a) Explain the SC test of a single-phase transformer with neat diagram

(OR)

b)Explain the construction and working principle of single phase transformer

a) Explain the construction and working principle of 3-phase induction motor

(OR)

b)Explain the construction and working principle of the DC motor.

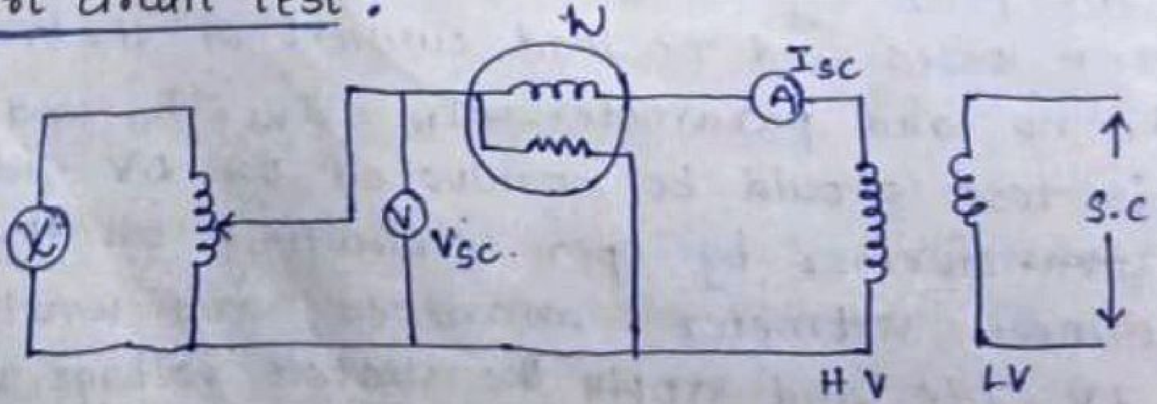
a)Explain different types of Earthing?

(OR)

b)Explain about the MCB in detail.

1:21 pm

## 2) Short circuit test :




→ The purpose of short circuit test is to determine copper losses at full load.

→ This test is conducted on HV winding side of the transformer by short circuiting on LV side.

→ Connect voltmeter, ammeter and wattmeter on HV side of the transformer and apply the reduced voltage (5–10%) upto the rated current flowing through the transformer.

→ And take the values of wattmeter ($P_c$), ammeter ($I_{sc}$) Voltmeter ($V_{s.c}$).

Full load copper losses

$$P_c = I_{sc}^2 R_{eq}$$

equivalent Resistance → $$\boxed{R_{eq} = \frac{P_c}{I_{sc}^2}}$$

equivalent Impedance → $$\boxed{Z = \frac{V_{s.c}}{I_{s.c}}}$$

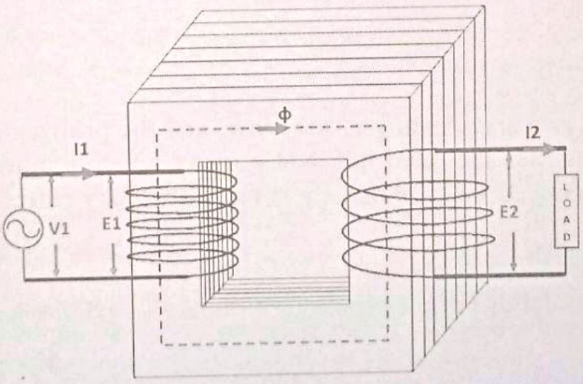
$$Z = \sqrt{X^2 + R^2}$$

equivalent Reactance → $$\boxed{X_{eq} = \sqrt{Z^2 - R_{eq}}}$$

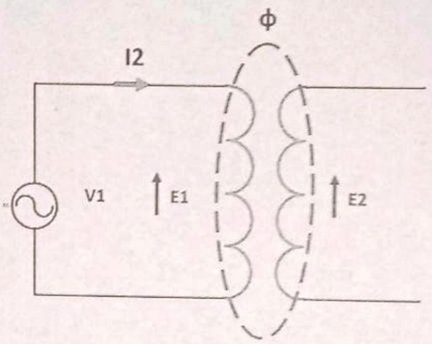
# Working Principle of a Transformer

The basic principle on which the transformer works is **Faraday's Law of Electromagnetic Induction** or mutual induction between the two coils. The working of the transformer is explained below. The transformer consists of two separate windings placed over the laminated silicon steel core.

The winding to which AC supply is connected is called primary winding and to which load is connected is called secondary winding as shown in the figure below. It works on the **alternating current only** because an alternating flux is required for mutual induction between the two windings.



When the AC supply is given to the primary winding with a voltage of $V_1$, an alternating flux $\phi$ sets up in the core of the transformer, which links with the secondary winding and as a result of it, an emf is induced in it called **Mutually Induced emf**. The direction of this induced emf is opposite to the applied voltage $V_1$, this is because of the Lenz's law shown in the figure below:




Physically, there is no electrical connection between the two windings, but they are magnetically connected. Therefore, the electrical power is transferred from the primary circuit to the secondary circuit through mutual inductance.

The induced emf in the primary and secondary windings depends upon the rate of change of flux linkage that is ($N\, d\phi/dt$). $d\phi/dt$ is the change of flux and is same for both the primary and secondary windings. The induced emf $E_1$ in the primary winding is proportional to the number of turns $N_1$ of the primary windings ($E_1 \propto N_1$). Similarly induced emf in the secondary winding is proportional to the number of turns on the secondary side. ($E_2 \propto N_2$).

# Construction of a Transformer

The transformer mainly consists of the Magnetic circuit, electric circuit, dielectric circuit, tanks, and accessories. The main elements of the transformer are the **primary and secondary windings** and the **steel core**. The core of the transformer is made up of silicon steel in order to provide a continuous magnetic path. Usually, the core of the transformer is laminated for minimizing the eddy current loss.

