SUBJECT : Basics of Electrical & Electronics Engineering

SUBJECT CODE: 23EE3101

UNIT- III : DC & AC MACHINES

DC MACHINES :

The direct current (DC) machine is an electromechanical energy conversion device, which converts electrical energy to mechanical energy (Motor) or, alternatively mechanical energy to Electrical energy (Generator). The energy conversion is based on the principle of Faraday's laws of electro-magnetic induction.

DC GENERATOR :

A DC generator is "a machine which converts mechanical energy into electrical energy". This energy conversion is based on the principle of the production of dynamically (or motionally) induced e.m.f. i.e. whenever a conductor cuts magnetic flux, dynamically induced e.m.f is produced in it. This e.m.f causes a current to flow if the conductor circuit is closed. Hence, the essential components of a DC generator are:

(i) A magnetic field

(ii) Conductor or group of conductors.

(iii) motion of conductor w.r.to magnetic field.

DC GENERATOR CONSTRUCTION:

A DC generator consists of the following essential parts:

1. Yoke or outer fram
2. Pole cores & pole shoes
3. Pole coils or field coils
4. Armature core
5. Armature winding or conductors
6. Commutator
7. Brushes and bearings.

→ The yoke, pole cores/shoes and field coils forms the magnetic field system, and is the stationary (fixed) part of the machine.

→ The rotating part of the machine is called the armature.

