UNIT-IV
Electrical Machines

Introduction:

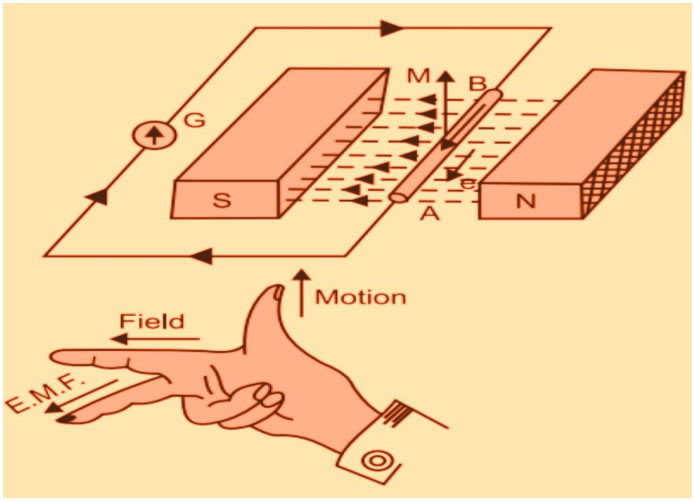
Electric machines are at the heart of our modern world. Whether it is a ceiling fan in your home, an alternator in your car, or a giant generator in a power plant, they all belong to one family – rotating electrical machines. These machines play an important role in industrialization, automation, and electrifying almost every aspect of life.

A rotating electrical machine is a device that converts electrical energy to mechanical energy or vice versa, through the principle of electromagnetic induction.

General Concept of Rotating Electrical Machines

The **general concept of rotating electrical machines** revolves around three principles:

1. **Electromagnetic Induction (Faraday's Law)**
   - Whenever a conductor cuts across magnetic flux, an **EMF (Electromotive Force)** is induced.
     $E=-Nd\Phi/dt$
   - If this conductor is part of a closed path, current flows, and energy transfer occurs.



2. **Lorentz Force**
   - A current-carrying conductor in a magnetic field experiences a force. (F)= q(v*B)
   - F = qBv sinΘ
   - This force is what produces **torque in motors**.
3. **Rotating Magnetic Field**
   - In AC machines, polyphase currents produce a rotating magnetic field in the air gap.
   - The rotor locks into or follows this field, enabling continuous rotation.

- **A generator** is a device that converts Mechanical energy to electrical energy.
- **A motor** is a device that converts electrical energy to mechanical energy.

DC MACHINES:

The dc machine can be operated either as a dc generator or dc motor.

DC GENERATOR

A DC generator converts mechanical energy to electrical energy and produces direct power.

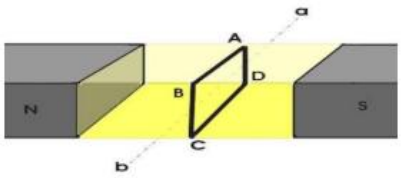
Principle of DC Generator

Based on Faraday's law of electromagnetic induction, when a conductor moves in a magnetic field it cuts magnetic lines of force, due to which an emf is induced in the conductor. The magnitude of this induced emf depends upon the rate of change of flux (magnetic line force) linkage with the conductor. This emf will cause a current to flow if the conductor circuit is closed.

Hence the most basic two essential parts of a generator are

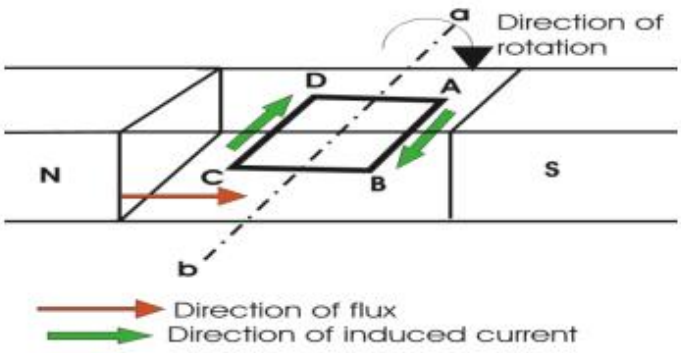
1. a magnetic field
2. conductors which move inside that magnetic field.