## Magnetic circuit

The magnetic circuit of a transformer consists of **core** and **yoke**. The circuit provides the path to the flow of magnetic flux. The transformer consists of a laminated steel core and the two coils. The two coils are insulated from each other and also from the core.

The core of the transformer is constructed from laminations of steel sheet or silicon steel assembled to provide a continuous magnetic path. At usual flux densities, the silicon steel material has low hysteresis losses.

The vertical position on which the coil is wound is called the **limb** while the horizontal position is known as the **yoke**.

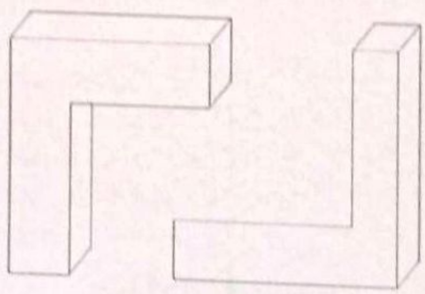
## Electric circuit

Construction of the electric circuit of the transformer consists of primary and secondary windings usually made of copper. The Conductors of the rectangular cross-section are generally used for low voltages winding and also for the high voltage winding for large transformers. Conductors of the circular cross-sectional area are used for high voltage winding in the small transformer.

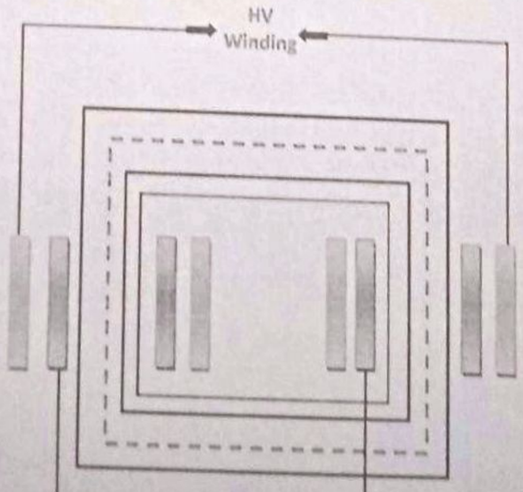
According to the core construction and the manner in which the primary and secondary windings are placed around it, the transformer is named as **core type** and **shell type**.

## Core Type Transformer

In a simple core type construction of the transformer, a rectangular frame laminations are formed to build the core of the transformer. The laminations are cut in the form of L-shape strips as shown in the figure below. In order to avoid high reluctance at the joints where laminations are butted against each other, the alternate layers are placed differently to eliminate the continuous joints.



The primary and the secondary windings are interleaved to reduce the leakage flux. Half of each winding are placed side by side or concentrically on either limb of the core.



While placing these windings, insulation of Bakelite former is provided between the core and low voltage winding (LV), between the two windings that are between low voltage (LV) and high voltage (HV) windings and also in between coils and yoke. And also in between HV limb and yoke as shown in the figure. To reduce the insulation, the low voltage winding is always placed nearer to the core.

# THREE PHASE INDUCTION MOTOR

**Introduction:** Three-phase induction motors are the most widely used electric motors in industry. Speed of this motors are frequency dependent. The induction motor may be considered to be a **transformer with a rotating secondary**

## Advantages

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

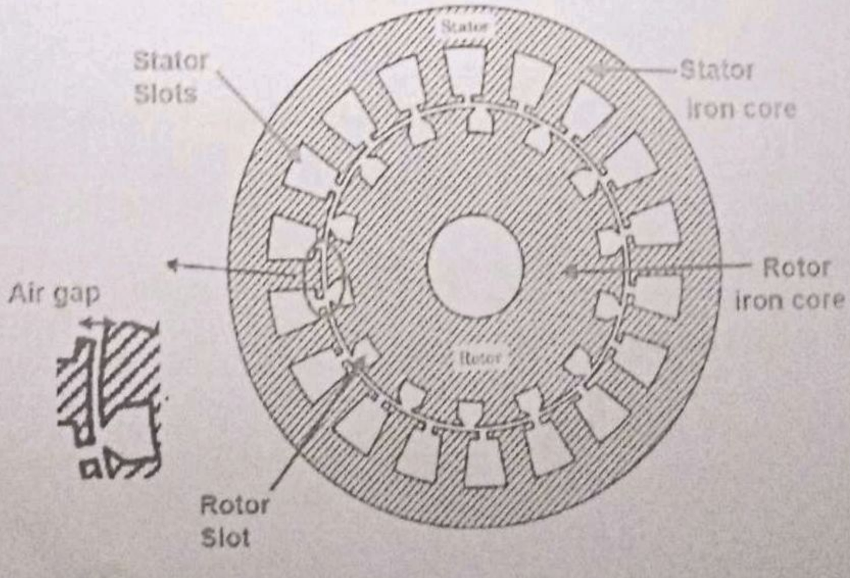
## Disadvantages

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

## Constructional Details of A Three Phase Induction Motor

A typical motor consists of two parts namely stator and rotor like other type of motors.