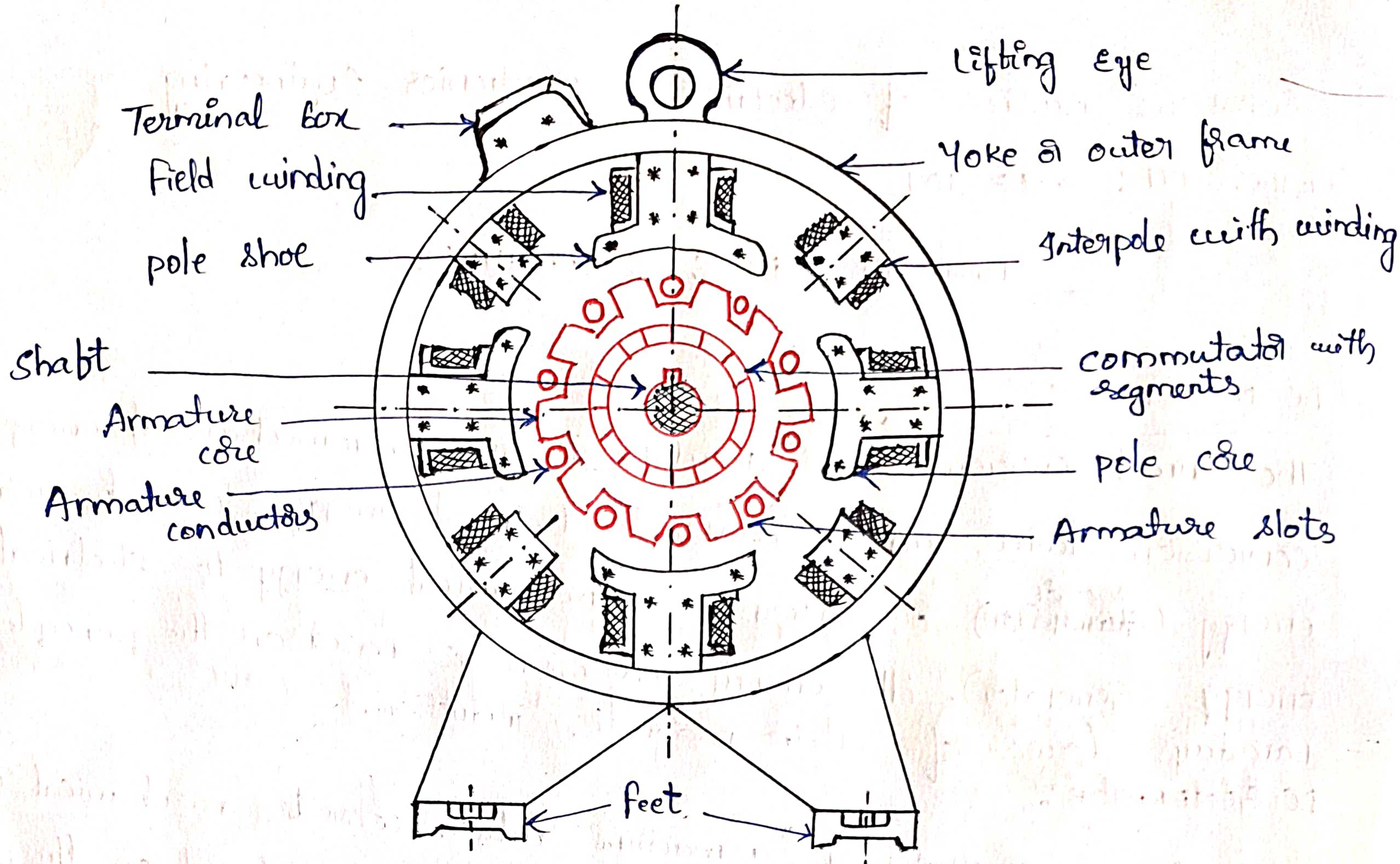


Figure : Cross-sectional view of DC Generator :

YOKE OR OUTER FRAME: It acts as a frame of the machine and carries the magnetic flux produced by the poles. It supports the pole cores and acts a a protecting cover to the machine. In small machines, cast iron yokes are used, whereas, yoke of large machine is invariably made of fabricated steel due to its high permeability.

POLE CORES & POLE SHOES: The pole cores are made of thin laminated sheets, to avoid heating and eddy current loss. It is used to carry the field winding, which produces magnetic flux needed for the generator. The pole shoe is located at the end of the pole core, acts as a support to the field coils/winding and spreads out the flux over the armature periphery more uniformly.

POLE COILS/FIELD COILS: They are usually made of copper wire or strip, ~~and~~ placed on each pole and are connected in series. They are wound in such a way that, when current is passed through these coils/winding, they electromagnetize the poles which produce the necessary flux that is cut by the revolving armature conductors.

ARMATURE CORE: It is a cylindrical & drum-shaped and is built up of usually circular sheet-steel discs or laminations approximately 0.5mm thick. the armature core has grooves or slots on its outer surface. It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets. In small machines, the laminations are keyed directly to the shaft. In large machines, they are mounted on a spider. the purpose of using laminations is to reduce eddy-current loss.

ARMATURE CONDUCTORS / WINDINGS: It is usually a former wound copper coil which rests in armature slots. the armature conductors are insulated from each other and also from the armature core. Arma-ture winding can be wound by one of the two method; lap winding ~~or~~ or wave winding.

COMMUTATOR: A commutator is mechanical rectifier which conver-ts the alternating current induced in the armature conductors into unidirectional current in the external load circuit. the function of the commutator is to facilitate collection of current from the armute conductors. It is of cylindrical structure and is built up of wedge-shaped segments of high-conductivity ~~hard~~ hard-drawn or drop forged copper. these segments are insulated from each other by thin layers of mica. the number of segments is equal to the number of armatu-re coils. Each commutator segment is connected to the armature conductor by means of a copper lug or strip (or riser).

BRUSHES & BEARINGS: the brushes function is to collect current from commutator, are usually made of a carbon and are in the shape of a rectangular block. these brushes are housed in brush-holders usually of the box-type variety. the pressure exerted by the brushes on the commutator can be adjusted and is maintained at a constant value by means of springs. Current produced in the armature winding is passed on to the commutator and then to the exitornal circuit by means of brushes.

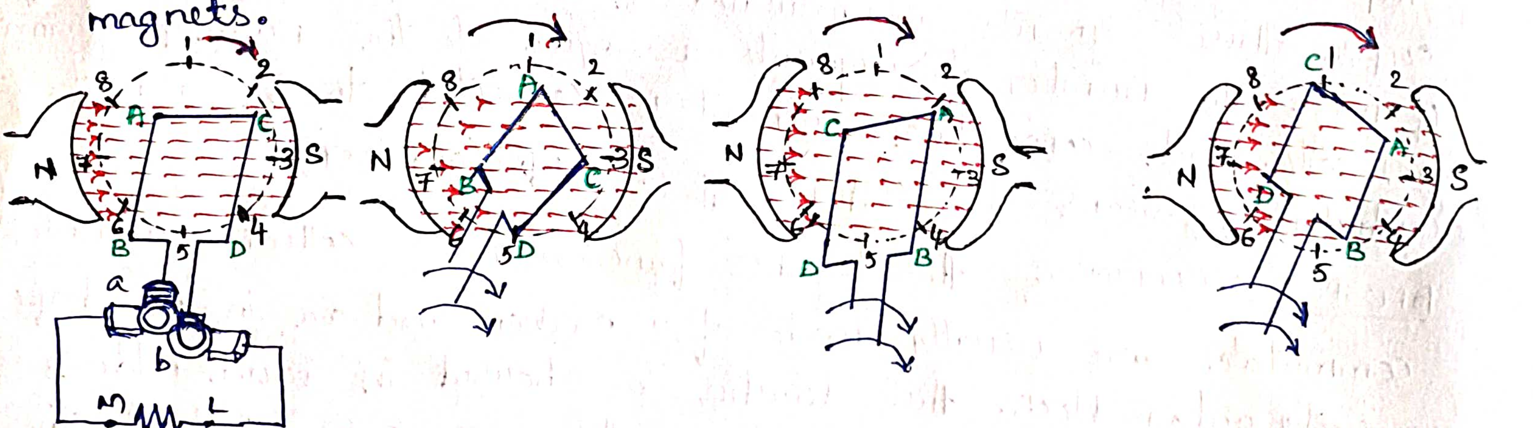
Because of their reliability, ball-bearings are frequently emplo-yed, though for heavy duties, roller bearings are preferable. The ball and rollers are generally packed in hard oil for quieter operation and for reduced bearing wear, sleeve bearings are used which are lubri-cated by ring oilers fed from oil reservoir in the bearing bracket.