Single Loop DC Generator

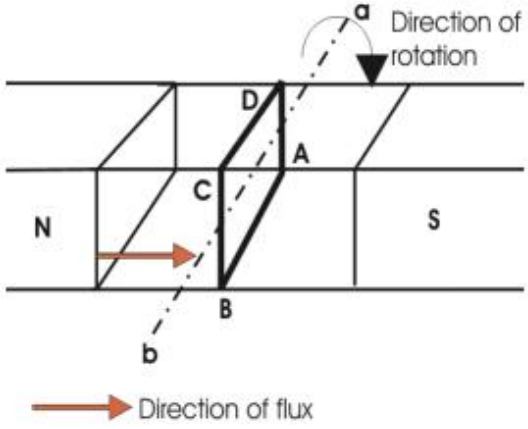


In the figure above, a single loop of conductor of rectangular shape is placed between two opposite poles of magnet.

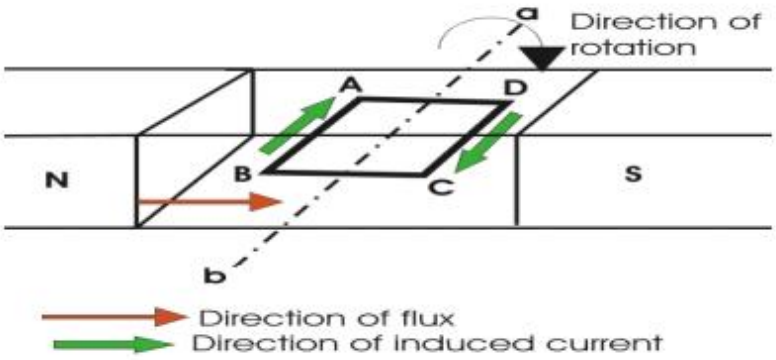
Let's us consider, the rectangular loop of conductor is ABCD which rotates inside the magnetic field about its own axis ab. When the loop rotates from its vertical position to its horizontal position, it cuts the flux lines of the field. As during this movement two sides, i.e. AB and CD of the loop cut the flux lines there will be an emf induced in these both of the sides (AB and BC) of the loop.



As the loop is closed there will be a current circulating through the loop. The direction of the current can be determined by Fleming's right hand Rule. This rule says that if you stretch thumb, index finger and middle finger of your right hand perpendicular to each other, then thumbs indicates the direction of motion of the conductor, index finger indicates the direction of magnetic field i.e. N - pole to S - pole, and middle finger indicates the direction of flow of current through the conductor. Now if we apply this right-hand rule, we will see at this horizontal position of the loop, current will flow from point A to B and on the other side of the loop current will flow from point C to D.



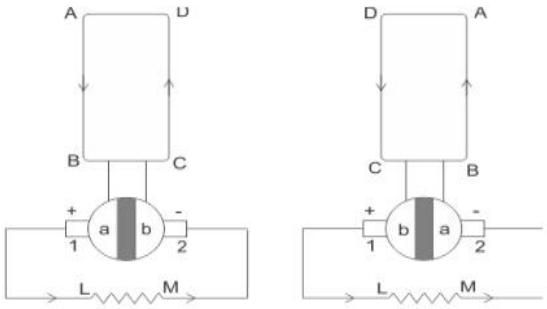
Now if we allow the loop to move further, it will come again to its vertical position, but now upper side of the loop will be CD and lower side will be AB (just opposite of the previous vertical position). At this position the tangential motion of the sides of the loop is parallel to the flux lines of the field. Hence there will be no question of flux cutting and consequently there will be no current in the loop. If the loop rotates further, it comes to again in horizontal position. But now, said AB side of the loop comes in front of N pole and CD comes in front of S pole, i.e. just opposite to the previous horizontal position as shown in the figure beside.