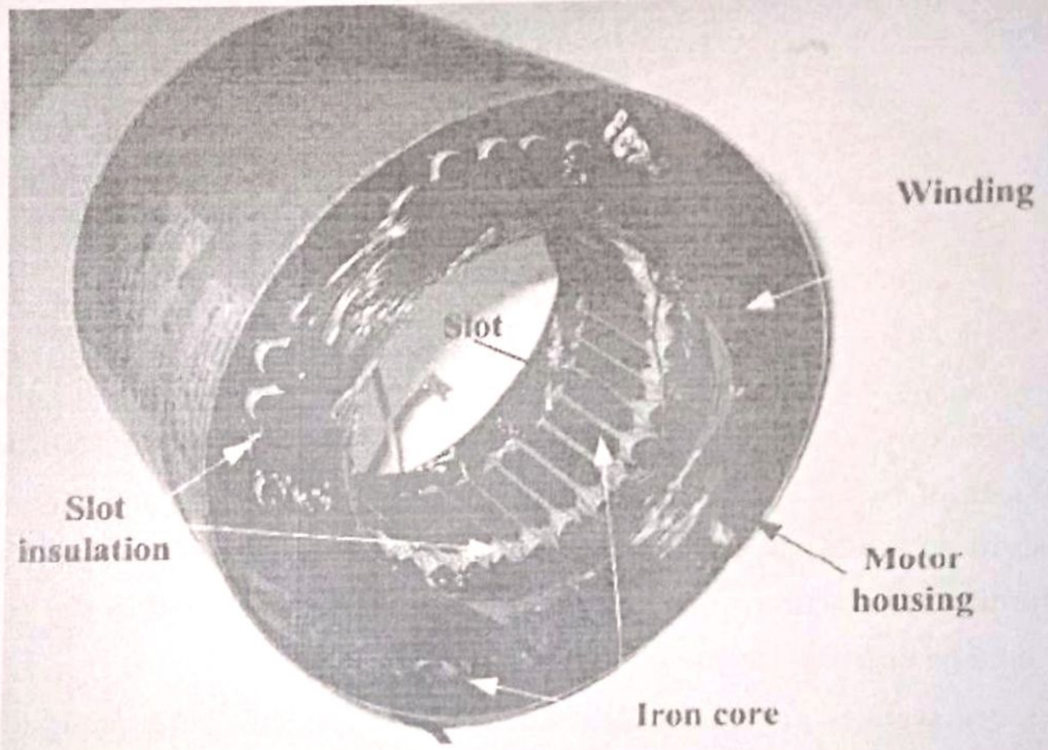
1. **Stator:** An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field
2. **Rotor:** An inside rotor attached to the output shaft that is given a torque by the rotating field.



**Stator:**

- It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel
- A number of evenly spaced slots are provided on the inner periphery of the laminations for providing 3 phase winding.
- The 3-phase stator winding is wound for a definite number of poles as per requirement of speed.
- When 3-phase supply is given to the stator winding, a rotating magnetic field of constant magnitude (1.5 $\phi_m$) is produced.

This rotating field induces currents in the rotor by electromagnetic induction



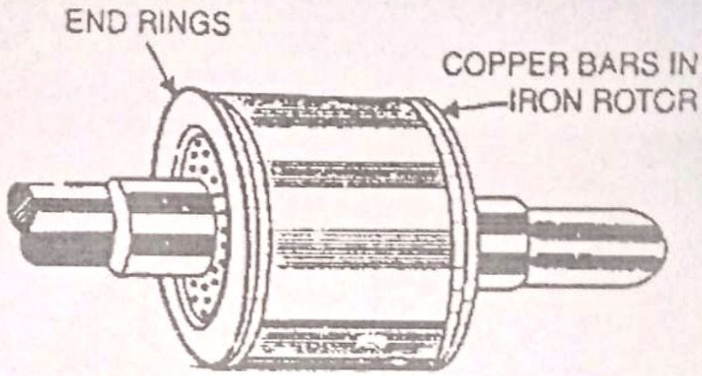

**Rotor:**

- 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 type (ii) Wound type

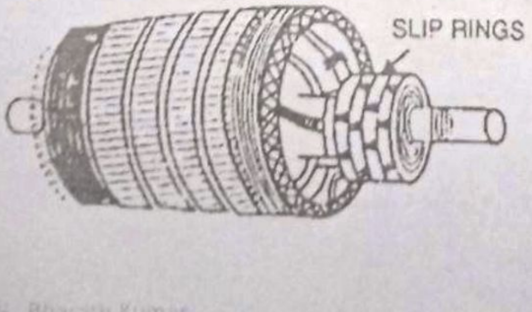
**Squirrel cage type**

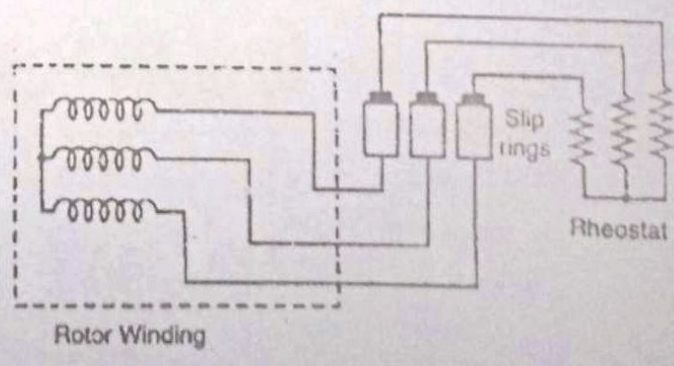
- Most of 3-phase induction motors use squirrel cage rotor.
- It has a remarkably simple and robust construction.
- The rotor winding consists of single copper or aluminum bars placed in the slots and short-circuited by end-rings on both sides of the rotor.
- It suffers from the disadvantage of a low starting torque.




**Wound type**

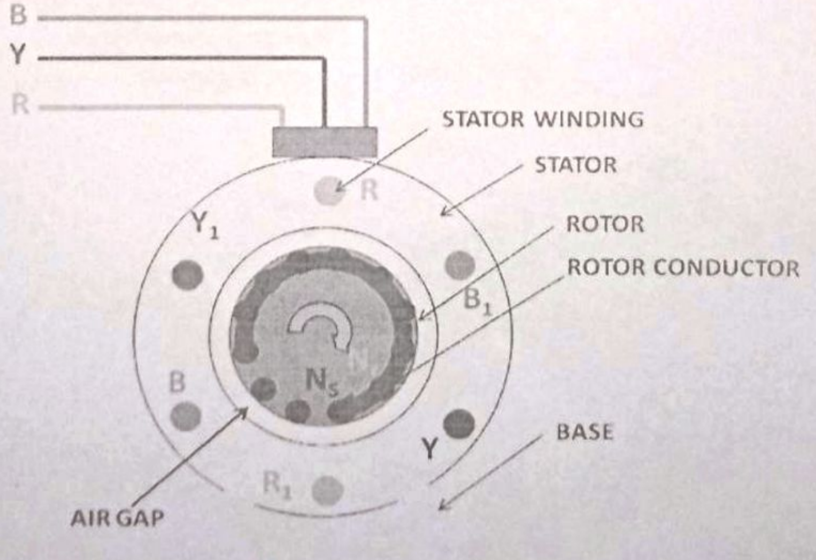
- In the wound rotor, an insulated 3-phase winding similar to the stator winding wound for the same number of poles as stator, is placed in the rotor slots.
- The ends of the star-connected rotor winding are brought to three slip rings on the shaft so that a connection can be made to it for starting or speed control.
- At the time of 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.