WORKING OF DC GENERATOR:

The working principle of DC generator is based on the principle of Faradays laws of electromagnetic induction; which states that, " When the magnetic flux linking a conductor or coil changes, an e.m.f. is induced in it".

Simple loop Generator:

Let us consider a single-turn rectangular copper coil ABCD rotating about its own axis in a magnetic field provided by either permanent magnets or electromagnets. The two ends of the coil are joined to two slip-rings 'a' and 'b' which are insulated from each other and from the central shaft. Two collecting brushes press agai-nst the slip-rings. Their function is to collect the current induced in the coil and to convey it to the external load resistance 'R'. The rotating coil may be called 'armature' and the magnets are 'field magnets.



Let us assume that the coil ABCD is rotating in clock-wise direction as shown. As the coil assumes successive positions in the magnetic field, the flux link with the coil changes. Hence, an e.m.f is induced in it which is proportional to the rate of change of flux linkages (i.e. $e = -N \frac{d\phi}{dt}$).

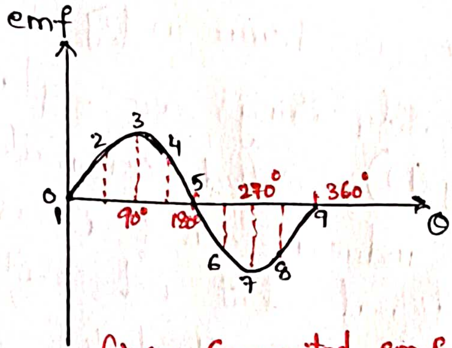


Fig (a). Generated em.f

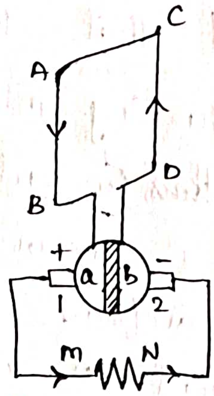


fig (b).

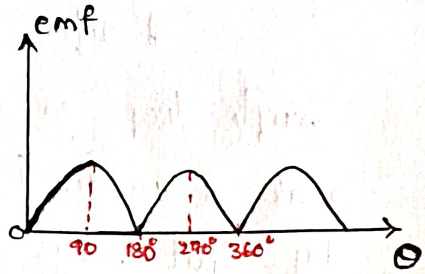


fig.(c) unidirectional voltage

When the plane of the coil is at right angles to the lines of flux i.e. when it is in position ①, then flux linked with the coil is maximum, but rate of change of flux linkages is minimum. Hence there is no induced emf in the coil (i.e. $e = 0$).

As the coil continues rotating in clockwise direction as shown, the rate of change of flux linkages, and hence induced e.m.f in it increases, till position ③ is reached where, $\theta = 90°$. Here, the coil plane is horizontal i.e. parallel to the lines of flux. As seen, the flux linked with the coil is minimum but rate of change of flux linkages is maximum. Hence, maximum e.m.f is induced in the coil as depicted in fig.(a).

In the next quarter revolution, i.e. from 90° to 180°, the flux linked with the coil gradually increases, but the rate of change of flux linkages decreases. Hence, the induced emf decreases gradually till in position ⑤ of the coil, it is reduced to zero value.