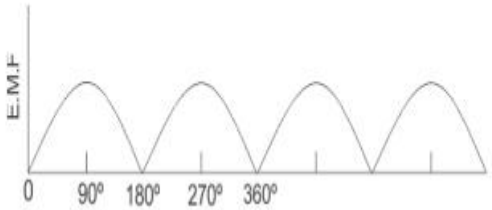
Here the tangential motion of the side of the loop is perpendicular to the flux lines, hence rate of flux cutting is maximum here and according to Fleming's right hand rule, at this position current flows from B to A and on other side from D to C.Now if the loop is continued to rotate about its axis, every time the side AB comes in front of S pole, the current flows from A to B and when it comes in front of N pole, the current flows from B to A. Similarly, every time the side CD comes in front of S pole the current flows from C to D and when it comes in front of N pole the current flows from D to C.

If we observe this phenomena in different way, it can be concluded, that each side of the loop comes in front of N pole, the current will flow through that side in same direction i.e. downward to the reference plane and similarly each side of the loop comes in front of S pole, current through it flows in same direction i.e. upwards from reference plane. From this, we will come to the topic of principle of DC generator.

Now the loop is opened and connected it with a split ring as shown in the figure below. Split ring are made out of a conducting cylinder which cuts into two halves or segments insulated from each other. The external load terminals are connected with two carbon brushes which are rest on these split slip ring segments.



It is seen that in the first half of the revolution current flows always along ABLMCD i.e. brush no 1 in contact with segment a. In the next half revolution, in the figure the direction of the induced current in the coil is reversed. But at the same time the position of the segments a and b are also reversed which results that brush no 1 comes in touch with the segment b. Hence, the current in the load resistance again flows from L to M. The wave form of the current through the load circuit is as shown in the figure. This current is unidirectional.



This is basic working principle of DC generator, explained by single loop generator model. The position of the brushes of DC generator is so arranged that the change over of the segments a and b from one brush to other takes place when the plane of rotating coil is at right angle to the plane of the lines of force. It is so become in that position, the induced emf in the coil is zero.

Construction of DC Generator/motor:

A DC generator/motor consists of the following parts
1. Yoke
2. Pole core and pole shoe
3. Field winding
4. Armature core and winding
5. Brushes and Commutator
6. Bearing

1. **Yoke** : Yoke or the outer frame of DC generator serves two purposes,
    - It holds the magnetic pole cores of the generator and acts as cover of the generator.
    - It carries the magnetic field flux.
    - In a small generator, yokes are made of cast iron. Cast iron is cheaper in cost but heavier than steel.
    - But for large construction of DC generators, where weight of the machine is concerned, lighter cast steel or rolled steel is preferable for constructing yoke
2. **Pole Cores and Pole Shoes**: There are mainly two types of construction available.

    - **Solid pole core:** where it is made of a solid single piece of cast iron or cast steel.
    - **Laminated pole core:**, where it is made of numbers of thin, limitations of annealed steel.
    - The pole core is fixed to the inner periphery of the yoke by means of bolts through the yoke and into the pole body.
    - Since the poles project inwards they are called salient poles. The pole shoes are so typically shaped, that they spread out the magnetic flux in the air gap and reduce the reluctance of the magnetic path. Due to their larger cross-section they hold the pole coil at its position.
3. **Field winding** : The field winding or pole coils are wound around the pole core. These are a simple coil of insulated copper wire or strip, which is placed on the pole which is placed between the yoke and pole shoes.

4. **a)Armature Core**
    - The purpose of the armature core is to hold the armature winding and provide a low reluctance path for the flux through the armature from N pole to S pole.
    - Although a DC generator provides direct current but induced current in the armature

is alternating in nature. That is why, cylindrical or drum shaped armature core is build up of circular laminated sheet.