**Principle of operation of three phase induction motors**

- When a 3-phase winding is energized from a 3-phase supply, a rotating magnetic field is produced.
- The speed at which stator magnetic field rotates is called **synchronous speed ($N_S$).**
- Magnitude of this rotating magnetic field is constant and is equal to $1.5\ \varphi_m$
- The rotating field passes through the air gap and cuts the rotor conductors, which as yet, are stationary.
- According to Faraday's laws of electromagnetic induction current flows through the short circuited conductors.
- The interaction of the rotating flux and the rotor current generates a force that drives the motor and a torque is developed consequently.
- Mechanical force acts on the rotor conductors and rotor start to rotate in the direction of rotating magnetic field.
- The torque is proportional with the flux density and the rotor
- The motor speed is less than the synchronous speed.
- The direction of the rotation of the rotor is the same as the direction of the rotation of the revolving magnetic field in the air gap



## Slip (s)

- In practice, the rotor can never reach the speed of stator flux ,Because of friction and windage losses makes the rotor to slow down.
- Hence, the rotor speed ($N_r$) is always less than the stator flux speed ($N_s$).
- **The difference between the synchronous speed Ns of the rotating stator field and the actual rotor speed Nr is called slip.**

It is usually expressed as a percentage of synchronous speed

i.e.,The quantity $N_s$ - $N_r$ is called slip speed.

**When the rotor is stationary** (i.e., $N_r = 0$), slip, s = 1 or 100 %

$$\% \, Slip = \frac{N_s - N_r}{N_s} * 100\%$$

## Rotor Frequency( $f_r$ )

- The frequency of a **voltage or current induced** due to the relative speed between rotor conductor and rotating magnetic field can be calculated by

$$f_r = \frac{(N_s - N_r)\,P}{120}$$

where $(N_s - N_r)$ = Relative speed between magnetic field and the armature winding

P = Number of poles

- For a rotor speed ($N_r$), the relative speed between the rotating flux ($N_s$) and the rotor is $(N_s - N_r)$.

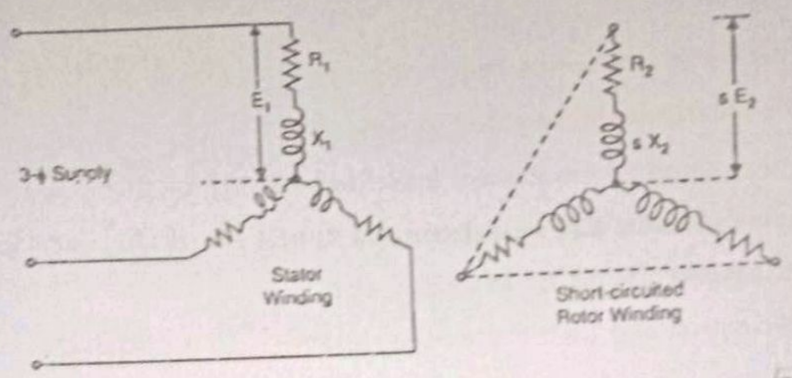
The frequency of supply voltage (stator rotating flux) is $f = \frac{N_s\,P}{120}$

$$\frac{f_r}{f} = \frac{\frac{(N_s - N_r)\,P}{120}}{\frac{N_s\,P}{120}} = \frac{N_s - N_r}{N_s} = s\,f$$

Problems:

1. A three phase induction motor is wound for 4 poles and is supplied from 50Hz system. Calculate (i) the synchronous speed (ii) the speed of the motor when slip is 4% and (iii) the motor rotor current frequency when the motor runs at 600 r.p.m.
2. A 6 pole, 3phase, 50 Hz induction motor is running at full load with a slip of 4%. The rotor is star connected and its resistance and stand still reactance are 0.25 Ω and 1.5 Ω per phase. The e.m.f between slip rings is 100V. Find the rotor current per phase and power factor, assuming the slip rings are short circuited.

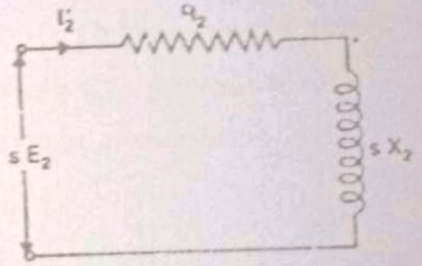
## Rotor Current




- The e.m.f induced in rotor windings at standstill (s=1) is $E_2 = \sqrt{2}\,\pi f N_2 \phi_m$
- The e.m.f induced in rotor windings under running condition is

$$E_2' = \sqrt{2}\,\pi f_r N_2 \phi_m = \sqrt{2}\,\pi (s\,f) N_2 \phi_m = s\,E_2$$

**Torque Equation of 3-Phase Induction Motor**




Rotor equivalent circuit diagram for a 3-ph induction motor

$$\textit{Rotor Current induced / phase}\quad I_2 = \frac{\textit{e.m.f induced / phase}}{Z_2}$$

$$\text{Rotor power factor} = \cos\phi_2 = \frac{R_2}{Z_2}$$

**At standstill Slip s=1**

$$\textit{Rotor Current / phase}\quad I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{R_2^2 + X_2^2}}$$

