} = \frac{N_2}{N_1}$$

(i) **Y-Y Connection**. In the Y-Y connection shown in Fig. (5.13 (i)), 57.7% (or 1/√3) of the line voltage is impressed upon each winding but full line current flows in each winding. Power circuits supplied from a Y-Y bank often create serious disturbances in communication circuits in their immediate vicinity. Because of this and other disadvantages, the Y-Y connection is seldom used.

(ii) Δ-Δ **Connection**. The - connection shown in Fig. (5.13 (ii)) is often used for moderate voltages. An advantage of this connection is that if one transformer gets damaged or is removed from service, the remaining two can be operated in what is known as the open-delta or V-V connection. By being operated in this way, the bank still delivers three-phase currents and voltages in their correct phase relationships but the capacity of the bank is reduced to 57.7% of what it was with all three transformers in service.

(iii) **Y- Δ Connection**. The Y- Δ connection shown in Fig. (5.13 (iii)) is suitable for stepping down a high voltage. In this case, the primaries are designed for 57.7% of the high-tension line voltages.

(iv) **Δ -Y Connection**. The Δ –Y connection shown in Fig. (5.13(iv)) is commonly used for stepping up to a high voltage

1.3.5. Applications of Transformers

There are four principal applications of transformers viz.

(i) power transformers (ii) distribution transformers

(iii) autotransformers (iv) instrument transformers

(i) **Power Transformers**. They are designed to operate with an almost constant load which is equal to their rating. The maximum efficiency is designed to be at full-load. This means that full-load winding copper losses must be equal to the core losses.

(ii) **Distribution Transformers**. These transformers have variable load which is usually considerably less than the full-load rating. Therefore, these are designed to have their maximum efficiency at between 1/2 and 3/4 of full- load.

(iii) **Autotransformers**. An autotransformer has only one winding and is used in cases where the ratio of transformation (K), either step-up or step down, differs little from 1. For the same output and voltage ratio, an autotransformer requires less copper than an ordinary 2-winding transformer. Autotransformers are used for starting induction motors (reducing applied voltage during starting) and in boosters for raising the voltage of feeders.

(iv) **Instrument transformers**. Current and voltage transformers are used to extend the range of a.c. instruments.

(a) Current transformer

A current transformer is a device that is used to measure high alternating current in a conductor. Fig. (5.14.) illustrates the principle of a current transformer. The conductor carrying large current passes through a circular laminated iron core. The conductor constitutes a one-turn primary winding. The secondary winding consists of a large number of turns of much fine wire wrapped around the core as shown. Due to transformer action, the secondary current is transformed to a low value which can be measured by ordinary meters.

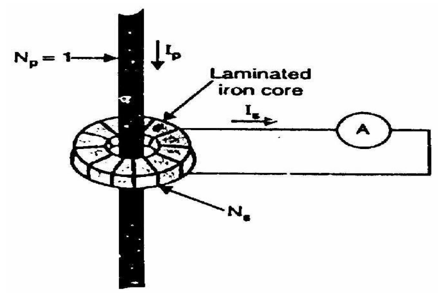


Fig. (5.14): current transformer

(b) Voltage transformer

It is a device that is used to measure high alternating voltage. It is essentially a step-down transformer having small number of secondary turns as shown in Fig. (5.15).The high alternating voltage to be measured is connected directly across the primary. The low voltage winding (secondary winding) is connected to the voltmeter. The power rating of a potential transformer is small (seldom exceeds 300W) since voltmeter is the only load on the transformer.

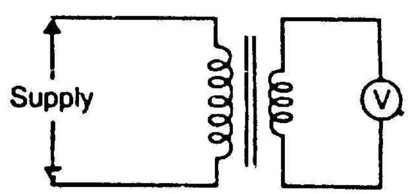


Fig.(5.15): Voltage Transformer

1.3.6. Testing of transformer

(a) open-circuit and short-circuit tests

These two tests on a transformer help to determine

(i) The parameters of the equivalent circuit

(ii) The voltage regulation and

(iii) Efficiency

The equivalent circuit parameters can also be obtained from the physical dimensions of the transformer core and its winding details. Complete analysis of the transformer can be carried out, once its equivalent circuit parameters are known. The power required during these two tests is equal to the appropriate power loss occurring in the transformer.

(b) Open Circuit (or No-Load) Test

The circuit diagram for performing open circuit test on a single phase transformer is given in Figure 5.16 (a).In this diagram, a voltmeter, wattmeter and an ammeter are shown connected on the low voltage side of the transformer. The high voltage side is left open circuited. The rated frequency voltage applied to the primary, i.e. low voltage side, is varied with the help of a variable ratio auto-transformer. When the voltmeter reading is equal to the rated voltage of the L.V. winding, all three instrument readings are recorded.

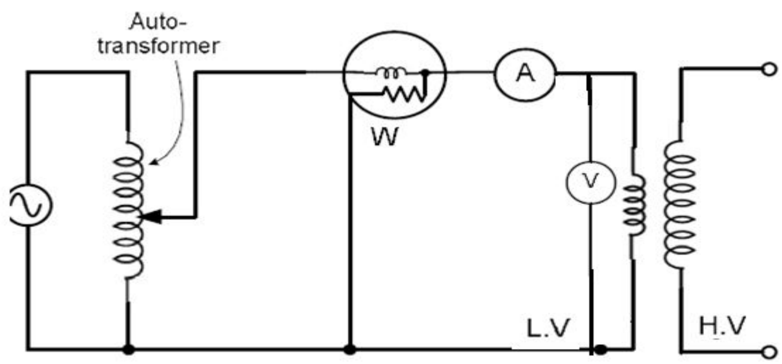


Fig: 5.16: open circuit test

The-ammeter records the no-load current or exciting current Ie. Since Ie is quite small (2 to 6%) of rated current), the primary leakage impedance drop is almost negligible, and for all practical purposes, the applied voltage V1 is equal to the induced emf E1.

(c) Short-Circuit Test

The low voltage-side of the transformer is short-circuited and the instruments are placed on the high voltage side, as illustrated in Figure .

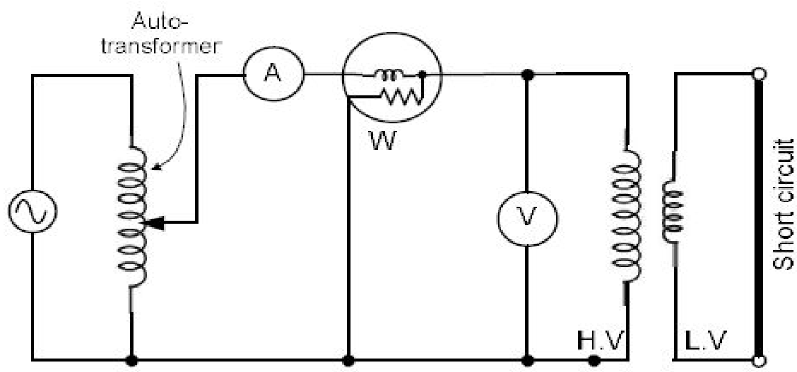


Fig: 5.17: short circuit test

The-ammeter records the no-load current or exciting current Ie. Since Ie is quite small (2 to 6%) of rated current), the primary leakage impedance drop is almost negligible, and for all practical purposes, the applied voltage V1 is equal to the induced emf E1.

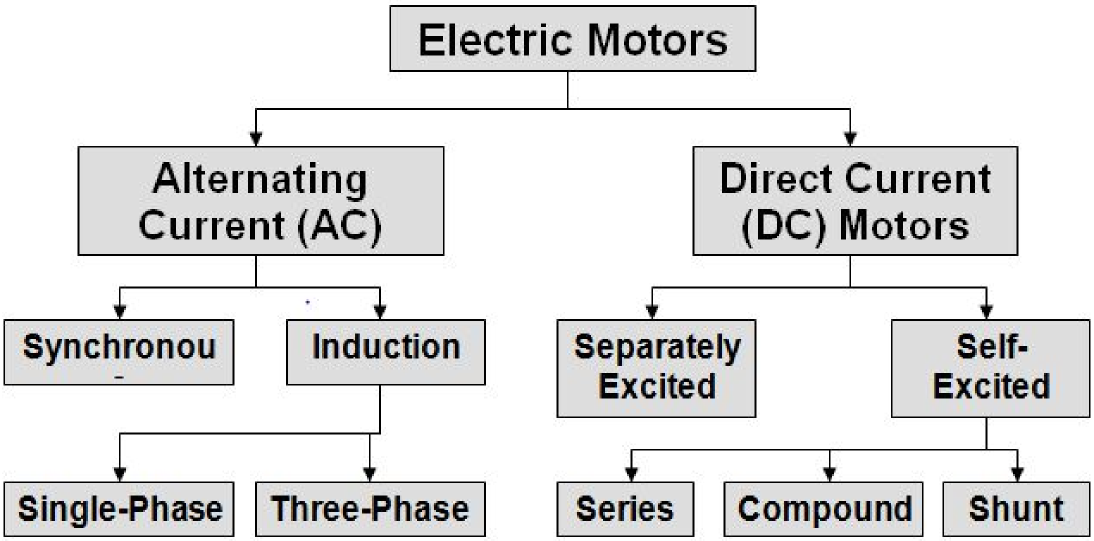
The applied voltage is adjusted by auto-transformer, to circulate rated current in the high voltage side. In a transformer, the primary m.m.f. is almost equal to the secondary m.m.f., therefore, a rated current in the H.V. winding causes rated current to flow in the L.V. winding

1.4. Types and operation of DC Machine

1.4.1. Introduction

Electric motors and generators are referred to as electric machines. Electricians are most frequently concerned with electric motors; due to their extensive application.The electric motor must be one of man's most useful inventions. In the manufacturing industries they are used in large numbers, to drive lathes, drilling and milling machines, augers, conveyors, cranes, hoists, lifts, fans and steel rolling equipment. In the process industries they are used to pump liquids and gases. They are used in transport to start engines,

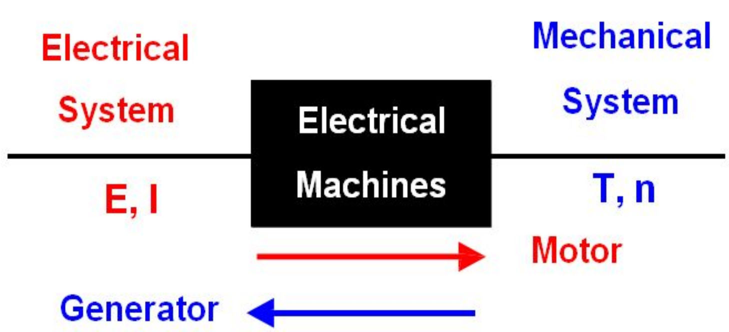
operate windscreen wipers, open and close windows and power electric vehicles. In domestic situations they are used in washing machines, clothes dryers, cookers, fridges, freezers, vacuum cleaners, food mixers, audio / video equipment, cameras, clocks etc.Electric motors are popular because they are compact, reliable, and cheap, need little attention, and are convenient to use. They can be provided in a wide range of sizes and can be designed to have different characteristics for various applications. Also, there is a readily available supply of electricity.



In these machines, conversion of energy results from the following two electromagnetic phenomena:

i. When a conductor moves in a magnetic field voltage is induced in the conductor (generator action)

ii. When a current –carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force (Motor action)



Note that the two systems in fig.above, electrical and mechanical, are different in nature.

- ✓ In electrical system the primary quantities involved are voltage & current

- ✓ While in mechanical system, the analogous quantities are torque & speed.

The coupling medium between these different systems is the magnetic field.The dc machines are versatile and extensively used in industry. A wide variety of volt-ampere or torque-speed characteristics can be obtained from various connections of the field winding. Dc machines can work as generators, motors & brakes.

- ✓ In the generator mode the machine is driven by a prime mover (such as a steam turbine or a diesel engine) with the mechanical power converted into electrical power.
- ✓ While in the motor mode, the machine drives a mechanical load with the electrical power supplied converted into mechanical power.
- ✓ In the brake mode, the machine decelerates on account of the power supplied or dissipated by it and, therefore, produces a mechanical braking action.