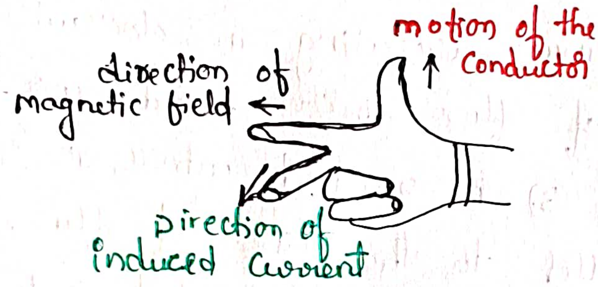
In the next half revolution, i.e. from 180° to 360°, the variations in the magnitude of e.m.f. are similar to those observed in the first-half revolution. Its value is maximum when coil is in position ⑦ and minimum when in position ① i.e. at $\theta = 360°$. However, it is found that the direction of the induced current is from 'C' to 'D' and 'B' to 'A'. Hence, the direction of current flow is ABMLDC. The current through the load resistance 'R' flow from 'M' to 'L' during the first half revolution of the coil, and during the second-half revolution from 'L' to 'M' (current flows from CDLMBA).

therefore it is found that, the generated e.m.f from a simple loop generator is alternating in nature as shown in fig.(a). To make a unidirectional e.m.f/ ~~thus~~ current, the slip rings are replaced by split-rings (arrangement is shown in fig.(b)), called commutator. the resultant generated waveform of the induced e.m.f is as shown in fig.(c). this current is unidirectional but not continuous like pure direct current.

* In general, generated e.m.f, $\boxed{E_g = \frac{\phi Z N P}{60 A}}$ volts

ϕ – flux/pole
Z – No. of armature conductors/coils
N – Speed of armature in rpm
P – No. of poles
A – No. of parallel paths

* the direction of induced e.m.f is found by the 'Fleming right hand rule'.



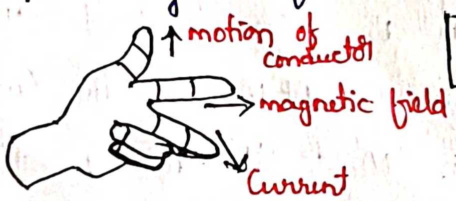
DC MOTOR :

A DC motor is an electromechanical ~~ma~~energy conversion ~~machine~~ machines, which converts electrical energy into mechanical energy.

DC motor operation is based on the principle ~~of~~ that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's left-hand rule and whose magnitude is given by

$\boxed{F = BIl}$ Newton

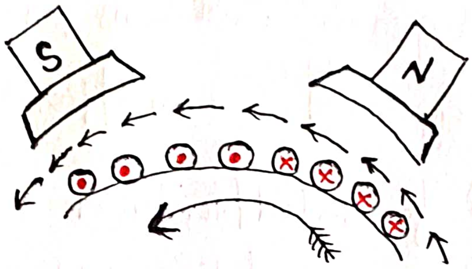
B – magnetic flux density
I – Current
l – length of the conductor.



Basically, there is no constructional difference between a DC generator and a DC motor. In fact, the ~~DC~~ ~~mac~~ same DC machi-ne can be used interchangeably as a generator & as a motor.

DC MOTOR WORKING PRINCIPLE:

Figure represents ~~the~~ a part of multipolar DC motor. When its field magnets are excited by an external source of DC supply, N and S poles are formed as shown.



: Figure :

The armature conductors under N-pole carry current in one direction (crosses) and those under S-poles, to carry in another/ opposite direction (dots). Since each armature conductor is carrying current and is placed in the magnetic field, mechanical force acts on it. By applying Fleming's left-hand rule, the direction of force on each conductor can be found. It is shown by small arrows placed above each conductor. It is observed that each conductor experiences a force F (= BIL Newton) which tends to rotate the armature in anticlockwise direction. These forces collectively produce a driving torque which sets the armature rotating.

It should be noted that the function of a commutator in the motor is the same as in a generator. By reversing current in each conductor as it passes from one pole to another, it helps to develop a continuous and unidirectional torque.

EMF EQUATION OF A GENERATOR:

The emf generated in a DC generator, according to Faraday's laws of electromagnetic induction.

Let ϕ = flux per pole in Weber

Z = Total number of armature conductors.

= No. of slots × No. of conductors / slot.

P = No. of generator poles

A = No. of parallel paths in armature.

N = Speed of armature in revolutions per minute (r.p.m).

E_g = e.m.f of the generator = e.m.f / parallel path.

Now average e.m.f generated / conductor $= \frac{d\phi}{dt}$ volts

Flux cut / conductor in one revolution, $d\phi = \phi P$ Wb.

Time taken to complete one revolution is $dt = \frac{60}{N}$ seconds

Hence, according to Faraday's laws, $E_g = \frac{d\phi}{dt} = \frac{\phi P N}{60}$ volt.

For simplex wave-wound generator;

No. of parallel paths = 2.