**When running at slip s**

$$\textit{Rotor Current / phase}\quad I_2' = \frac{E_2'}{Z_2} = \frac{s\,E_2}{Z_2} = \frac{s\,E_2}{\sqrt{R_2^2 + (s\,X_2)^2}} \quad \text{and} \quad \cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + (s\,X_2)^2}}$$

Torque T developed is directly proportional to rotor flux , rotor current and power factor

$$T \;\alpha\; \phi_2 I_2' \cos\phi_2 \quad \text{and} \quad \phi_2 \;\alpha\; E_2$$

$$\therefore \quad T \;\alpha\; E_2 I_2' \cos\phi_2 = k\,E_2 I_2' \cos\phi_2$$

$$T = k\,E_2 \frac{s\,E_2}{\sqrt{R_2^2 + (s\,X_2)^2}} \frac{R_2}{\sqrt{R_2^2 + (s\,X_2)^2}} \qquad T = k\,\frac{s\,E_2^2}{R_2^2 + (s\,X_2)^2}$$

Starting torque **s=1** $\quad T = k\,\dfrac{E_2^2}{R_2^2 + X_2^2}$

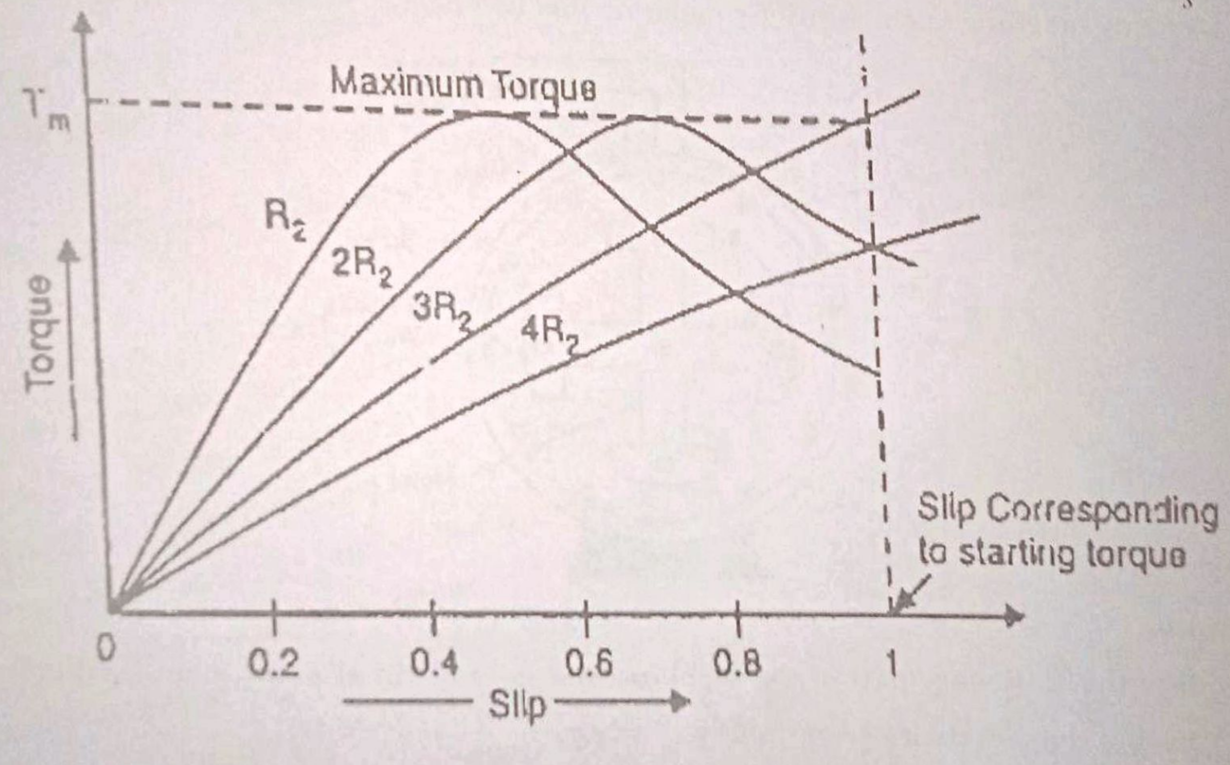
**Torque Slip Characteristics**

If a curve is drawn between the torque and slip for a particular value of rotor resistance $R_2$, the graph thus obtained is called torque-slip characteristic.

**At s = 0, T = 0** so that torque-slip curve starts from the origin

**At normal speed**, slip is small so that $sX_2$ is negligible $T \alpha s$ and the torque increases and becomes maximum at $s = \frac{R_2}{X_2}$

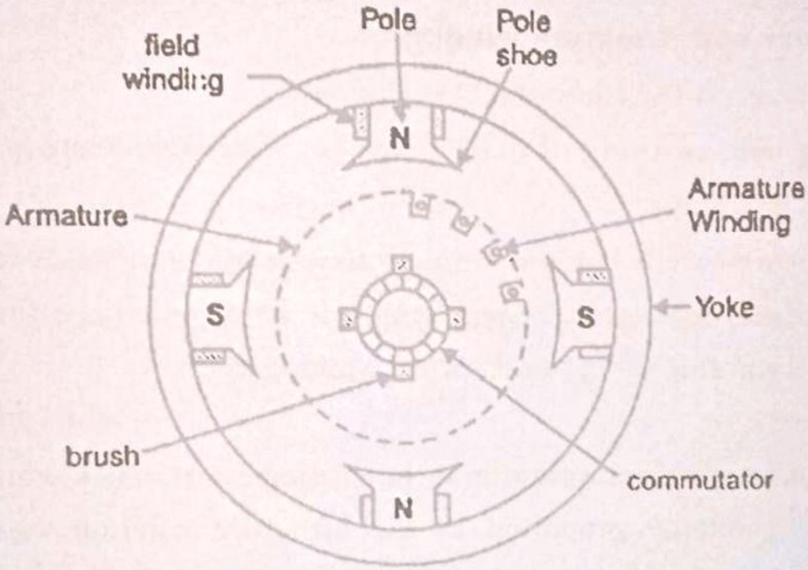
**For high values of slip** $R_2$ value is less compared to $sX_2$ value so $R_2^2 \approx 0$ and $T \alpha \frac{1}{s}$



# DC MACHINES

## Constructional details of a DC Machine:

- A DC machine can be used as a DC generator or a DC motor without any constructional changes. Thus, a DC generator or a DC motor can be broadly termed as a DC machine.
- when the machine is being assembled, we do not know whether it is a dc generator or motor. Any dc generator can be run as a dc motor and vice-versa.
- The following figure shows the constructional details of a simple **4-pole** DC machine




A DC machine consists of two basic parts, stator and rotor.