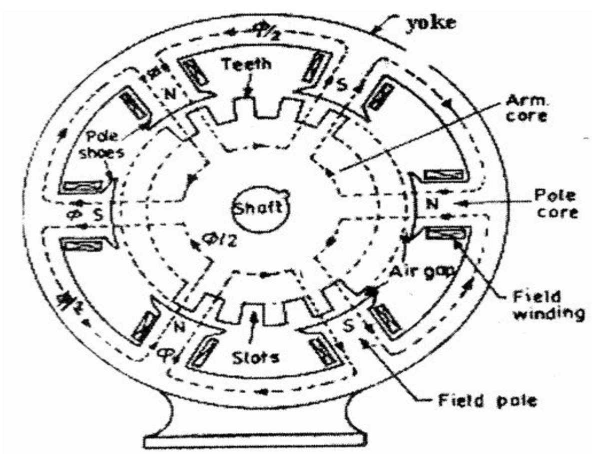
1.4.2. Construction

The dc machines used for industrial applications have essentially three major parts:

a) Field system (Stator)

b) Armature (Rotor) and

c) Commutator



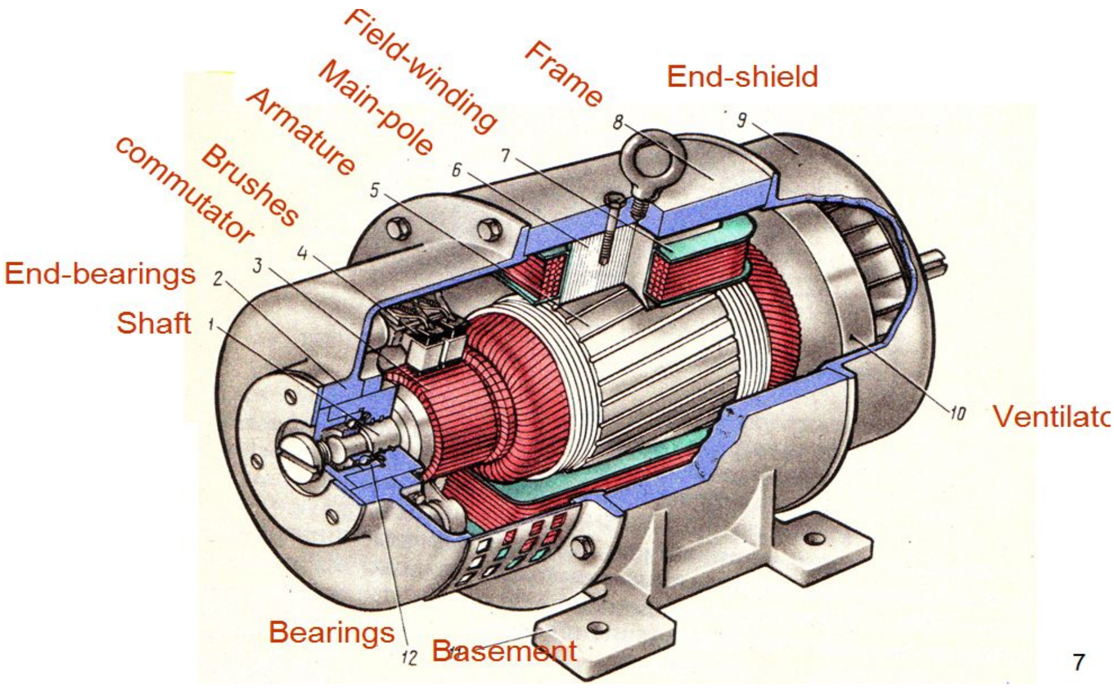


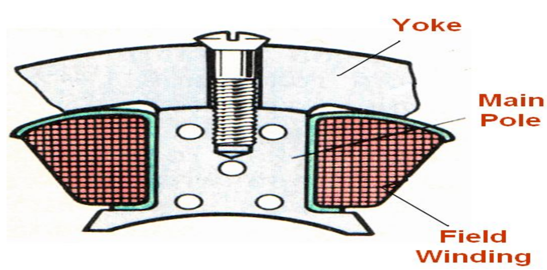
Fig.5.2. Cutaway view of DC Machines away view of DC Machines

a) Filled system

The field system is located on the stationary part of the machine called stator. The field system is designated for producing magnetic flux and, therefore, provides the necessary excitation for operation of machine.

The stator of dc machines comprises of

i. Frame(yoke)
ii. Main poles
iii. Inter-poles



- **Stator**

The stator of a dc machines consists of a frame or yoke, and poles, which support the field windings.

- The frame or yoke in addition to being a part of a magnetic circuit serves as mechanical support for entire assembly.

i. Yoke

Earlier, cast iron was used for the construction of yoke but it has been replaced by cast steel.

- This is because cast iron has saturation density of 0.8 Wb/m^2 while saturation occurs in cast steel at density of approximately 1.5 Wb/m^2.
- Thus, the cross section of the cast steel frame or yoke is half that of iron cast and hence cast steel is used in case it is desired to reduce the weight of machine.
- Fabricated steel yokes are commonly used, as they are economical and have consistent magnetic & mechanical properties used.

ii. Main poles

- Poles are made of sheet steel laminations of 1,0 to 1,2mm thickness (nowadays the thickness becomes 0.4-0.5mm)
- The pole shoes support the field coils placed on the pole body and also spread the total flux over a greater area, thereby reduce the air gap reluctance and giving the desired flux distribution to limit saturation in the teeth of the armature.
- The poles are secured to the yoke by means of bolts. In small machines the pole are built of steel forgings, bolted directly to the yoke.
- In case of machines having compensating windings, the pole face is slotted to accommodate the windings.

iii. Interpole

- In addition to the main poles, modern direct current machines are also provided with interlopes with windings on them in order to improve commutation under loaded conditions.
- They are arranged midway between the mains poles and are bolted to the yolk.
- Laminated interlopes are used in machine with sever commutator problems.
- For small and medium size machines they could be solid

b) Armature

- The armature is the rotating part (rotor) of the dc machine where the process of electromechanical energy conversion takes pace.
- The armature is a cylindrical body, which rotates between the magnetic poles.
- The armature and the field system are separated from each other by an air gap.

The armature consists of:

- ✓ Armature core with slots and
- ✓ Armature winding accommodated in slots

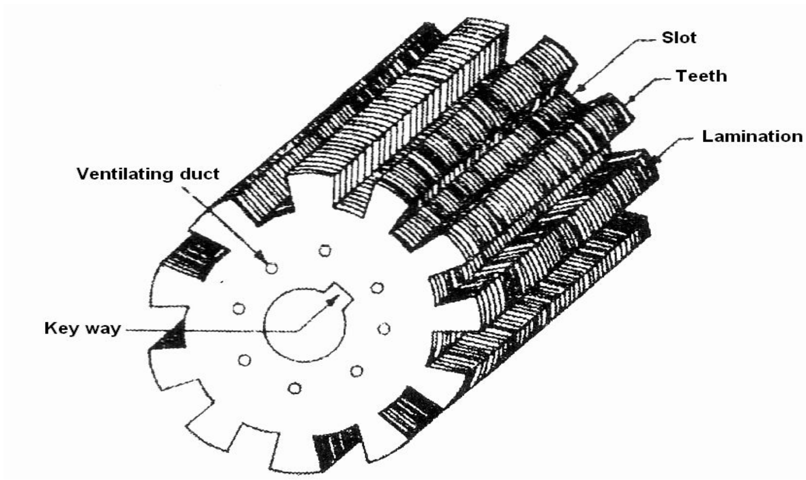
- ✓ The armature of the dc machines is a cylindrical shape, consists of slots, teeth, winding and the core.
- ✓ The purpose of the armature is to rotate the conductors in the uniform magnetic field and to induce an alternating emf in its winding.
- ✓ The armature core is normally made from high permeability silicon- steel laminations of 0.4-0.5mm thickness, which are insulated from one another by varnish or ceramic insulation.

The use of high grade steel is made:

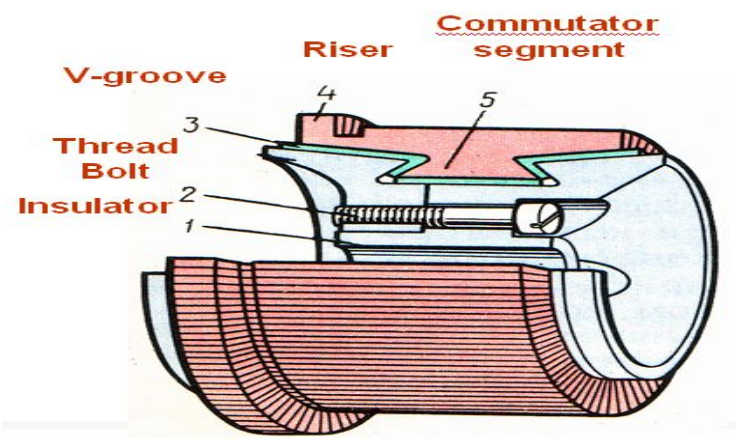
- ✓ To keep hysteresis loss low, which is due to cyclic change of magnetization caused by rotation of the core in the magnetic field and
- ✓ To reduce the eddy current in the core which are induced by the rotation of the core in the magnetic field

- ✓ In order to dissipate the heat produced by hysteresis and eddy current losses etc, ventilating ducts are provided.

By the fanning action of the armature, air is drawn in through these ducts, thus producing efficient ventilation.



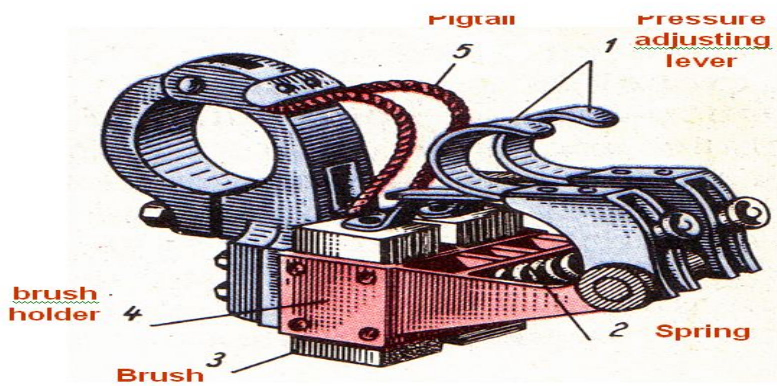
- The commutator is mounte on the rotor of a dc machine and it performs with help of brushes a mechanical rectification of power from
  - ✓ ac to dc in case of generators and
  - ✓ dc to ac in case of motors.



- **Brushes And Brush Holder**

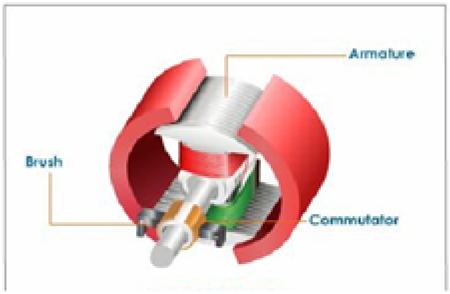
✓ Brushes are needed to collect the current from the rotating commutator or to lead the current to it.

- ✓ Normally brushes are made up of carbon and graphite, so that while in contact with the commutator, the commutator surface is not spoiled.
- ✓ The brush is accommodated in the brush holder where a spring presses ita gains the commutator with pressure of 1,5 to 2,0 Ncm^2
- ✓ A twisted flexible copper conductor called pigtail securely fixed in to the brush is used to make the connection between the brush and its brush holder.
- ✓ Normally brush holders used in dc machines are of box type.
- ✓ The numbers of brush holders usually equal to the number of main poles in dc machines.



1.4.3. Dc Motor Principle

As showed in the illustration below the stator consists of a permanent magnet, a DC voltage is applied to the brushes, a current flows into the rotor coil. The excitation field applies a force to the rotor coil and a torque is exerted, the rotor starts rotating. When passing the horizontal position, the commutator reverses the polarity of the current, but since position of the rotor is also reversed the current flows in the same direction, exerting the torque in the same direction.



Machine that converts dc power into mechanical energy is known as dc motor. Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of the force is given by Fleming 's left hand rule.

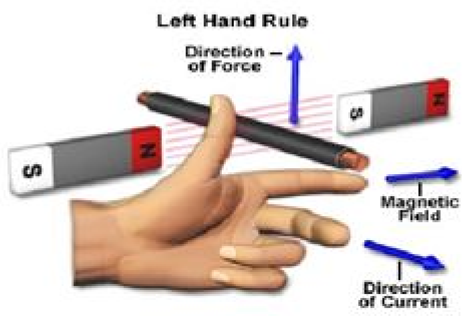
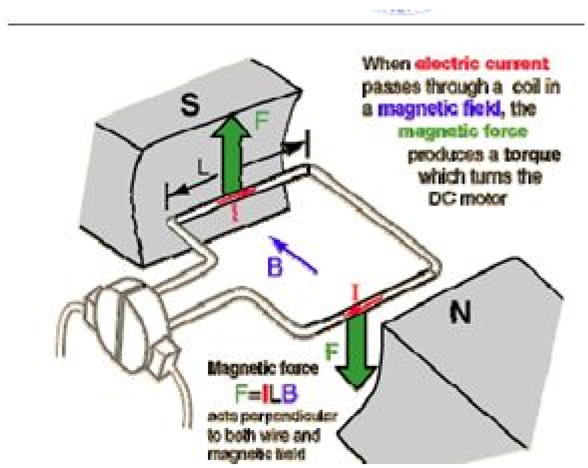


Fig. 5.2.2 Fleming Left Hand Rule



1.4.4. Working of D.C. Motor

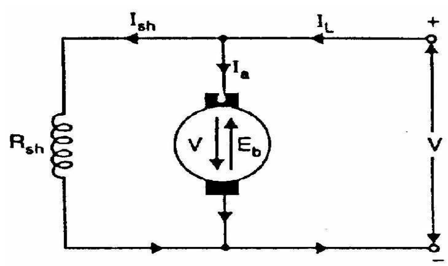
When the terminals of the motor are connected to an external source of d.c. supply:

(i) The field magnets are excited developing alternate N and S poles;
(ii) The armature conductors carry ^currents.