No. of conductors in one path = $Z/2$

$$\therefore E_g = \frac{\phi P N}{60} \times \frac{Z}{2}$$

$$\Rightarrow \boxed{E_g = \frac{\phi Z N P}{120}} \text{ volts.}$$

Similarly, for simplex lap-wound generator, since number of parallel paths, $\boxed{A = P}$, $\boxed{E_g = \frac{\phi Z N}{60}}$ volts.

In general, $\boxed{E_g = \frac{\phi Z N}{60} \times \left(\frac{P}{A}\right)}$ volts.

BACK (or) COUNTER EMF IN A DC MOTOR :

When the armature of a DC motor rotates under the influence of 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 ~~opp~~ opposite direction to the applied voltage, 'V' (according to Lenz's law) and is known as 'back or counter e.m.f, E_b. The back e.m.f, $\boxed{E_b = \frac{\phi Z N P}{60 A}}$ is always less than the applied voltage 'V', although this difference is small when the motor is running under normal conditions.

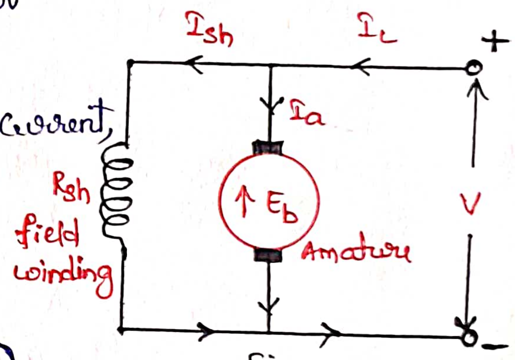
SIGNIFICANCE OF THE BACK EMF :

The presence of back e.m.f. makes the DC 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 load.

Considering figure, the armature current,

$$I_a = \frac{\text{Net voltage}}{\text{Armature resistance}}$$

$$\Rightarrow \boxed{I_a = \frac{V - E_b}{R_a}} \text{ Amphere} \longrightarrow ①$$



:Figure:

We know that, the back e.m.f,

$$\boxed{E_b = \frac{\phi Z N P}{60 A}} \text{ Volts} \longrightarrow ②$$

The back e.m.f depends, among other factors, upon the armature speed 'N'. If speed is high, 'E_b' is large, hence the armature current, 'I_a' seen from the eq. ①, is small. If the speed is less, then 'E_b' is less, hence more current flows which develops motor torque. So, it is find that 'E_b' acts like a governor i.e. it makes a motor self-regulating so that it draws as much current as it just necessary.

APPLICATIONS:

Generators:

- Charging batteries
- Light and power supply purposes.
- Laboratory and commercial testing
- Speed regulation tests
- High-voltage DC power transmission,...

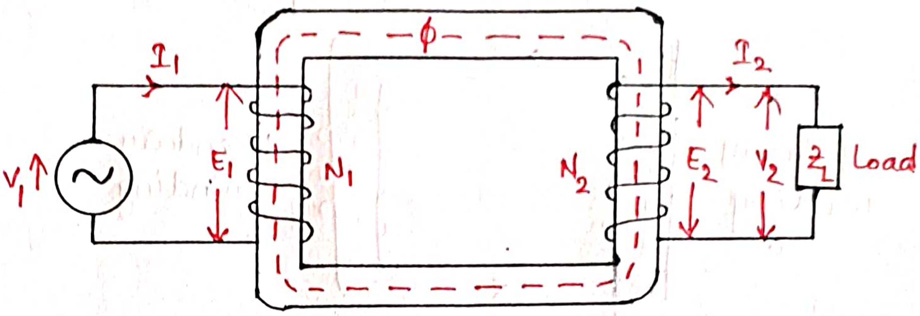
Motors:

- Elevators,
- Steel mills
- Rolling mills
- Locomotives
- Electric vehicles
- Conveyors.
- Printing presses
- Lathes
- Air compressors
- Traction works
- Blowers and fans
- Machine tools
- centrifugal pumps,...

AC MACHINES:

TRANSFORMERS:

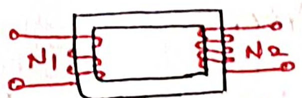
The transformer is an electromagnetic energy conversion device that transfers electrical energy from one electrical circuit to another electrical circuit through the medium of magnetic field and without a change in the frequency.



:Figure:

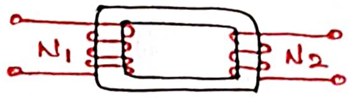
The electric circuit which receives energy from the supply mains is called primary winding and the other circuit which delivers electric energy to the load is called the secondary winding. Here, the primary and the secondary windings of a transformer are not connected electrically, but are coupled magnetically. This coupling magnetic field allows the transfer of energy in either direction, from high-voltage to low-voltage circuits and vice-versa.