The other important parts are described below.

**1. Yoke:**

- The outer frame of a D.C Machine (Generator or Motor) is called as yoke. Yoke is made up of cast iron or steel.
- Yoke provides mechanical strength for whole assembly of the D.C Machine
- It also carries the magnetic flux produced by the poles.

**2. Poles:**

- Poles are to support field windings or coils which are wound around it.
- Poles are joined to the yoke with the help of screws or welding.

**3. Pole shoe:**

- Pole shoe is an extended part of the pole which serves two purposes,

  (i) To prevent field coils from slipping and

  (ii) To spread out the flux in air gap uniformly.

**4. Field winding:**

- Field winding is wound on poles and connected in series or parallel with armature winding.
- Field coils are mounted on the poles and carry the dc exciting current.
- The field coils are connected in such a way that adjacent poles have opposite polarity.

**5. Armature core and Armature winding:**

- Armature core is the rotor of a D.C Machine.
- Armature core is cylindrical in shape on which slots are provided to carry armature winding.
- The armature core is laminated to reduce the eddy current loss.
- Armature winding can be wound by one of the two methods known as

  Lap winding (A=P) and Wave winging (A=2)

**6. Commutator:**

- In DC Generator, commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes.
- In DC Motor, commutator acts as mechanical inverter which converts direct voltage into alternating voltage.
- The commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine.

**7. 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.
- Thus brushes are physically in contact with armature conductors hence wires can be connected to brushes.

# D.C GENERATOR

An electrical Generator is a machine which converts mechanical energy (or power) into electrical energy (or power).

## Principle of Operation of D.C Generator:

According to Faraday's Laws of Electromagnetic Induction

"Whenever a conductor cuts magnetic flux, dynamically induced e.m.f. is produced in it".

The magnitude of the EMF is given by

$$E=Bl\upsilon \text{ (Volts)}$$

Where, B= Magnetic filed

l = Effective length of conductor

$\upsilon$ = Velocity of conductor in magnetic field

The direction of the induced emf / current is given by Fleming's Right Rule

**Fleming's Right Rule:**

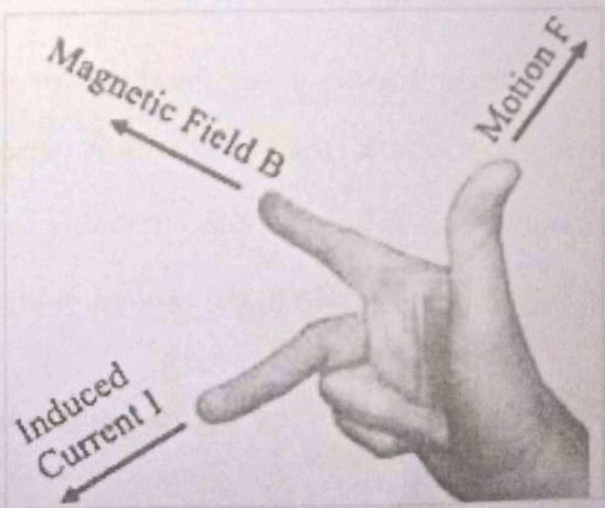
Stretch the thumb, fore finger and centre finger of Right hand in mutually perpendicular directions such that

**When**

- The Thumb represents the direction of the Motion of the Conductor (F).
- The Fore finger represents the direction of the magnetic Field (B).

**Then**

- The Centre finger represents the direction of the Current (I).



**Necessity of earthing:**

The requirement for provision of earthing can be listed as follows:

1. To protect the operating Personnel from the danger of shock.
2. To maintain the line voltage constant under unbalanced load condition.
3. To avoid the risk of fire due to earthing leakage current through unwanted path.
4. Protection of the equipment's
5. Protection of large building and all machines fed from overhead lines against lightning.

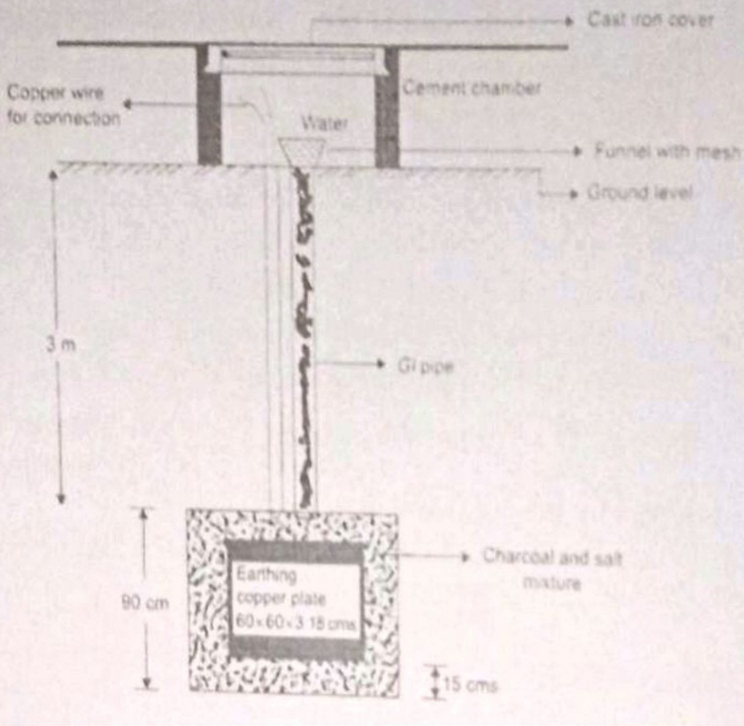
## METHODS OF EARTHING

The various methods of earthing are:

1. Plate earthing.
2. Pipe earthing.
3. Rod earthing.
4. Strip or Wire earthing.

### 1. Plate earthing

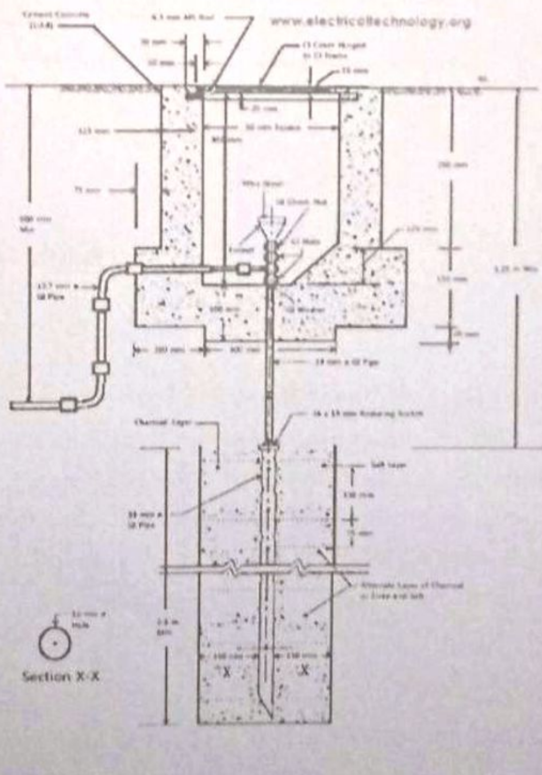
In this method either a copper plate of 60cm*60cm*3.18 or GI (galvanized iron) plate is used for earthing. The plate is buried into the ground not less than 3 meters from the ground level. The Earth plate is embedded in alternate layers of coal and salt of thickness of 15cms. In addition, water is poured for keeping the Earth electrode resistance value below a maximum of 5Ω. The Earth wire is securely bolted to at the plate. A cement masonry chamber is built with a cast-iron cover for easy maintenance.




## 2. Pipe Earthing

A galvanized steel and a perforated pipe of approved length and diameter is placed vertically in a wet soil in this kind of system of earthing. It is the most common system of earthing.

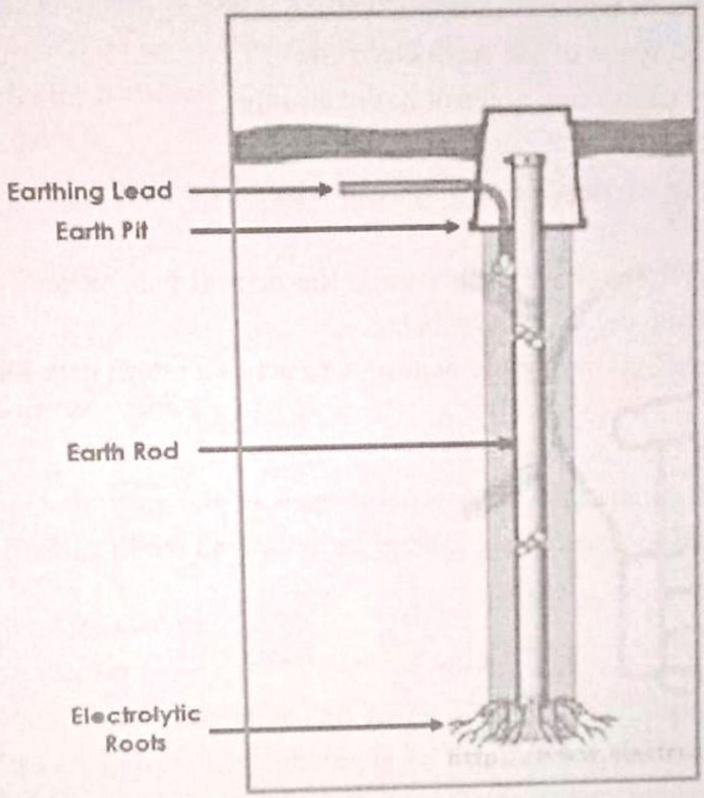
The size of pipe to use depends on the magnitude of current and the type of soil. The dimension of the pipe is usually 40mm (1.5in) in diameter and 2.75m (9ft) in length for ordinary soil or greater for dry and rocky soil. The moisture of the soil will determine the length of the pipe to be buried but usually it should be 4.75m (15.5ft).



When compared to the plate earth system the pipe earth system can carry large leakage currents due to large surround area in contact with the soil for a given electrode size. This system also enables easy maintenance as the earth wire connected is house at ground level.

**3. Rod Earthing**

It is the same method as pipe earthing. A copper rod of 8.5mm diameter or 16 mm diameter of galvanized steel of GI pipe is of length above 2.5 meters are buried upright in the earth manually or with the help of pneumatic hammer. The length of the embedded electrode in the soil reduces at the resistance to your desired value.




**4. Strip or Wire Earthing**

In this method of earthing, strip electrodes of cross-sectional not less than 25mm*1.6mm is buried in a horizontally trenches of minimum depth of 0.5 m.

The length of the conductor buried in the ground would give a sufficient earth resistance and this length not less than 15m. This type of earthing is used where the earth bed has a rocky soil and Excavation work is difficult.