All conductors under N-pole carry currents in one direction while all the conductors under S-pole carry currents in the opposite direction. Suppose the conductors under N-pole carry currents into the plane of the paper and those under S-pole carry currents out of the plane of the paper

1.4.5. Back or Counter E.M.F.

When the armature of a D.C. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence e.m.f. is induced in them as in a generator. The induced e.m.f. acts in opposite direction to the applied voltage Consider a shunt wound motor shown in.



When d.c. voltage V is applied across the motor terminals, the field magnets are excited and armature conductors are supplied with current. Therefore, driving torque acts on the armature which begins to rotate. As the armature rotates, back e.m.f. Eb is induced which opposes the applied voltage V. The applied voltage V has to force current through the armature against the back e.m.f. Eb. The electric work done in overcoming and causing the current to flow against Eb is converted into mechanical energy developed in the armature. It follows, therefore, that energy conversion in a d.c. motor is only possible due to the production of back e.m.f. Eb.

Net voltage across armature circuit = V - Eb

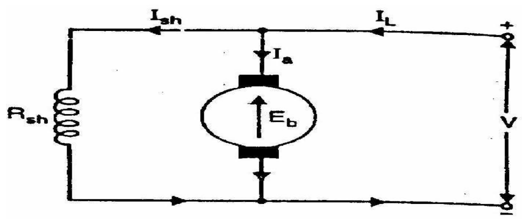
If Ra is the armature circuit resistance, then Ia =V –Eb/Ra

Since V and Ra are usually fixed, the value of Eb will determine the current drawn by the motor. If the speed of the motor is high, then back e.m.f.

- **Significance of Back E.M.F.**

The presence of back e.m.f. makes the d.c. motor a self-regulating machine i.e.,it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the la. Armature current Ia=V-Ea/Ra

Voltage Equation of D.C. Motor



- Let in a d.c. motor
- V = applied voltage
- Eb = back e.m.f.
- Ra = armature resistance
- Ia = armature current
- Since back e.m.f. Eb acts in opposition to the
- Applied voltage V, the net voltage across the armature circuit is V- Eb. The
- armature current Ia is given by
- V-Ea/Ra
- V=Ea+IaRa

1.4.6. Types of D.C. Motors Shunt

i. Shunt Wound Motor

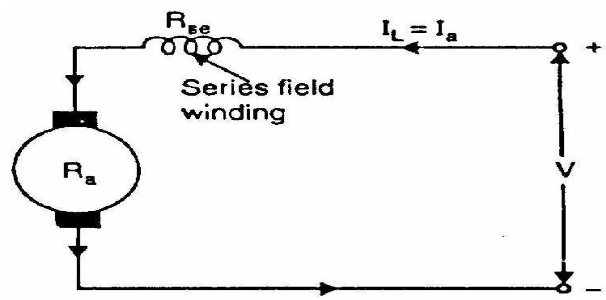
In shunt wound motor the field winding is connected in parallel with the armature. The current through the shunt field winding is not the same as the armature current. Shunt field windings are designed to produce the necessary m.m.f. by means of a relatively large number of turns of wire having high resistance. Therefore, shunt field current is relatively small compared with the armature current. Application of d,c shunt motor fans, blowers, centrifugal pumps, machine tools

✓ **Characteristics of Shunt Motors**

Shows the connections of a D.C. shunt motor. The field current Ish is constant since the field winding is directly connected to the supply voltage V which is assumed to be constant. Hence, the flux in a shunt motor is approximately constant.00 for short periods125% to 200% full load torque starting torque

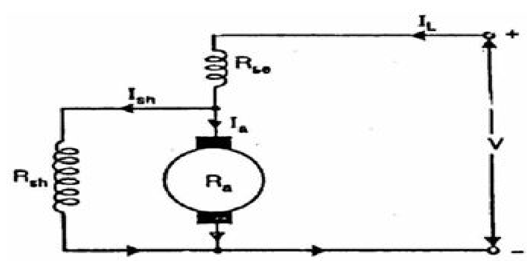
ii. Series Wound Motor

In series wound motor the field winding is connected in series with the armature [See Fig.below]. Therefore, series field winding carries the armature current. Since the current passing through a series field winding is the same as the armature current, series field windings must be designed with much fewer turns than shunt field windings for the same m.m.f.Therefore, a series field winding has a relatively small number of turns of thick wire and, therefore, will possess a low resistance.

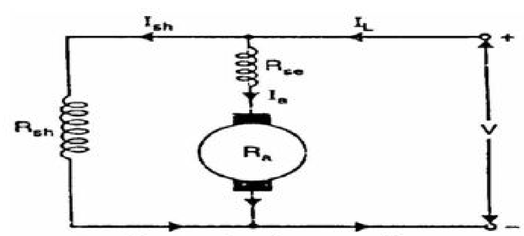


iii. Compound Wound Motor

Compound wound motor has two field windings; one connected in parallel with the armature and the other in series with it. There are two types of compound motor connections (like generators). When the shunt field winding is directly connected across the armature terminals it is called short-shunt connection. When the shunt winding is so connected that it shunts the series combination of armature and series field it is called long-shunt connection.



Short-shunt connection



Long-shunt connection

- Performance is roughly between series-wound and shunt-wound
- Moderately high starting torque
- Moderate speed control
- Inherently controlled no-load speed
  - safer than a series motor where load may be disconnected

e.g. cranes

1.4.7. Starting Methods of DC Motor

If we apply full voltage to a stationary DC motor, the starting current in thearmature will be very high and we run the risk of

- Burning out the armature;
- Damaging the commutator and brushes, due to heavy sparking;
- Overloading the feeder;
- Snapping off the shaft due to mechanical shock;
- Damaging the driven equipment because of the sudden mechanical hammer blow.

All dc motors must, therefore, be provided with a means to limit the starting current to reasonable values, usually between 1.5 and twice full-load current. One solution is to connect a rheostat in series with the armature. The resistance is gradually reduced as the motor accelerates and is eventually eliminated entirely.

1.5. Dc Generator

An electric generator is a machine that converts mechanical energy into electrical energy. An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by Fleming's right hand rule. Therefore, the essential components of a generator are:

(a) a magnetic field
(b) conductor or a group of conductors
(c) Motion of conductor w.r.t. magnetic field

1.5.1. Construction of d.c. Generator

The d.c. generators and d.c. motors have the same general construction. In fact, when the machine is being assembled, the workmen usually do not know whether it is a d.c. generator or motor. Any d.c. generator can be run as a d.c. motor and vice-versa. All d.c. machines have five principal components viz. (i) field system (ii) armature core (iii) armature winding (iv) commutator (v)brushes.

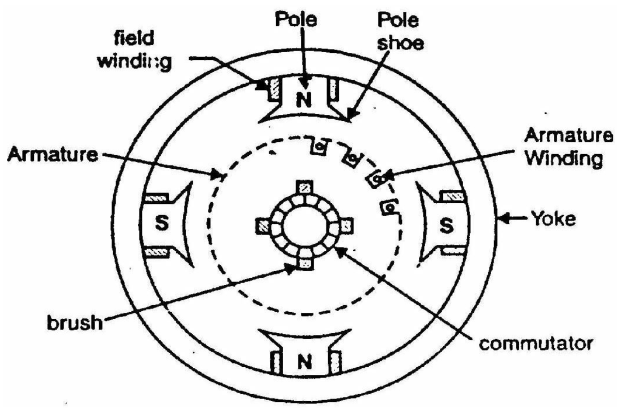


Fig. 5.3.1 d.c. generators

✓ **Field system**

The function of the field system is to produce uniform magnetic field within which the armature rotates. It consists of a number of salient poles (of course, even number) bolted to the inside of circular frame (generally called yoke). The m.m.f. developed by the field coils produces a magnetic flux that passes through the pole pieces, the air gap, the armature and the frame.

Practical d.c. machines have air gaps ranging from 0.5 mm to 1.5 mm. Since armature and field systems are composed of materials that have high permeability, most of the m.m.f. of field coils is required to set up flux in the air gap. By reducing the length of air gap, we can reduce the size of field coils (i.e. number of turns).

✓ **Armature core**

The armature core is keyed to the machine shaft and rotates between the field poles. It consists of slotted soft-iron laminations (about 0.4 to 0.6 mm thick) that are stacked to form a cylindrical core as shown in Fig below. The laminations (See Fig. below) are individually coated with a thin insulating film so that they do not come in electrical contact with each other. The purpose of laminating the core is to reduce the eddy current loss. The laminations are slotted to accommodate and provide mechanical security to the armature winding and to give shorter air gap for the flux to cross between the pole face and the armature "teeth".

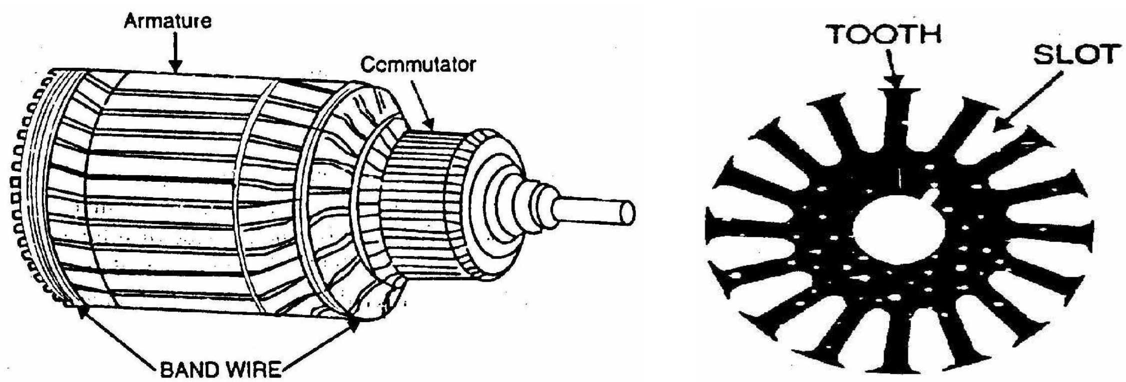


Fig. 5.3.2. Armature Core

1.5.2. Armature winding

The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as armature winding. This is the winding in which "working" e.m.f. is induced. The armature conductors are connected in series-parallel; the conductors being connected in series so as to increase the voltage and in parallel paths so as to increase the current. The armature winding of a d.c. machine is a closed-circuit winding; the conductors being connected in a symmetrical manner forming a closed loop or series of closed loops.

1.5.3. Commutator

A commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes. The commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine. The armature conductors are soldered to the commutator segments in a suitable manner to give rise to the armature winding. Depending upon the manner in which the armature conductors are connected to the commutator segments, there are two types of armature winding in a d.c. machine viz., (a) lap winding (b) wave winding

1.5.4. Brushes

The purpose of brushes is to ensure electrical connections between the rotating commutator and stationary external load circuit. The brushes are made of carbon and rest on the commutator. The brush pressure is adjusted by means of adjustable springs (See Fig. 5.4.3). If the brush pressure is very large, the friction produces heating of the commutator and the brushes. On the other hand, if it is too weak, the imperfect contact with the commutator may produce sparking.

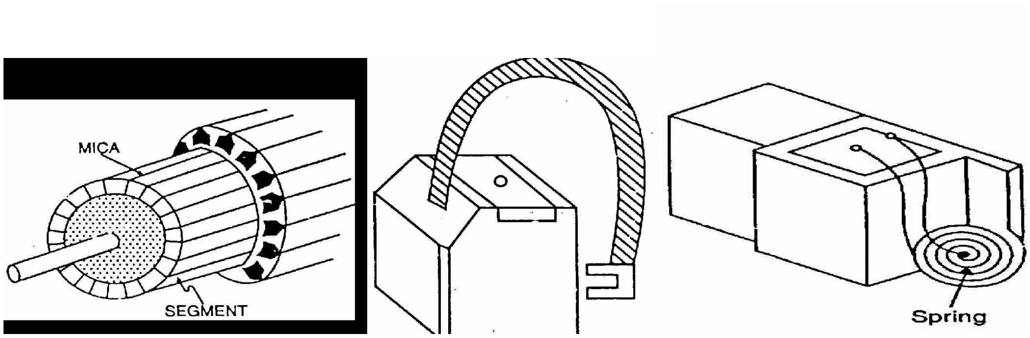


Fig. 5.4.3.

Multi pole machines have as many brushes as they have poles. For example, a 4-pole machine has 4 brushes. As we go round the commutator, the successive brushes have positive and negative polarities. Brushes having the same polarity are connected together so that we have two terminals viz., the +ve terminal and the -ve terminal.