* If the secondary winding has more turns than the primary winding, then the secondary voltage is higher than the primary voltage and the transformer is called a 'step-up transformer'.



* If the secondary winding has less turns than the primary winding, then the secondary voltage is lower than the

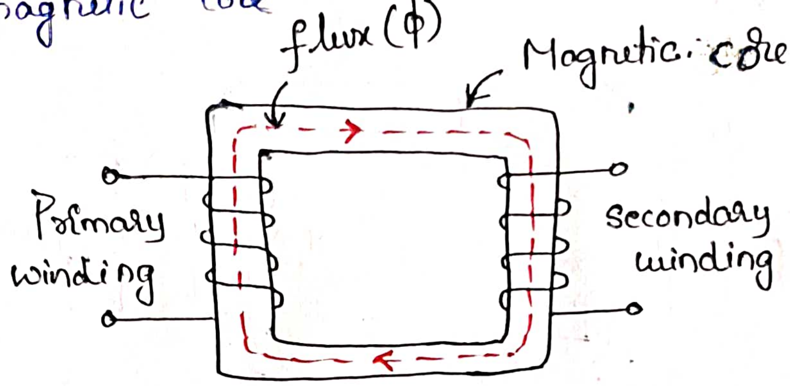
primary voltage and the transformer is called a "Step-down transformer".



CONSTRUCTION OF TRANSFORMER :

Basically a transformer consists of two main parts:

1. Two coils (primary winding and secondary winding)
2. A magnetic core



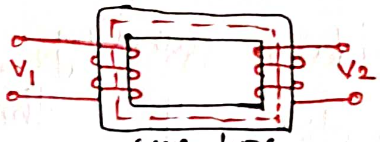
: Transformer :

The primary winding is one which is connected to the AC source, and the secondary winding is one which is connected to the load. ~~The magnetic core acts a~~ Both prim connected to the load. -ary and secondary windings are made of conducting wire such as copper or aluminium wire. these wires are insulated and wound on the magnetic core.

The magnetic core is a stack of thin silicon-steel laminations about 0.35 mm of thick, have high permeability and low hysteresis loss. In order to reduce the eddy curr -ent losses, these laminations are insulated from one another by thin layers of varnish. the magnetic core acts as a path for magnetic flux.

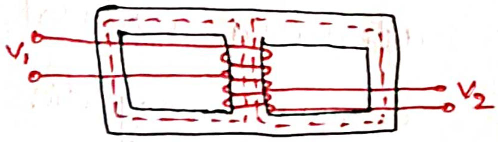
Other necessary parts are: some suitable container for assembled core and windings; a suitable medium for insulating the core and its windings from its container; Suitable bushings for insulating and bringing out the terminals of windings from the tank. Constructionally, the transformers are of two general type :

(i) Core type: the windings surround a considerable part of the core as shown.



Core-type

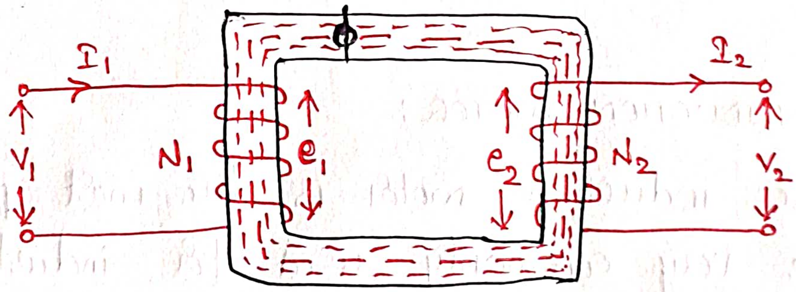
(ii) Shell type: the core surrounds a considerable portion of the windings.



Shell-type

WORKING PRINCIPLE OF A TRANSFORMER :

The working principle of the transformer is based on Faraday's law of electromagnetic induction. According to this principle, when the magnetic field linking the coil changes, an emf is induced in the coil.



: Transformer :

$V_1 \rightarrow$ applied voltage to the primary
$I_1 \rightarrow$ Current in the primary
$N_1 \rightarrow$ No. of turns in the primary
$\phi \rightarrow$ flux produced
$e_1 \rightarrow$ ~~Self~~ Induced emf in primary.
Similarly, V_2, I_2, N_2, e_2 to the secondary

When the primary winding of the transformer is connected to a source of AC supply, an alternating current flows through it. Since the primary winding is wound around the magnetic core, thus the alternating current flowing through the primary winding produces an alternating magnetic flux in the core. This alternating magnetic flux travels to the secondary winding and links with it. Because the magnetic flux is alternating, hence it induces an emf in the secondary winding according to the principle of electromagnetic induction. Thus the transformer action requires the existence of a alternating mutual flux linking the various winding on a common magnetic core.