## MINIATURE CIRCUIT BREAKER:

Miniature circuit breakers are electromechanical devices which protect an electrical circuit from over currents. Over currents in an electric circuit may result from short circuit, overload or faulty design. An MCB is a better alternative than fuse, since it does not require any replacement once an overload is detected. MCB is a switch which automatically turns off when the current flowing through it passes the maximum allow-able limit. Generally MCB is designed to protect against overcurrent and over temperature faults.

### Working principle:

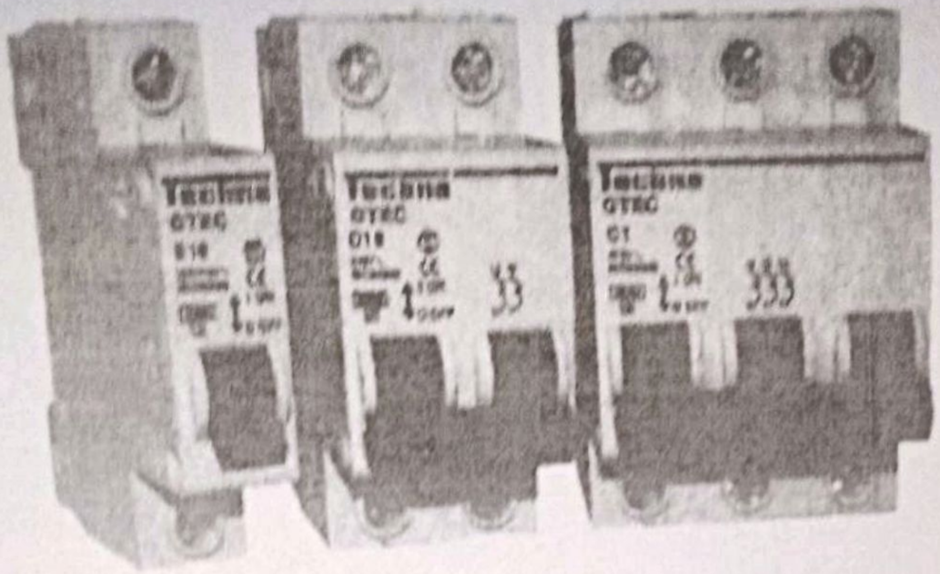
There are two contacts i.e., one is a fixed and other is movable. When a current exceeds the predefined limit, a solenoid forces the movable contact to open and the MCB gets turned off, thereby stopping the current flow from flowing in the circuit.

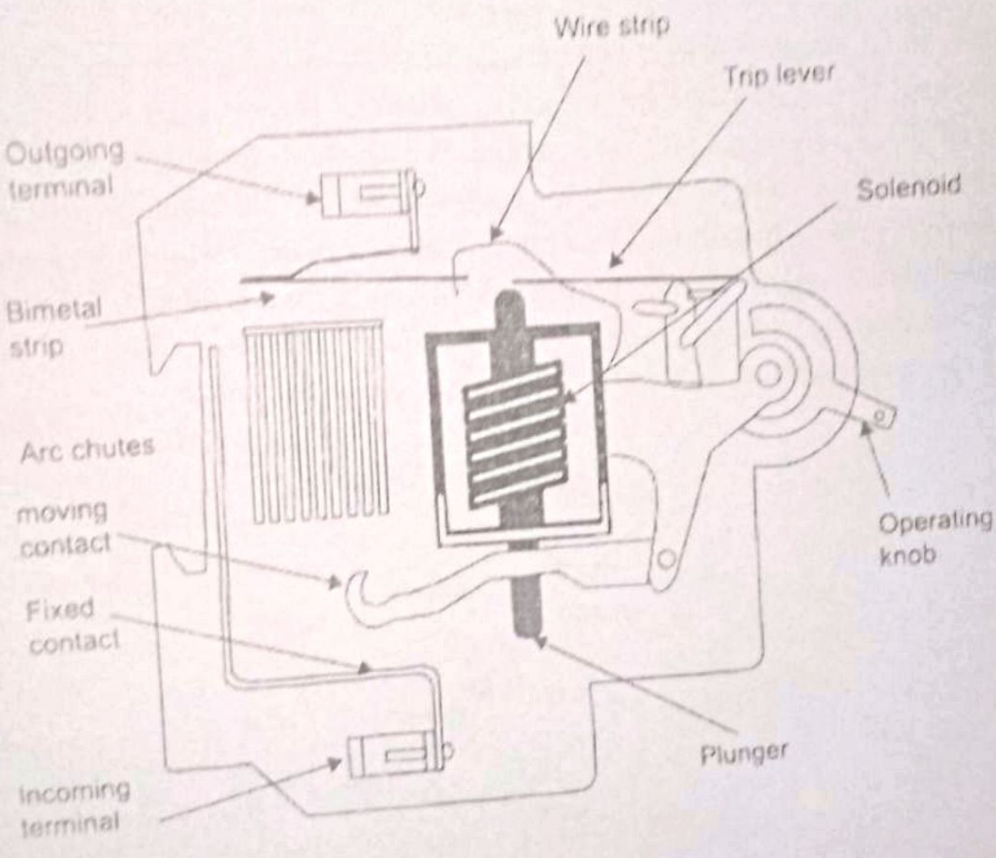
### Operation:

It's mainly consists of bimetallic strip, one trip coil and one hand operated on-off lever.

If the circuit is overloaded for a long time the bimetallic strip becomes over heated and deformed. This deformation of bimetallic strip causes displacement of latch point. The moving contact of the MCB is so arranged by means of spring, with this latch point, that a little displacement of latch causes release of spring and makes the moving contact to move for opening the MCB. The current coil our trip coil is placed in such a manner that during short circuit fault, the MMF of the coil causes its plunger to hit the same latch point and force the latch to be displaced. Hence, the MCB is opened in same manner.

When the moving contact is separated from the fixed contact, there may be a high chance of Arc. This Arc then goes up through the arc Runner and enters into the arc splitters and then finally quenched.






**Advantages:**

MCB are replacing the re-wearable switch.

MCB is a combination of three functions in a wiring system like switching, overloading and short circuit protection.