1.6. Types and operation of AC Machines

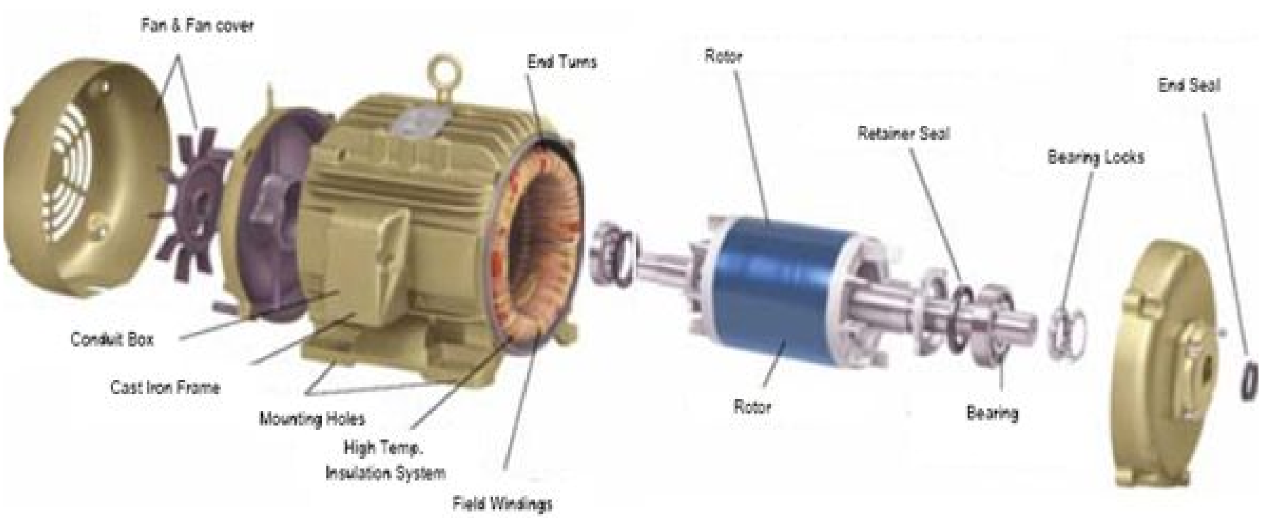
1.6.1. Introduction

Ac machine are motor that convert a.c electrical energy to mechanical energy and generator that convert mechanical energy to a.c electrical energy. A set of three phase a.c voltage is induced in to the stator armature winding of an a.c machine by the rotor field winding (generator action). AC machines, also known as induction machines, use ac (alternating current i.e. sinusoidal) voltages and currents to establish the required magnetic fields, and utilize ac values at its terminals .Induction machines are the most widely used type of electric machine, and can range in size from small sub one-horsepower machines to large many thousands of horsepower machines. The larger ac machines use what is known as three phase power and will be the type of machine we will focus on.

When a single-phase supply is connected to a single stator winding it provides an alternating rather than a rotating magnetic field and the rotor will not turn. However, single-phase motors will run successfully provided that an initial start is given to the rotor. They will run in either direction depending on the direction of the initial start. This initial start is produced by providing an artificial phase, which simulates a two-phase supply. In order to create this artificial phase, single-phase induction motors are manufactured with two separate windings. These windings are connected in parallel with each other during starting. One winding is called the Main Winding (or Run Winding),while the other winding is called the Auxiliary Winding (or Start Winding). The main winding is always left in circuit, but the auxiliary winding may be disconnected once the motor has started.

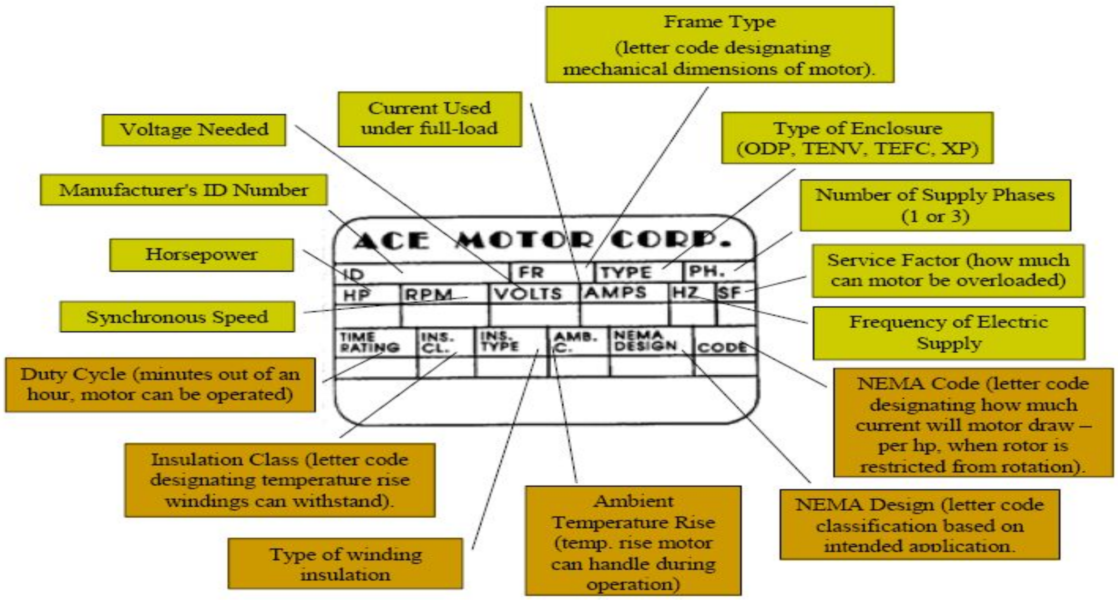
They are in common use, particularly in domestic, agricultural and commercial spheres. Single-phase induction motors cannot compete with the performance or efficiency of three-phase induction motors. They are more troublesome, mainly on account of the ancillary starting equipment required. They are also physically larger than equally rated three-phase motors.

1.6.2. Parts of Ac Motor



1.6.3. AC Motor Data Plate

Each motor has a plate mounted on its frame, with electrical and mechanical information.



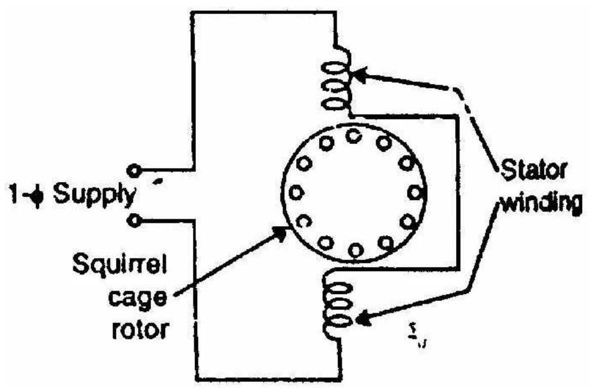
1.6.4. Types of AC Motors

1.6.4.1. Single-phase Induction Motor

single phase a.c motors as the name suggests, these motors are used on single-phase supply. Single phase motors are the most familiar of all electric motors because they are extensively used in home appliances, shops, offices etc. It is true that single phase motors are less efficient substitute for 3-phase motors but 3-phase power is normally not available except in large commercial and industrial establishments. Since electric power was originally generated and distributed for lighting only, millions of homes were given single-phase supply. This led to the development of single-phase motors. Even where 3-phase mains are present, the single-phase supply may be obtained by using one of the three lines and the neutral. In this chapter, we shall focus our attention on the construction, working and characteristics of commonly used single-phase motors

- **Construction single phase induction motor**

A single phase induction motor is very similar to a 3-phase squirrel cage_induction motor. It has (i) a squirrel-cage rotor identical to a 3-phase motor and_(ii) a single-phase winding on the stator. Unlike a 3-phase induction motor, a single-phase induction motor is not self-starting but requires some starting means. The single-phase stator winding produces a magnetic field that pulsates in strength in a sinusoidal manner. The field polarity reverses after each half cycle but the field does not rotate. Consequently, the alternating flux cannot produce rotation in a stationary squirrel-cage rotor. However, if the rotor of a single-phase motor is rotated in one direction by some mechanical means, it will continue to run in the direction of rotation. As a matter of fact, the rotor quickly accelerates until it reaches a speed slightly below the synchronous speed. Once the motor is running at this speed, it will continue to rotate even though single-phase current is flowing through the stator winding. This method of starting is generally not convenient for large motors. Nor can it be employed fur a motor located at some inaccessible spot.



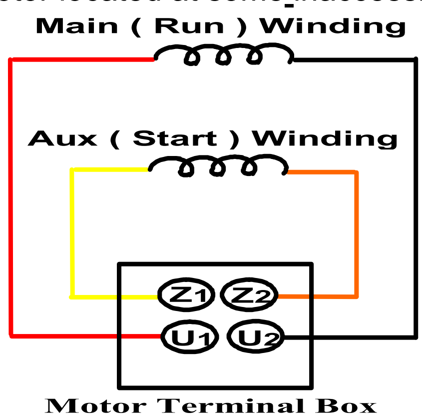


Fig 5.4.1. Single-phase induction motor

Having a squirrel cage rotor and a single phase distributed stator winding. Such a motor inherently docs not develop any starting torque and, therefore, will not start to rotate if the stator winding is connected to single-phase a.c. supply. However, if the rotor is started by auxiliary means, the motor will quickly attain me final speed.

- **Types of Single-Phase Motors**

Single-phase motors are generally built in the fractional-horsepower range and may be classified into the following four basic types:

(a) Single-phase induction motors
  (i) Split-phase type
  (ii) Capacitor type
  (iii) Shaded-pole type
(b) A.C. series motor or universal motor
(c) Repulsion motors
  (i) Repulsion-start induction-run motor

(ii) Repulsion-induction motor

(a) Single-phase induction motors

i. split-phase induction motor

The stator of a split-phase induction motor is provided with an auxiliary or starting winding S in addition to the main or running winding M. The starting winding is located 90° electrical from the main winding and operates only during the brief period when the motor starts up. The two windings are so resigned that the starting winding S has a high resistance and relatively small reactance while the main winding M has relatively low resistance and large reactance consequently, the currents flowing in the two windings have reasonable phase difference c (25° to 30°)

ii. capacitor-start motor

The capacitor-start motor is identical to a split-phase motor except that the starting winding has as many turns as the main winding. Moreover, a capacitor C is connected in series with the starting winding .The value of capacitor is so chosen that Is leads Induction motor by about 80° (i.e., 75~ 80°)which is considerably greater than 25° found in split-phase motor . Consequently, starting torque (Ts = k Im Is sin &) is much more than that of a split-phase motor Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed

- **Characteristics of single phase capacitor-start motor**

Although starting characteristics of a capacitor-start motor are better than those of a split-phase motor, both machines possess the same running characteristics because the main windings are identical. The phase angle between the two currents is about 80° compared to about25° in a split-phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a split-phase motor. Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.

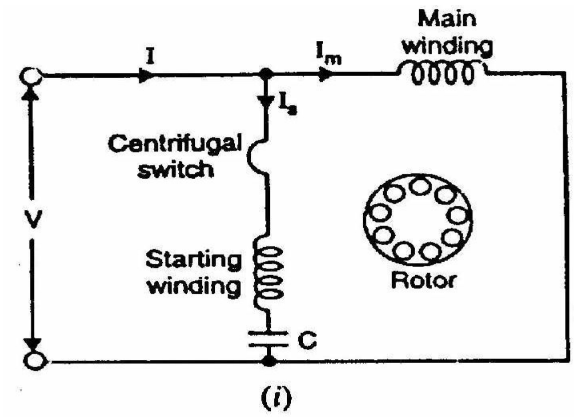


Fig 5.4.2. Capacitor-start motors

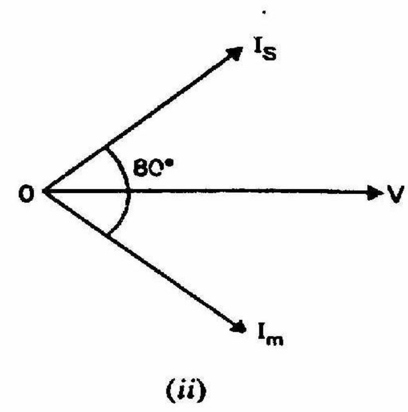


Fig 5.4.2. phaser diagram

Capacitor-start motors are used where high starting torque is required andwhere the starting period may be long e.g., to drive:

- compressors
- large fans
- Pumps
- high inertia loads

The power rating of such motors lies between 120 W and 7-5 kW.

iii. capacitor-start capacitor - run motor

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting. Two designs are generally used. (i) In one design, a single

capacitor C is used for both starting and running as shown in Fig.(5.4.3. (i)). This design eliminates the need of a centrifugal switch and at the same time improve the power factor and efficiency of the motor.