The frequency of the induced emf in the secondary winding is the same as that of the flux & that of the AC supply voltage. When an electrical load is connected to the secondary winding of the transformer, an electric current flows in the secondary winding due to induced emf.

emf equation of a transformer, $\boxed{E_2 = 4.44 f N_2 B_m A}$ Volts

(or) $\boxed{E_1 = 4.44 f N_1 B_m A}$ Volts.

THREE-PHASE INDUCTION MOTOR:

Three-phase induction motor is the most popular type of AC motor. It is very commonly used for industrial drives since it is cheap, robust, efficient, and reliable. They run at essentially constant speed from no-load to full-load. The physical size of such a motor for a given output rating is relatively small as compared with other types of motors.

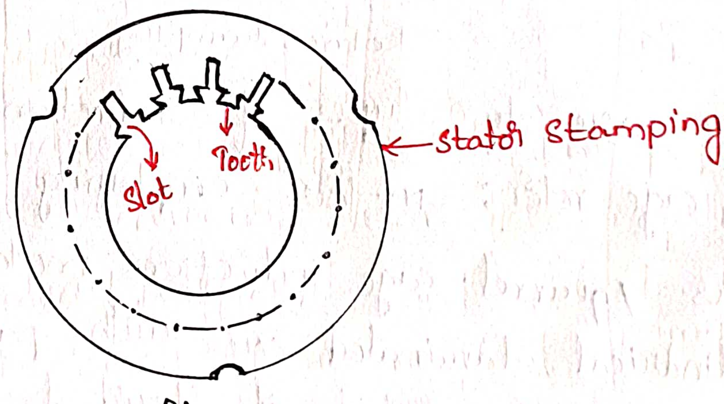
A induction motor may be considered to be a ~~trans~~ 'rotating transformer' in the sense that the power is transferred from the stator (primary) to the rotor (secondary) winding only by mutual induction. For this reason such a machine is often called the 'induction machine'.

CONSTRUCTION OF 3-ϕ I.M.:

A three-phase induction motor ($3\phi IM$) is very simple in construction compared to a dc motor & a synchronous motor. A 3-ϕIM essentially consists of two parts: the stator and the rotor. Other necessary parts are: a stiff shaft to preserve the very short air-gap ($\approx$ 0.4mm to 4mm), a frame to form the stator housing and carry the end covers, bearing and terminal box. Non-salient pole construction is used for all three-phase induction motors.

STATOR:

The stator is the stationary part of the machine, and is built up of high-grade alloy steel laminations to reduce hysteresis and eddy current losses.



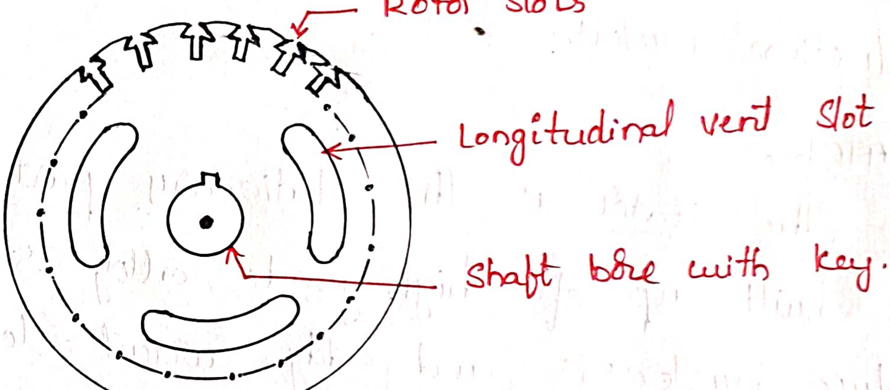
:Figure:

As shown in figure, a number of evenly spaced slots are provided on the inner periphery of the laminations. The insulated stator conductors are connected to form a three-phase winding, may be either star or delta connected.

The stator winding is wound for a definite number of poles, the exact number of poles being determined by the requirements of speed. Greater the number of poles, lesser the speed and vice-versa.

ROTOR:

The rotor is a rotating part of the machine, and is also built up of thin laminations of the same material (high grade alloy steel) as stator. The laminated cylindrical core is mounted directly on the shaft or a spider carried by the shaft. These laminations are slotted on their outer periphery to receive the rotor conductors.