- In every circular lamination, slots are either die - cut or punched on the outer periphery and the key way is located on the inner periphery as shown.
- Air ducts are also punched of cut on each lamination for circulation of air through the core for providing better cooling.

b) Armature winding: Armature windings are generally formed wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape in a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots, which are lined with tough insulating material. This slot insulation is folded over above the armature conductors placed in it and secured in place by special hard wooden or fiber wedges. Two types of armature windings are used - Lap winding and Wave winding.

5. **a)Commutator:** The commentator collects current from armature and sends it to the load as direct current. It actually takes alternating current from armature and converts it to direct current and then send it to external load. It is cylindrical structured and is build up of wedge-shaped segments of high conductivity, hard drawn or drop forged copper. Each commentator segment is connected with corresponding armature conductor through segment riser or lug.

   b)Brushes: The brushes are made of carbon. These are rectangular block shaped. The only function of these carbon brushes is to collect current from commutator segments.

6. **Bearings**
   For small machines, ball bearing is used and for heavy machines roller bearings are used. The bearing must always be lubricated properly for smooth operation and long life of the machine..

Types of DC machine:

There are two main types of DC machines . first one is a generator and the second one is a DC motor.

DC motor uses DC current and provides mechanical power.

DC generator generates DC voltage.

Depending on the method of excitation, the DC machines are further divided into different types that are described here.

- ➢ Separately excited DC machine.
- ➢ Shunt DC machine.
- ➢ Series DC machine.
- ➢ Compound DC machine.

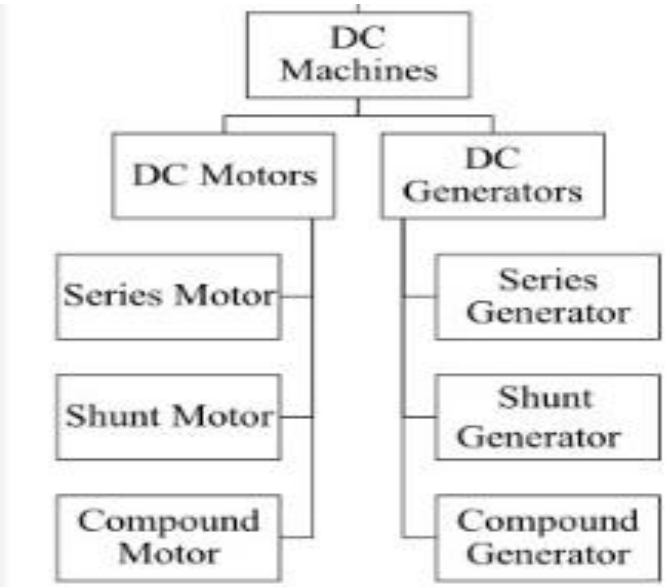
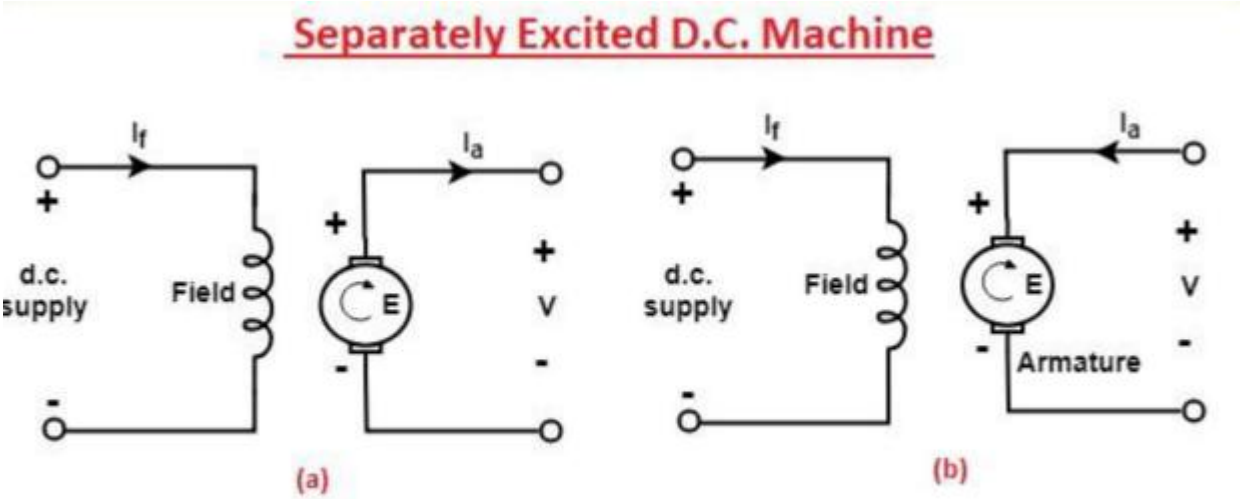