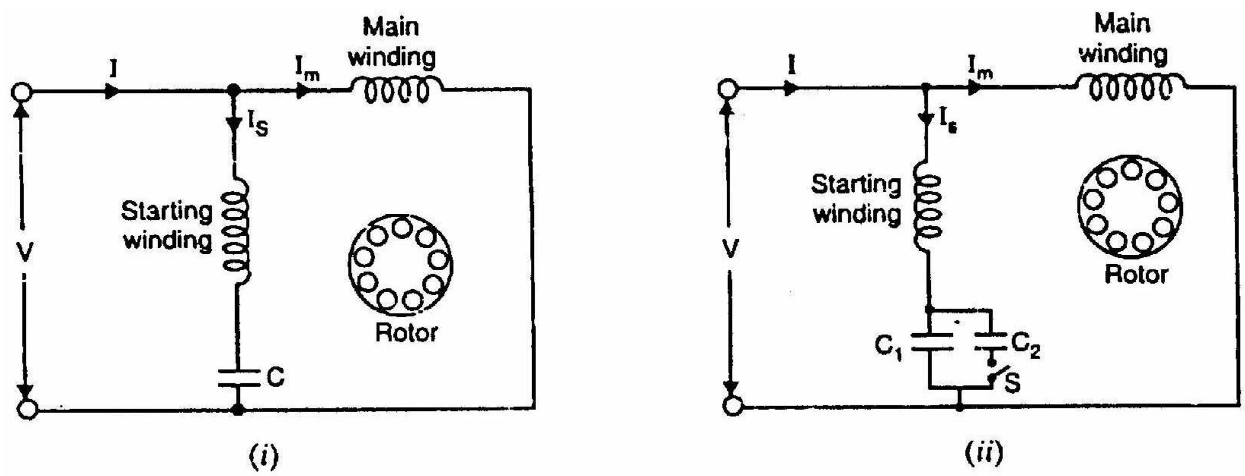
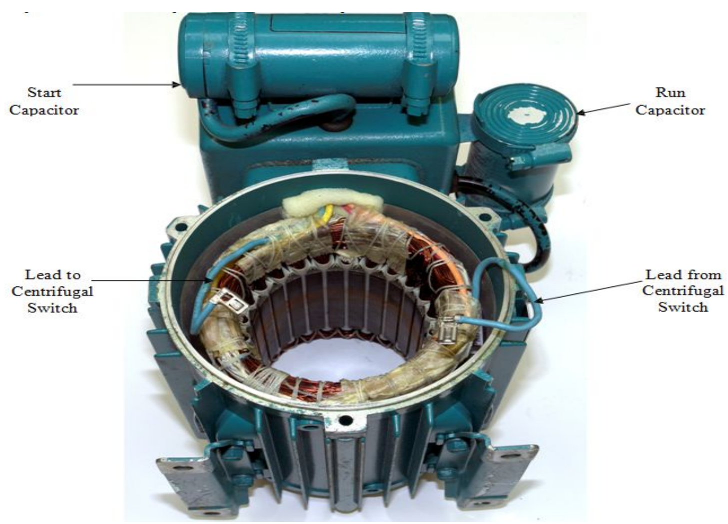


Fig 5.4.3. Capacitor-start capacitor - run motor



In the other design, two capacitors C1 and C2 are used in the starting winding as shown in Fig. 5.4.3. (ii)). The smaller capacitor C1 required for optimum running conditions is permanently connected in series with the starting winding. The much larger capacitor C2 is connected in parallel withC1 for optimum starting and remains in the circuit during starting. The starting capacitor C1 is disconnected when the motor approaches about 75%of synchronous speed. The motor then runs as a single-phase induction motor

iv. shaded-pole motor

The shaded-pole motor is very popular for ratings below 0.05 H.P.(~ 40 W) because of its extremely simple construction. It has salient poles on the stator excited by single-phase supply and a squirrel cage rotor as shown in Figure 5.2.4. A portion of each pole is surrounded by a short-circuitedturn of copper strip called shading

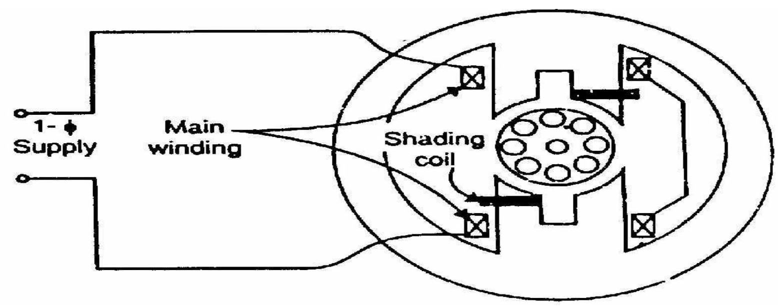


Figure 5.4.4. Shaded-pole motor

- **Characteristics shaded-pole motor**

✓ The salient features of this motor are extremely simple construction and absence of centrifugal switch.

✓ Since starting torque, efficiency and power factor are very low, these motors are only suitable for low power applications e.g., to drive:
  - small fans
  - toys
  - hair driers
  - desk fans etc.

The power rating of such motors is up to about 30 W.

(b) A.c series motor or universal motor

A d.c. series motor will rotate in the same direction regardless of the polarity of the supply. One can expect that a d.c. series motor would also operate on a single-phase supply. It is then called an a.c. series motor. However, some changes must be made in a d.c. motor that is to operate satisfactorily on a.c. supply.

- **Operation of universal motor**

When the motor is connected to an a.c. Supply, the same alternating current flows through the field and armature windings. The field winding produces an alternating flux that reacts with the current flowing in the armature to produce a torque. Since both armature current and flux reverse simultaneously, the torque always acts in the same direction. It may be noted that no rotating flux is produced in this type of machines; the principle of operation is the same as that of a d.c. series motor.

- **Characteristics of universal motor**

The operating characteristics of an a.c. series motor are similar to those of a d.c. series motor.

- The speed increases to a high value with a decrease in load. In very small series motors, the losses are usually large enough at no load that limits the speed to a definite value (1500 - 15,000 r.p.m.).
- The motor torque is high for large armature currents, thus giving a high starting torque.
- At full-load, the power factor is about 90%. However, at starting or when carrying an overload, the power factor is lower

- **Applications of universal motor**

The fractional horsepower a.c. series motors have high-speed (and corresponding small size) and large starting torque. They can, therefore, be used to drive:

- high-speed vacuum cleaners
- sewing machines
- electric shavers
- drills
- machine tools etc

c) Single-Phase Repulsion Motor

A repulsion motor is similar to an a.c. series motor except that brushes are not connected to supply but are short-circuited [See Fig.5.2.5). Consequently, currents are induced in the armature conductors by transformer action. the field structure has non-salient pole construction. By adjusting the position of short-circuited brushes on the commutator, the starting torque can be developed in the motor.

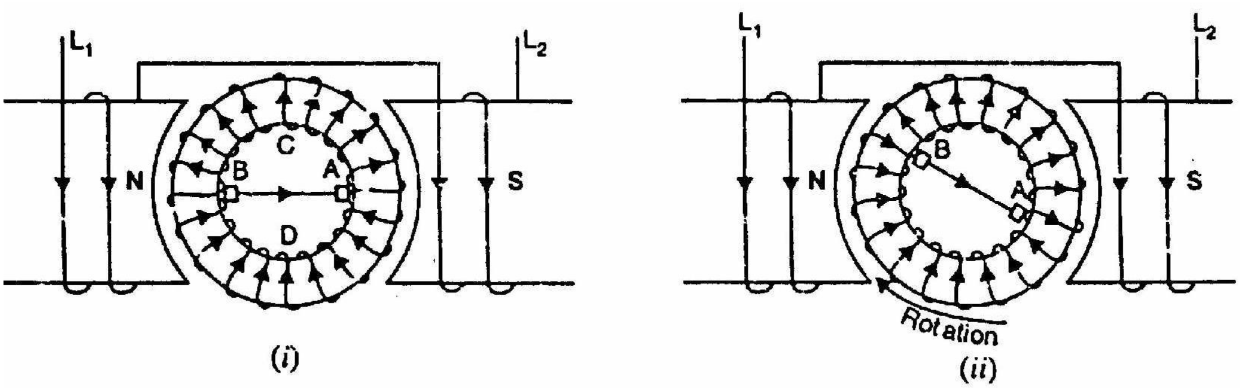


Fig. 5.4.5. repulsion motor

- **Construction Single-Phase Repulsion Motor**

The field of stator winding is wound like the main winding of a split-phase motor and is connected directly to a single-phase source. The armature or rotor is similar to a d.c. motor armature with drum type winding connected to a commutator (not shown in the figure). However, the brushes are not connected to supply but are connected to each other or short-circuited. Short-circuiting the brushes effectively makes the rotor into a type of squirrel cage. The major difficulty with an ordinary single-phase induction motor is the low starting torque. By using a commutator motor with brushes short-circuited, it is possible to vary the starting torque by changing the brush axis. It has also better power factor than the conventional single-phase motor.

- **Characteristics of single phase repulsion motor**

✓ The repulsion motor has characteristics very similar to those of an a.c. series motor i.e., it has a high starting torque and a high speed at no load.

✓ The speed which the repulsion motor develops for any given load will depend upon the position of the brushes.

✓ In comparison with other single-phase motors, the repulsion motor has a high starring torque and relatively low starting current.

1.6.4.2. The three-phase induction motors

- **Introduction**

The three-phase induction motors are the most widely used electric motors in industry. They run at essentially constant speed from no-load to full-load. However, the speed is frequency dependent and consequently these motors are not easily adapted to speed control. We usually prefer d.c. motors when large speed variations are required. Nevertheless, the 3-phase induction motors are simple, rugged, low-priced, easy to maintain and can be manufactured with characteristics to suit most industrial requirements. In this chapter, we shall focus our attention on the general principles of 3-phase induction motors.

Like any electric motor, a 3-phase induction motor has a stator and a rotor. The stator carries a 3-phase winding (called stator winding) while the rotor carries a short-circuited winding (called rotor winding). Only the stator winding is fed from 3-phase supply. The rotor winding derives its voltage and power from the externally energized stator winding through electromagnetic induction and hence the name. The induction motor may be considered to be a transformer with a rotating secondary and it can, therefore, be described as a “transformer type” a.c. machine in which electrical energy is converted into mechanical energy.

- **Advantages 3-phase induction motor**

  - ✓ It has simple and rugged, almost un breakable construction.
  - ✓ It is relatively cheap.
  - ✓ It requires little maintenance.
  - ✓ It has high efficiency and reasonably good power factor.
  - ✓ It has self starting torque

- **Disadvantages**

  - ✓ It is essentially a constant speed motor and its speed cannot be changed easily.
  - ✓ Its starting torque is inferior to d.c. shunt motor.

- **Construction of A 3-phase induction motor**

A 3-phase induction motor has two main parts (i) stator and (ii) rotor. The rotor is separated from the stator by a small air-gap which ranges from 0.4mm to 4mm, depending on the power of the motor.

✓ **Stator**

It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses. A number of evenly spaced slots are provided on the near periphery of the lamination A 3-phase induction motor. The insulated connected to form a balanced 3-phase star or delta connected circuit. The 3-phase stator winding is wound for a definite number of poles as per requirement of speed. Greater the number of poles, lesser is the speed of the motor and vice-versa. When 3-phase supply is given to the stator winding, a rotating magnetic field of constant magnitude is produced. This rotating field induces currents in the rotor by electromagnetic induction.

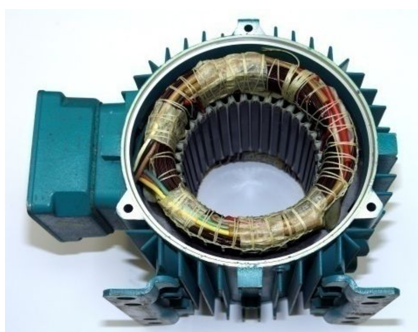


Fig.5.2.6. stator winding

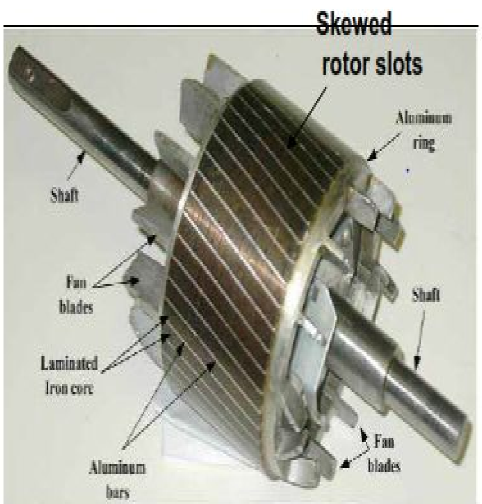
✓ **Rotor**

The rotor, mounted on a shaft, is a hollow laminated core having slots on its outer periphery. The winding placed in these slots (called rotor winding) may be one of the following two types:

(i) Squirrel cage rotor
(ii) Wound rotor

i. Squirrel cage rotor.

It consists of a laminated cylindrical core having parallel slots on its outer periphery. One copper or aluminum bar is placed in each slot. All these bars are joined at each end by metal rings called end rings. This forms a permanently short-circuited winding which is indestructible. The entire construction (bars and end rings) resembles a squirrel cage and hence the name. The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator. Those induction motors which employ squirrel cage rotor are called squirrel cage induction motors. Most of 3-phase induction motors use squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances. However, it suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque.



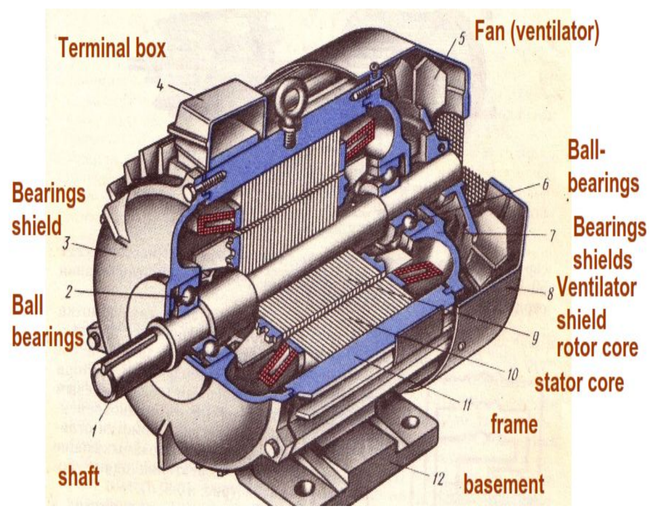


Fig. 5.4.7. squirrel cage rotor

ii. Wound rotor.

It consists of a laminated cylindrical core and carries a 3-phase winding, similar to the one on the stator. The rotor winding is uniformly distributed in the slots and is usually star-connected. The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring. The three brushes are connected to a 3-phase star-connected rheostat. At starting, the external resistances are included in the rotor circuit to give a large starting torque.

These resistances are gradually reduced to zero as the motor runs up to speed. The external resistances are used during starting period only. When the motor attains normal speed, the three brushes are short-circuited so that the wound rotor runs like a squirrel cage rotor.

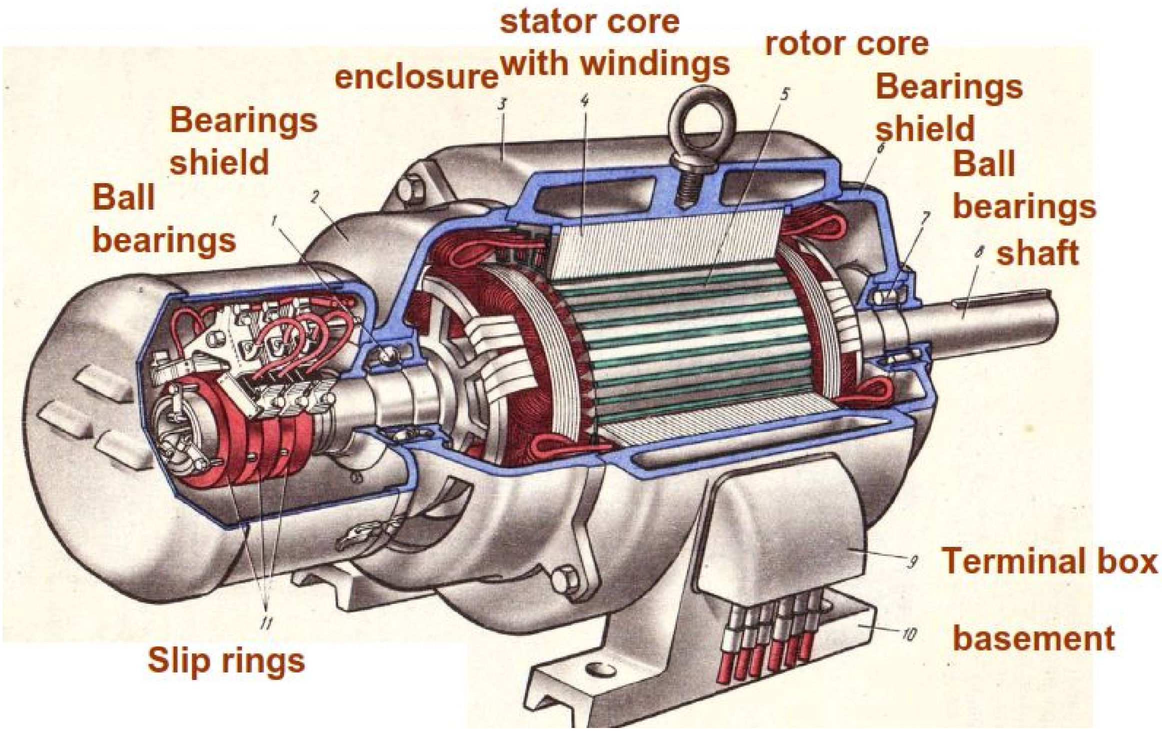


Fig. 5.4.8. wound rotor motor

- **Principle of Operation**

When a 3-phase winding is energized from a 3-phase supply, a rotating magnetic field is produced. This field is such that its poles do no remain in a fixed position on the stator but go on shifting their positions around the stator. For this reason, it is called a rotating Held. It can be shown that magnitude of this rotating field is constant and is equal to 1.5 m where m is the maximum flux due to any phase .To see how rotating field is produced, consider a 2-pole,phase winding a The three phases X, Y and Z are energized from a 3-phase source and currents in these phases are indicated as Ix, Iy and Iz the fluxes produced by these currents are given by Here m is the maximum flux due to any phase. Fig.5.2.9. shows the phasor

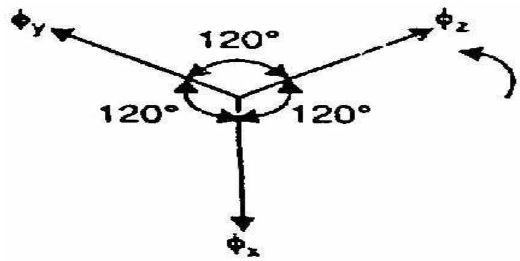


Fig 5.4.9 the phasor diagram

Consider a portion of 3-phase induction motor. The operation of the motor can be explained as when 3-phase stator winding is energized from a 3-phase supply, a rotating magnetic field is set up which rotates round the stator at synchronous speed Ns (= 120 f/P).The rotating field passes through the air gap and cuts the rotor conductors, which as yet, are stationary. Due to the relative speed between the rotating flux and the stationary rotor, e.m.f.s are induced in the rotor conductors. Since the rotor circuit is short-circuited, currents start flowing in the rotor conductors. The current-carrying rotor conductors are placed in the magnetic field produced by the stator. Consequently, mechanical force acts on the rotor conductors. The sum of the mechanical forces on all the rotor conductors produces a torque which tends to move the rotor in the same direction as the rotating field. The fact that rotor is urged to follow the stator field (i.e., rotor moves in the direction of stator field) can be explained by Lenz's law. According to this law, the direction of rotor currents will be such that they tend to oppose the cause producing them. Now, the cause producing the rotor currents is the relative speed between the rotating field and the stationary rotor conductors. Hence to reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch it.

- **Direction of rotating magnetic field**

The phase sequence of the three-phase voltage applied to the stator winding is X-Y-Z. If this sequence is changed to X-Z-Y, it is observed that direction of rotation of the field is reversed i.e., the field rotates counterclockwise rather than clockwise. However, the number of poles and the speed at which the magnetic field rotates remain unchanged. Thus it is necessary only to change the phase sequence in order to change the direction of rotation of the magnetic field. For a three-phase supply, this can be done by interchanging any two of the three lines. As we shall see, the rotor in a 3-phase induction motor runs in the same direction as the rotating magnetic field. Therefore, the direction of rotation of a 3-phase induction motor can be reversed by interchanging any two of the three motor supply lines.

- **Slip**

We have seen above that rotor rapidly accelerates in the direction of rotating field. In practice, the rotor can never reach the speed of stator flux. If it did, there would be no relative speed between the stator field and rotor conductors, no induced rotor currents and, therefore, no torque to drive the rotor. The friction and windage would immediately cause the rotor to slow down. Hence, the rotor speed (N) is always less than the suitor field speed (Ns). This difference in speed depends upon load on the motor. The difference between the synchronous speed Ns of the rotating stator field and the actual rotor speed N is called slip. It is usually expressed as a percentage of synchronous speed.

i.e. % age slip, $s=Ns-N/Ns \times 100$

i. The quantity Ns □□N is sometimes called slip speed.
ii. When the rotor is stationary (i.e., N = 0), slip, s = 1 or 100 %.
iii. In an induction motor, the change in slip from no-load to full-load is hardly 0.1% to 3% so that it is essentially a constant-speed motor

- **Rotor Current Frequency**

The frequency of a voltage or current induced due to the relative speed between a vending and a magnetic field is given by the general formula

$Frequency=NP/120$

where N = Relative speed between magnetic field and the winding

P = Number of poles

For a rotor speed N, the relative speed between the rotating flux and the rotor is Ns =N. Consequently, the rotor current frequency f' is given by; $f'=(Ns-N)/120$

$S=Nsp/120=Sf$

$S=Ns-N/Ns$

$f=Nsp/120$

- **Squirrel cage motors**

The speed of a squirrel cage motor is changed by changing the number of stator poles. Only two or four speeds are possible by this method. Two-speed motor has one stator winding that may be switched through suitable control equipment to provide two speeds, one of which is half of the other. For instance, the winding may be connected for either 4 or 8 poles, giving synchronous speeds of 1500 and 750 r.p.m. Four-speed motors are equipped with two separate stator windings each of which provides two speeds. The disadvantages of this method are:

i. It is not possible to obtain gradual continuous speed control.
ii. Because of the complications in the design and switching of the interconnections of the stator winding, this method can provide amaximum of four different synchronous speeds for any one motor

- **Wound rotor motors**

The speed of wound rotor motors is changed by changing the motor slip. This can be achieved by;

i. varying the stator line voltage
ii. varying the resistance of the rotor circuit
iii. inserting and varying a foreign voltage in the rotor circuit

- **Power Stages in an Induction Motor**

The input electric power fed to the stator of the motor is converted into mechanical power at the shaft of the motor. The various losses during the energy conversion are:

✓ **Fixed losses**

i. Stator iron loss
ii. Friction and windage loss

The rotor iron loss is negligible because the frequency of rotor currents under normal running condition is small.

✓ **Variable losses**

i. Stator copper loss

ii. Rotor copper loss

Electric power fed to the stator of an induction motor suffers losses and finally converted into mechanical power. The following points may be noted from the above diagram:

(a) Stator input, Pi = Stator output + Stator losses

= Stator output + Stator Iron loss + Stator Cu loss

(b) input, Pr = Stator output

It is because stator output is entirely transferred to the rotor through airgap by electromagnetic induction.

(c) Mechanical power available, Pm = Pr□□Rotor Cu loss

This mechanical power available is the gross rotor output and will produce a gross torque Tg.

(d) Mechanical power at shaft, Pout = Pin Friction and windage loss

Mechanical power available at the shaft produces a shaft torque Tsh. Clearly, $P_m - P_{out}$ = Friction and windage loss

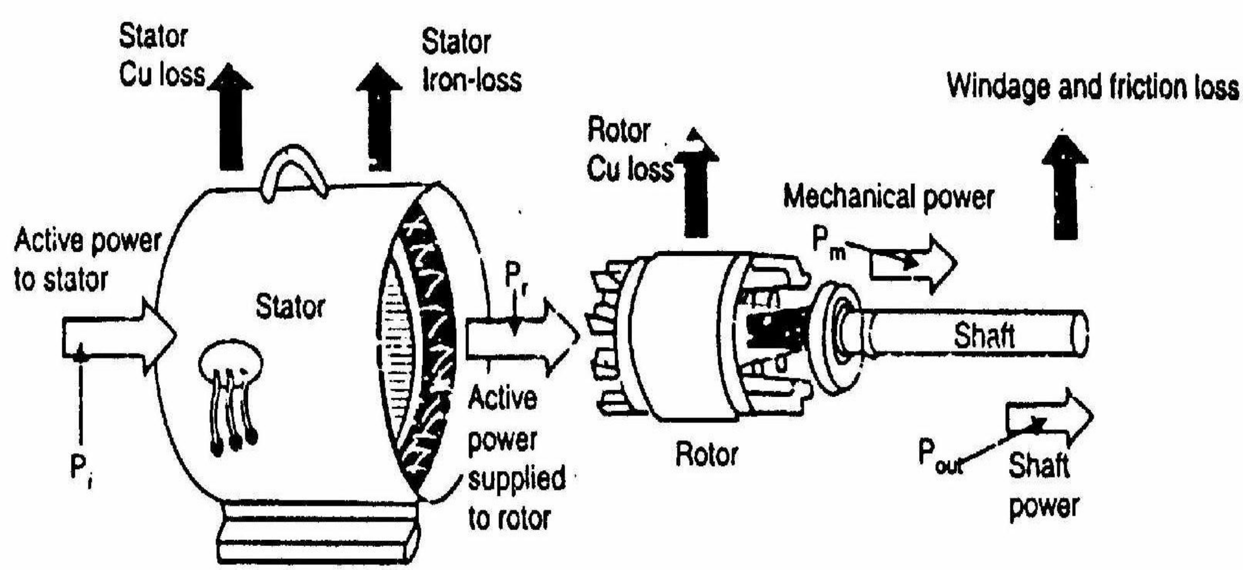


Fig. 5.4.10. stator and rotor loss

1.6.5. Ac generator

An electrical generator that converts mechanical energy to electrical energy in the form of alternating current. For reasons of cost and simplicity, most alternators use a rotating magnetic field with a stationary armature. Occasionally, a linear alternator or a rotating armature with a stationary magnetic field is used. In principle, any *AC electrical generator* can be called an alternator, but usually the term refers to small rotating machines driven by *automotive* and other *internal combustion engines.* An alternator that uses a permanent magnet for its magnetic field is called a magneto. Alternators in power stations driven by steam turbines are called turbo-alternators. Large 50 or 60 Hz three phase alternators in power plants generate most of the world's electric power, which is distributed by electric power**.** all electrical generators, whether dc or ac, depend upon the principle of magnetic induction. An emf is induced in a coil as a result of

- ✓ a coil cutting through a magnetic field, or
- ✓ a magnetic field cutting through a coil. As long as there is relative motion between a conductor and a magnetic field, a voltage will be induced in the conductor.