Fig: Classification of dc machines

1. **Separately Excited DC Machine:**

   If there is no internal voltage induced at the field windings and there is no field current so external power source is connected at the field winding to produce current and voltage these winding is known as separate windings.

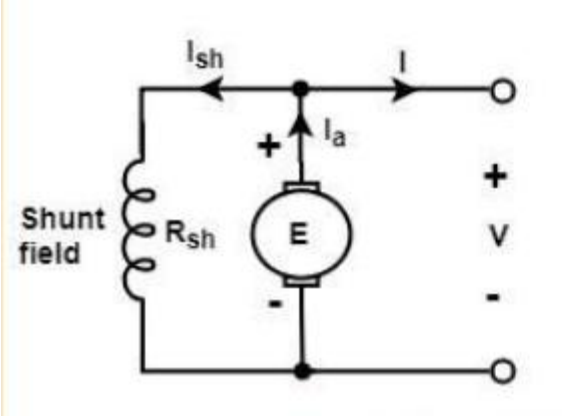


(a) Separately excited D.C. Generator (b) Separately excited D.C. Motor

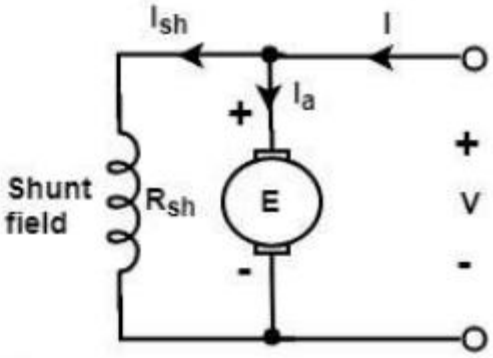
2. **Self-Excited DC Machines**

   a) Shunt DC Machine: In this type of DC machine, the field winding (it is located at the stator of a machine) linked with the armature winding (wound rotor) in parallel.
   Due to a parallel connection, the voltage across the field windings is equal to the supply voltage in the case of a motor and equals generated voltage in the case of a generator.

These windings have large no of turns



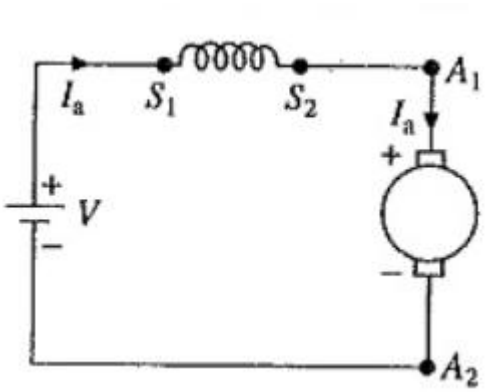
(a) dc shunt generator



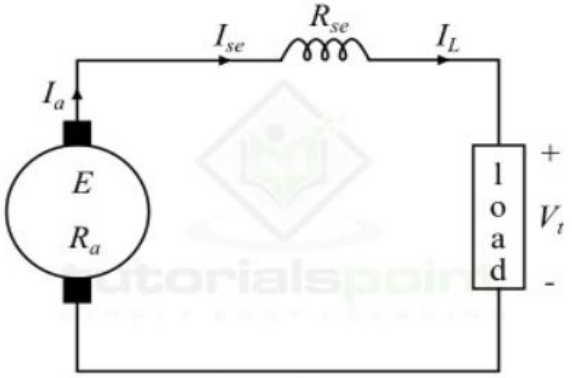
(b) dc shunt motor

b) Series Wound DC Machine:

- ➢ In these DC machines, the field windings are connected with the armature windings in series connection schemes.
- ➢ As this winding is in series so the armature current also passes through it that has high value for less power losses the turns of the field windings are less in this machine.



fig(a) dc series motor



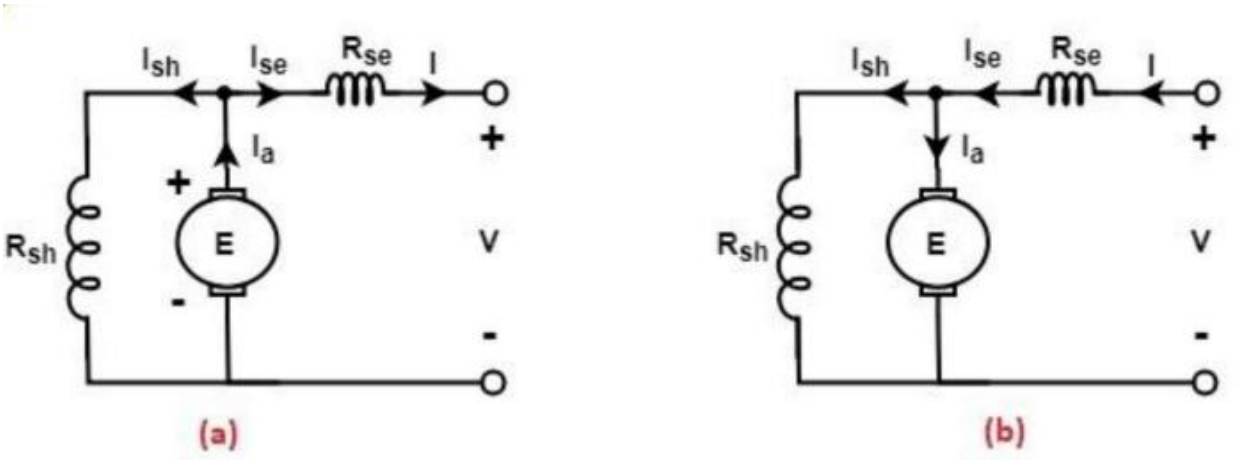
fig(b) dc series generator

c)Compound DC Machine:

- ➢ This machine consists of series and shunts windings in its circuitry. two windings are placed at every pole of the machine.
- ➢ The number of turns in the series is less due to the large value of armature current flowing through it and shunt windings have large no of turns.