That part of a generator that produces the magnetic field is called the field. That part in which the voltage is induced is called the armature. For relative motion to take place between the conductor and the magnetic field, all generators must have two mechanical parts a rotor and a stator. The Rotor is the part that Rotates; the Stator is the part that remains Stationary. In a dc generator, the armature is always the rotor. In alternators, the armature may be either the rotor or stator.

1.6.5.1. Types of ac generators

Various types of alternating current generators are utilized today ,whoever they all perform the same basic function .the types discussed in the following paragraphs are typical of the more predominant ones in use .

i. Rotating armature alternator

In the rotating armature AC generator as illustrated in Fig 5.4.11, the stator provides a stationary electromagnetic field. The rotor, acting as the armature, rotates in the field, cutting the lines of force and producing the desired output voltage. The output voltage is taken from the rotor by the slip rings and brushes. One slip ring is attached to each end of the rotating loop.

The brushes make sliding electrical contact with the slip rings. The generator's AC output voltage can be transferred from the slip ri ngs through the brushes to an external circuit.

Rotating armature alternator is essentially a loop rotating through a stationary magnetic fealties cutting action of the loop through the magnetic field generates ac in the loop. This ac is removed from the loop by means of slip rings and applied to an external load.

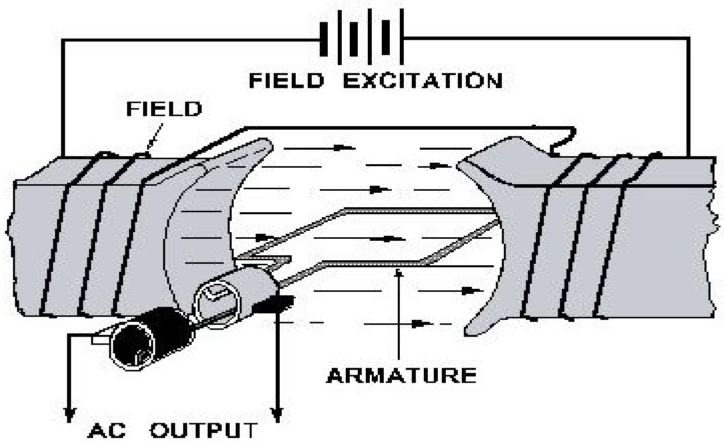


Fig 5.4.11 Rotating armature alternator

Rotating armature AC generators are typically used i n applications involving small amounts of power. With larger amounts of power, a great deal more current flow occurs through the slip rings and brushes. It is difficult and expensive to build slip rings and brushes to carry large amounts of current. Therefore, most large AC generators are rotating field generators.

ii. Rotating Field Generator

The rotating field AC generator as illustrated in Fig 5.4.12. is by far the most widely used generator. In this type of generator, direct current from a separate source is passed through wiendings on the rotor by means of slip rings and brushes.

This maintain ns a rotating electromagnetic field of fi xed polarity (similar to a rotating bar magnet). The rotating magnetic field of the rotor extends outward and cuts through the armature windings embedded in the surrounding stator. As the rotor turns, alternating voltages are induced i n the windings because magnetic fields of first one polarity and then the other cut through them. Because the output power is taken from stationary windings, the output may be connected through fixed terminals. The advantage in this type of construction is that larger amounts of currents can be handled because there are no sliding contacts and the whole output circuit is continuously insulated.

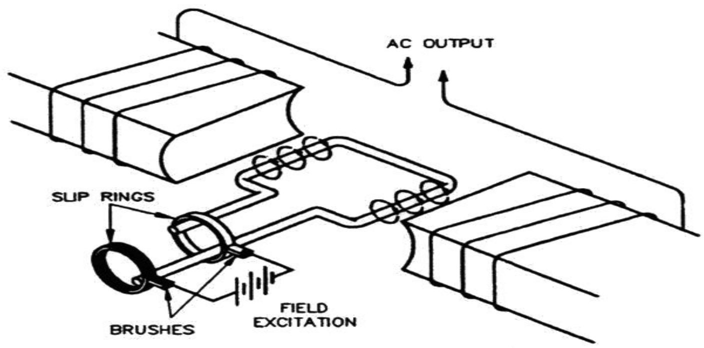


Figure 5.4.12. Rotating Field Generator

Slip rings and brushes are adequate for the DC field supply because the current level in the is much smaller than in than in the armature circuit.

The rotating-field alternator has a stationary armature winding and a rotating-field winding, view B The advantage of having a stationary armature winding is that the generated voltage can be connected directly to the load. A rotating armature requires slip rings and brushes to conduct the current from the armature to the load. The armature, brushes, and slip rings are difficult to insulate, and arc-overs and short circuits can result at high voltages. For this reason, high-voltage alternators are usually of the rotating-field type. Since the voltage applied to the rotating field is low voltage dc, the problem of high voltage arc-over at the slip rings does not exist. The stationary armature, or stator, of this type of alternator holds the windings that are cut by the rotating magnetic field. The voltage generated in the armature as a result of this cutting action is the ac power that

will be applied to the load. The stators of all rotating-field alternators are about the same. The stator consists of a laminated iron core with the armature windings embedded in this core as shown in figure 5.4.12.The core is secured to the stator frame.

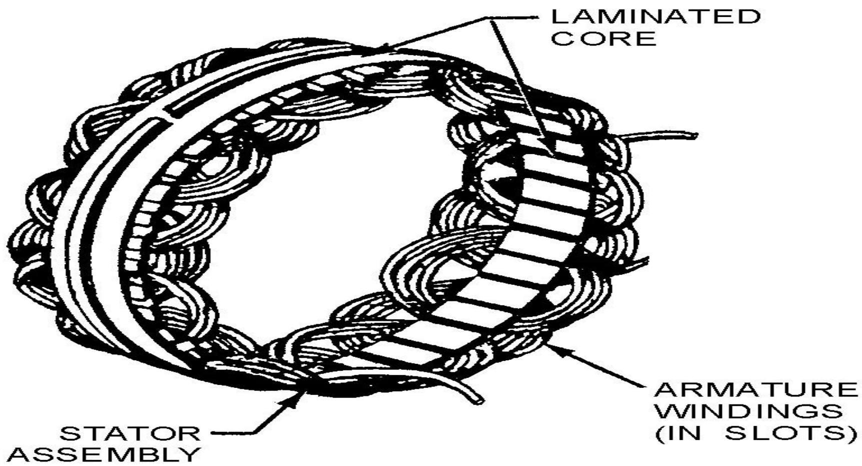


Fig. 5.4.12. stator frame

1.6.5.2. SINGLE-PHASE ALTERNATORS

A generator that produces a single, continuously alternating voltage is known as a SINGLE-PHASE alternator. All of the alternators that have been discussed so far fit this definition. The stator (armature) windings are connected in series. The individual voltages, therefore, add to produce a single-phase ac voltage. Fig.5.3.3. shows a basic alternator with its single-phase output voltage.

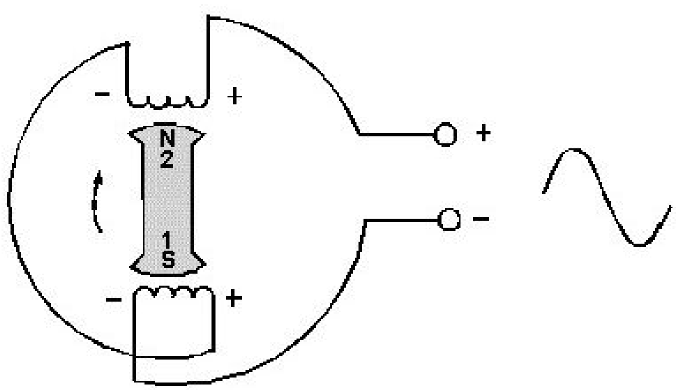


Figure 5.4.13. Single-phase alternator.

Now, it may be easier to think of the word *phase* as meaning voltage as in single voltage. The need for a modified definition of phase in this usage will be easier to see as we go along.

Single-phase alternators are found in many applications. They are most often used when the loads being driven are relatively light. The reason for this will be more apparent as we get into multiphase alternators (also called polyphase).

Power that is used in homes, shops, and ships to operate portable tools and small appliances is single-phase power. Single-phase power alternators always generate single-phase power. However, all single-phase power does not come from single-phase alternators. This will sound more reasonable to you as we get into the next subjects.

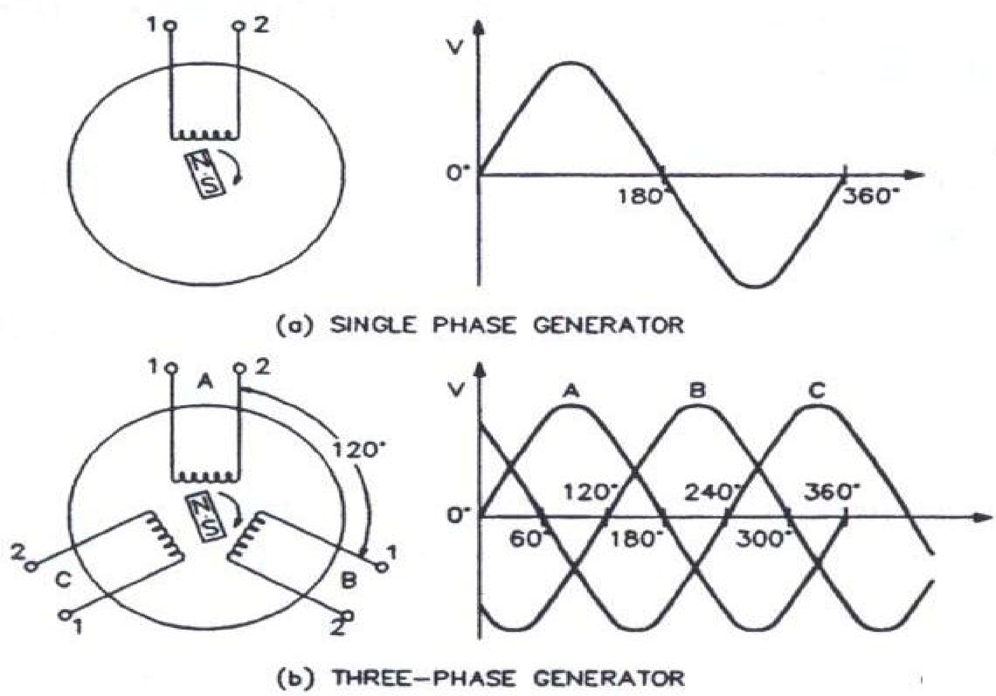


Figure 5.4.15. Voltage Output of a Three-Phase Generator

6. Insulation Resistance Testor (Megger)

If the motor is not put into operation immediately upon arrival, it is important **to protect it against external factors** like moisture, high temperature and impurities in order to avoid damage to the insulation. Before the motor is put into operation after a long period of storage, you have to measure the winding insulation resistance.

If the motor is kept in a place with high humidity, **a periodical inspection is necessary**. It is practically impossible to determine rules for the actual minimum insulation resistance value of a motor because resistance varies according to method of construction, condition of insulation material used, rated voltage, size and type. In fact, it takes many years of experience to determine whether a motor is ready for operation or not.

A general rule-of-thumb is 10 Megohm or more.

Insulation resistance value	Insulation level
2 Meg ohm or less	Bad
2-5 Meg ohm	Critical
5-10 Meg ohm	Abnormal
10-50 Meg ohm	Good
50-100 Meg ohm	Very good
100 Meg ohm or more	Excellent

The measurement of insulation resistance is carried out by means of a meg ohmmeter – high resistance range ohmmeter. This is how the test works: **DC voltage of 500 or 1000 V** is applied between the windings and the ground of the motor.

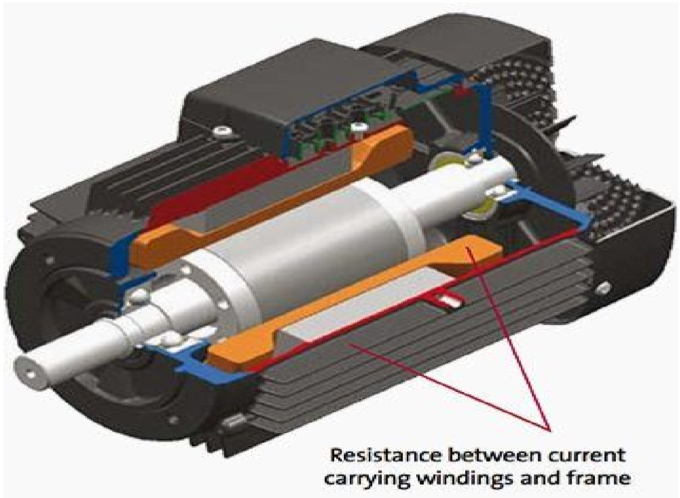


Figure 5.4.16: Ground insulation test of a motor

During the measurement and immediately afterwards, some of the terminals carry dangerous voltages and ***MUST NOT BE TOUCHED.***

Now, three points are worth mentioning in this connection: Insulation resistance, Measurement and Checking.

i. Insulation resistance

4. The minimum insulation resistance of new, cleaned or repaired windings with respect to ground is **10 Meg ohm or more**.
5. The minimum insulation resistance, **R**, is calculated by multiplying the **rated voltage U_n**, with the **constant factor 0.5 Meg ohm/kV**.

   For example: If the rated voltage is 690 V = 0.69 kV, the minimum insulation resistance is: 0.69 kV x 0.5 Meg ohm/kV = **0.35 Meg ohm**

ii. Measurement

- Minimum insulation resistance of the winding to ground is measured with **500 V DC**. The winding temperature should be **25°C ± 15°C**.
- Maximum insulation resistance should be measured with 500 V DC with the windings at a operating temperature of **80 – 120°C** depending on the motor type and efficiency.

iii. Checking

- If the insulation resistance of a new, cleaned or repaired motor that has been stored for some time is less then **10 Mohm**, the reason might be that the windings are humid and need to be dried.
- If the motor has been operating for a long period of time, the minimum insulation resistance **may drop to a critical level**. As long as the measured value does not fall below the calculated value of minimum insulation resistance, the motor can continue to run However, if it drops below this limit, **the motor has to be stopped immediately**, in order to avoid that people get hurt due to the high leakage voltage.

Self-Check -5	Written Test

Directions: Choose the best answer.

1. Which of the following is type of special transformer that is used only for motor control system to reduce the starting current of big motor?
   A. Auto transformer
   B. Welding transformer
   C. Power transformer
   D. All of the above
2. From the given alternative one is not included in instrumentation transformer
   A. Current transformer
   B. Voltage transformer
   C. Auto transformer
   D. All of the above
3. A type of three phase transformer which is commonly used for stepping up to a high voltage.
   A. Δ –Y connection C. Δ – Δ connection
   B. Y – Δ connection D. All of the above
4. The primery and secondary voltage is 220v and 110v respectively, Calculate the secondary number of turn if the primery turn is 100 turns.
   A. 200 turns C. 60 turns
   B. 100 turns D. 50 turns
5. If N2 < N1 then the transformer is known as
   A. step-up transformer
   B. step-down transformer
   C. A and B
   D. None of the above
6. _______ convert a.c electrical energy to mechanical energy?
   A. Single phase motor C. Dc motor
   B. Three phase motor D. A and B
7. _______ is the advantage of a three phase induction motor?
   A. It has self starting torque C. It is relatively cheep

B. Little maintenance
D. All

8. One is not a type of single phase motor?
   A. Shaded pole motor
   C. Universal motor
   B. Capacitor start motor
   D. Squiral cage rotor motor
9. From the given alternative one is not self starting motor?
   A. Shaded pole motor
   C. Wound rotor motor
   B. Squirrel cage rotor motor
   D. B and C
10. The difference between synchronous speed and rotor speed is______?
    A. Centrifugal switch
    C. slip
    B. Voltage regulator
    D. All of the above
11. Machine that converts dc power into mechanical energy is known as
    A. dc motor
    C. ac motor
    B. ac generator
    D. dc generator
12. In ________ motor the field winding is connected in series with the armature
    A. Shunt wound
    C. Compound wound
    B. Series wound
    D. All of the above
13. An electric machine that converts mechanical energy into electrical energy
    A. Generator
    C. Transformer
    B. Motor
    D. None of the above
14. A D.C. generator whose field magnet winding is supplied from an independent external D.C. source.
    A. Self excited generator
    C. A and B

B. Separately excited generator D. None of the above

I. Mach column A with column B.

Column A	Column B
1. Motor	A. Convertion from mechanical to electrical.
2. Dc machines	B. The rotating part of DC machine.
3. Generator	C. Convertion from electrical to mechanical
4. Rotor	D. if the electrical system is DC

***Note:* Satisfactory rating - 10points** **Unsatisfactory - below 10 points**

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

Information Sheet :6	Prepare Work instructions according to machine's manual

6.1. Introduction to work instructions

- More than nine out of 10 workplace accidents are due to human error. These result in serious injuries and cost industry billions of dollars every year. Yet much of this could be avoided with better, clearer work instructions. This guide will show you how to write work instructions – or Standard Operating Procedures.
- Knowing how to write work instructions, or SOPs (Standard Operating Procedures), clearly and concisely for your colleagues ensures they know exactly how their various tasks should be performed. It reduces risk because the likelihood of things going wrong is lessened. It also improves efficiency; work instructions ensure the very best way of doing a job is clear and known to the people doing it.
- Work instructions are also called work guides, Standard Operating Procedures (SOPs), job aids or user manuals, depending on the situation. In any case, the purpose of work instructions is to clearly explain how a particular work task is performed. They're like the step-by-step instructions we receive when we learn to drive a car: check gear stick is in neutral, start ignition, press clutch, change to first gear and so forth.
- What's important is that work instructions should not be confused with processes or process maps. Let's quickly look at where work instructions fit into our overall process documentation levels:

6.2. Important of work instructions

- They reduce the impact when key people leave

Work instructions, or SOPs, build and preserve the knowledge inside a company. When "how things are done" are passed on verbally, there is room for interpretation and human error. And knowledge about how to most efficiently perform a task is lost when said employee leaves the company and takes the knowledge with them. Good work instructions avoid all this.

- Work instructions reduce risk

They reduce risk because the safest way of doing a job is clear and known by the people that matter.

- Avoid errors and “the blame game”

Clarity avoid errors. Crucially, this avoids the blame game. When things go wrong the tendency is to blame or hold people responsible, which is natural. But if this happens often it can have an impact on staff morale. Having clear work instructions minimises this problem.

- Save time

The chart below shows Glue’s own research on the Return on Investment when writing work instructions. The point is that your initial investment in time is paid back once your work instruction has been used just three times. This only refers to time-saving – we haven’t even mentioned the value of avoiding errors and rework. This is also referred to as “Standard Work” within Lean:

6.3. How to write the work instruction

Next, the method of filling in the work instruction will be explained.

(1) Part number/part name

(2) Required amount/Classification number

(3) Affiliation/name

(4) Operation details

(5) Quality

(a) Checks - write the frequency by which the quality of assembled parts is checked, how often do we check an item (or perform one check).
Examples: (This is in the normal operation details)

- 1/1 – The check is performed every cycle.
- 1/10 – One item of every ten items is checked.
- 1/H – One item is checked every hour.
- 2/Shift – Two checks per shift.
- 1/D – One check per day.

(b) Gauges - write the type of measuring instruments (gauges) should be used to check the part.
(6) Key Points - Write the key points required (Corresponding to the work instructions).

Self-Check -6	Written Test

Directions: Choose the best answer

Directions: say true or false

1. More than nine out of 10 workplace accidents are due to human error
2. Work instructions are also called work guides
3. Gauges - write the type of measuring instruments (gauges) should be used to check the part.

Note: **Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ___________

Rating: ____________

Name: _________________________ Date: _____________

Information Sheet :7	Inform the schedule of work for concerned department/personnel

7.1.Report Writing

7.1.1. Formal Reports

A formal report contains the following:

- **Title Page:** includes the title of the project/report, to whom the report is submitted, b y whom it isprepared, the date it is written (*not* the date the report is due!),
- **Abstract:** *a short* paragraph indicating what the project was and what solution was f ound
- **Table of Contents:** contains page numbers of the titles and subtitles of different sec tions of the report.
- **Introduction:** a brief description of the problem, how it was approached, and what procedure wasused to solve it. It may also give the reader some information on wh at was done in the sections followingthe introduction (for longer reports).
- **Development:** describes the details of the methods, procedures, techniques, etc., used in solving theproblem. This section usually has subsections such as model d evelopment, calculations, experimentalprocedure, applications, etc.
- **Discussion:** a discussion of the findings and any discrepancies.
- **Conclusion and Suggestions:** This section is a brief summary of what the findings were and what thesignificance of the work is. If it is a research project, it also cont ains suggestions about future researchareas.

7.1.2. Informal Reports

An informal report consists of a memo plus attachments and contains the following sections

- **Heading** (required)**:** To whom the report is submitted, who wrote it, when it wa s *written* (*not* the datethe report is due!), and what it is about. (An example of the first page of an informal report is included onthe following page.)
- **Summary** (required)**:** The summary is a brief (one or two paragraphs) description of the project andthe results, plus a brief mention of cost and schedule (so that ma nagers don't have to read the entire reportto find this information). It should never e xtend onto the second page of the report and in most cases willnot contain figures, tables, or equations.
- **Design** (optional)**:** Describes how the circuit or system was designed.

- **Testing** (optional)**:** Describes how the circuit or system was constructed and teste
- **Results** or **Conclusion** (required): This section summarizes the results of the project, compares themeasured results to the design goals and numerical simul ations, gives detailed breakdowns of costs andtime spent (if required), etc.

Self-Check -4	Written Test

Directions: say true or false

1. Conclusion and Suggestions:the section is a brief summary of what the findings were and what thesignificance of the work.
2. describes the details of the methods, procedures, techniques, etc., used in solving t heproblem.
3. The summary is a brief (one or two paragraphs) description of the project andthe re sults

Note: **Satisfactory rating - 2 points** **Unsatisfactory - below 2 points**

Score = ___________

Rating: ____________

Name: _________________________ Date: _____________

Operation Sheet :1	Assemble and Disassemble of Dc Motor

Procedures for Assemble and Disassemble of Dc Motor then identify each constructional parts

1. First unfasten (Unlock) all tighten screws by using Allen key, socket wrench or adjustable wrench.
2. Disassemble the end plate of the motor part at both sides.
3. Takeout the armature from the inside of stator.
4. Identify each part of series, shunt and compound wound Dc motors.
5. Assemble all constructional parts of DC motor, according to disassembling procedure or sequence.
6. Set (bring back) all tools and equipment from picked up store room at proper placement.

Operation Sheet :2	Assemble and Disassemble of Ac Motor

Procedures for Assemble and Disassemble of Ac Motor then identify each constructional parts

1. First lose all tighten bolts from their constructional body and carefully collect all bolts and set up in one place.
2. Marked all dismantle parts by marker with their corresponding part.
3. Take out the armature from the inside of stator.
4. Identify each part of squirrel cage and wound rotor Ac motors.
5. Assemble all constructional parts of AC motor, according to disassembling procedure or sequence.
6. Set (bring back) all tools and equipment from picked up store room at proper placement.
7. Assemble all parts from their exact place.
8. Set up (bring back) all tools and equipment from picked up store room at proper placement.

LAP Test	Practical Demonstration

Name: ______________________________ Date: ________________

Time started: _________________________ Time finished: ________________

Instructions: Given necessary templates, tools and materials you are required to perform the following tasks within 2hour.

Task 1. Assemble and disassemble Dc motor then identify each constructional parts.

Task 2. Assemble and disassemble Ac motor then identify each constructional parts.

List of Reference Materials

1. A. Bellini, F. Filippetti, C. Tassoni, G. A. Capolino, "Advances in diagnostic techniques for induction motors", *IEEE Trans. Energy Convers.*, vol. 55, no. 12, pp. 4109-4126, Dec. 2008.

2. M. J. Devaney, L. Eren, "Detecting motor bearing faults", *IEEE Instrum. Meas. Mag.*, vol. 7, no. 4, pp. 30-50, Dec. 2004.

3. J. Faiz, B. M. Ebrahimi, "Mixed fault diagnosis in three-phase squirrel-cage induction motor using analysis of airgap magnetic field", *in Proc. Prog. Electro-Magn. Res. Symp.*, pp. 239-355, 2006.

4. M. E. H. Benbouzid, "A review of induction motors signature analysis as a medium of faults detection", *IEEE Trans. Ind. Electron.*, vol. 47, no. 5, pp. 984-993, Oct. 2000.

5. Eectric Machinery, 6e, Fitzgerald.

6. Principles of electrical machines(mehta)

7. Theraja

The trainers (who developed the Learning Guide)

No	Trainer Name	Education back graund	Region
1	SERKABEBA ABERA	MSC	DEBUB
2	MULU DAMANE	MSC	ADDIAABEBA
3	ABERA GEBRE	BSC	DIRADAWA
4	ESUBALEW AMSALU	MSC	HARER
5	MERON HUSEN	BSC	HARER
6	SHIMELS CHEKOLE	BSC	AMHARA
7	FISIHA BIREHANU	MSC	AMHARA
8	YIMER SEID	MSC	AFAR
9	HINDA IBRAHIM	BSC	SOMALI
10	TADDELE GASHAW	MSC	SOMALI