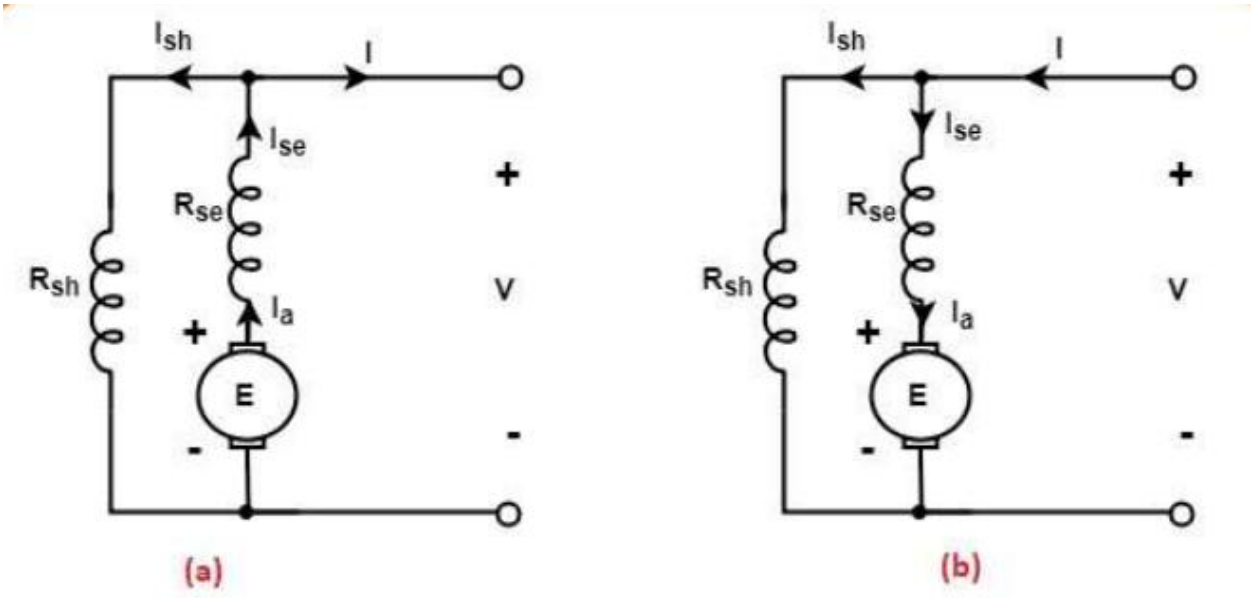
There are two methods by which these two windings are connected in these machines.

- ❖ **Short shunt compound machine** : if the field windings are in parallel with the armature windings, then the machines are known as the short shunt compound.



(a) Short-shunt compound D.C. generator (b) Short-shunt compound D.C. motor

- **Long shunt compound machine**: If the field windings are in parallel with the armature and series windings the machines are known as the long shunt compound machines.



(a) Long-shunt D.C. Generator (b) Long-shunt D.C. Motor

Three phase induction machine:

Construction:

Three phase induction machine consists of two major parts. they are Stator and rotor

1. Stator

It is the stationary part of the motor. It has three main parts:

a. Frame or Yoke:

- ➢ It is the outer part of the three phase induction motor.
- ➢ Its main function of the frame is to support the stator core & stator winding.
- ➢ It acts as a covering, and it provides protection & mechanical strength to all the inner parts of the three phase induction motor.

b. Stator core

- ➢ The main function of stator core is to carry the alternating flux.
- ➢ In order to reduce the eddy current loss, the stator core is laminated.
- ➢ The core is made up of thin silicon steel laminations. These are insulated from each other by varnish, the slots are cut on inner periphery of core stampings.
- ➢ The stator windings are placed in these slots.

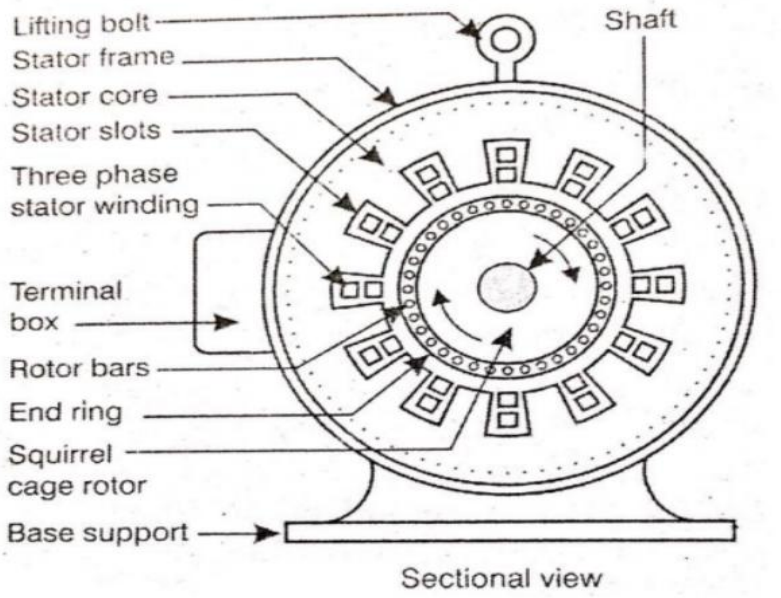


Fig 1: stator of 3-phase induction machine

c) Stator windings

- ❖ Stator winding is made up of super enamelled copper wire.
- ❖ 3-phase windings are placed in the stator core slots & six terminals are brought out.
- ❖ They may be star connected or may be delta connected.

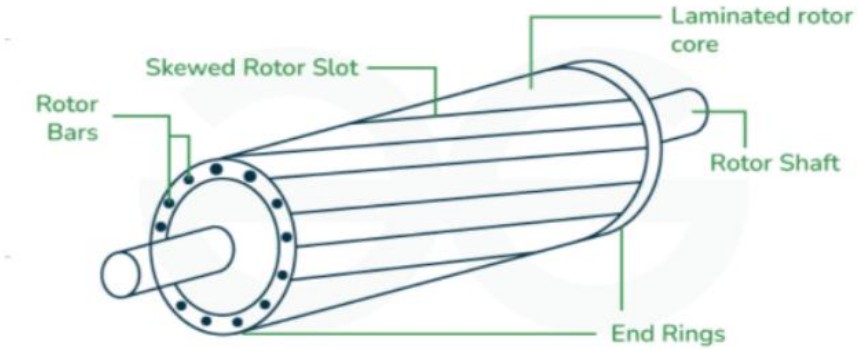
- ❖ The windings are connected in star form at starting.

2. Rotor

- ❖ It is a rotating part of the motor and it is mounted on the shaft.
- ❖ It consists of a hollow laminated core having slots on its outer periphery.
- ❖ The windings placed in these slots (rotor winding) may be one of the following two types

a) Squirrel cage rotor

- ➢ The rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors.
- ➢ The squirrel cage rotor consists of aluminium, brass or copper bars.
- ➢ These aluminium, brass or copper bars are called rotor conductors & are placed in the slots on the periphery of the rotor.
- ➢ The rotor conductors are permanently shorted by the copper, or aluminum rings called the end rings.
- ➢ To provide mechanical strength, these rotor conductors are braced to the end ring & hence form a complete closed circuit resembling a cage & hence got its name as squirrel cage induction motor.

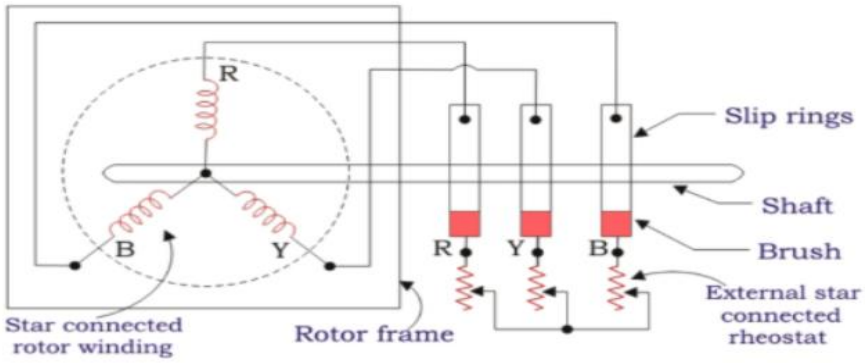


fig(a) squirrel cage rotor

b) Slip ring rotor or wound rotor or phase wound rotor

- ➢ The wound rotor consists of a slotted armature.
- ➢ Insulated conductors are put in the slots & connected to form a three phase double layer distributed winding similar to the stator winding. The rotor windings are connected in star.

- The open end of the start circuit are brought outside the rotor and connected to the insulated slip rings.
- The slip rings are mounted on the shaft with brushes testing on them.
- The brushes are connected to three phase variable resistors connected in star.
- The purpose of slip rings & brushes is to provide a means for connecting external resistors in the circuit.



fig(b) slip ring rotor