Rotor Stamping

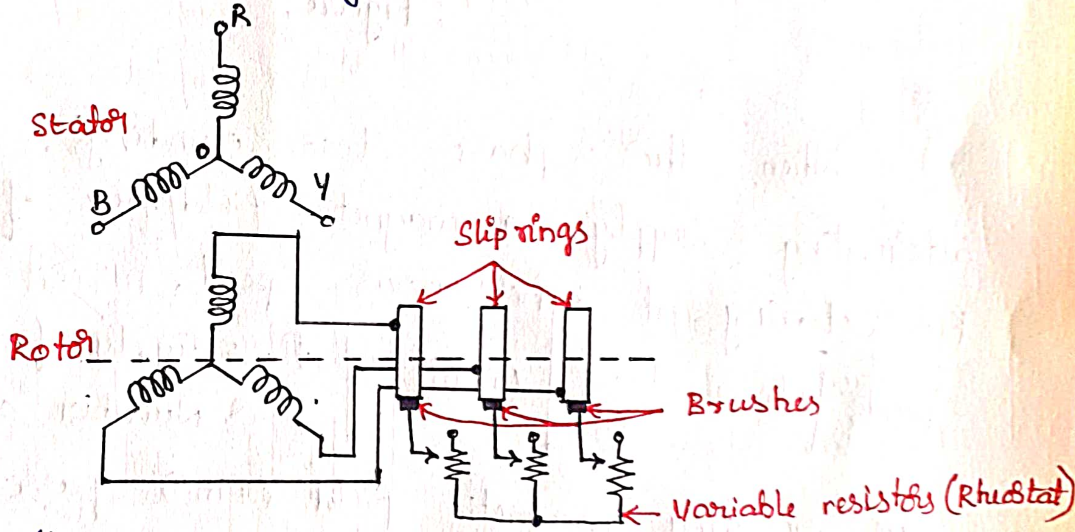
There are two types of induction motor rotors:

(i) Squirrel-cage rotor: Motors employing this type of rotor are known as squirrel-cage induction motors. The rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors which, it should be noted clearly, are not wires but consists of heavy bars of copper, alluminium or alloys. One bar is placed in each slot, rather the bars are inserted from the end when semi-closed slots are used. At each end of the rotor, the rotor bars are short-circuited by heavy end rings, thus giving us a 'squirrel-cage construction'. The rotor slots are usually not quite parallel to the shaft but are properly given a slight skew, which offers the following advantages:

a). It helps to make the motor run quietly by reducing the magnetic hum and

b) It helps to reducing the locking tendency of the rotor teeth with the stator teeth.

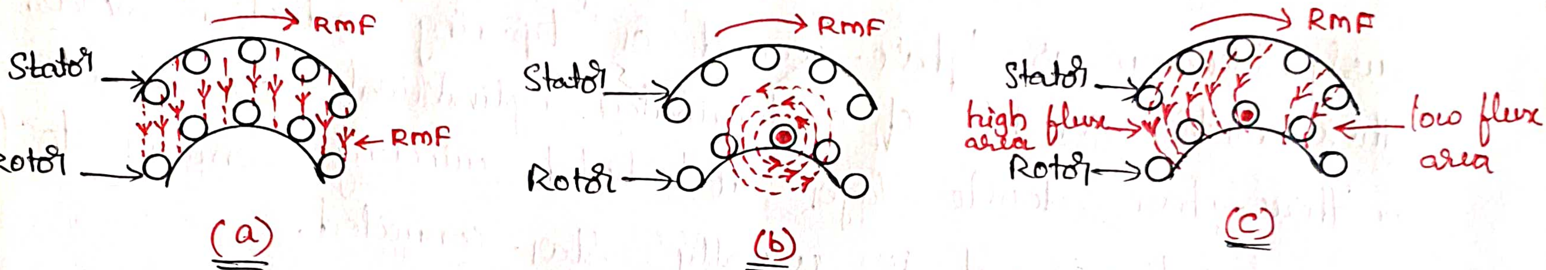
(ii). <u>Slip-ring rotor</u>: Motors employing this type of rotors are variously known as 'phase-wound' & 'slip-ring' induction motors. These rotors consists of a laminated cylindrical core and carries a three-phase double layer distributed winding similar to the stator winding, and is usually star-connected.



The open ends of the rotor windings are brought out and joined to three insulated slip-rings mounted on the rotor shaft with one brush resting on each slip-ring as shown. The purpose of slip-rings and brushes is to provide a means for connecting external resistances in the rotor circuit, which is 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. When the motor attains normal speed, the three-brushes are short-circuited so that the phase-wound rotor runs like a squirrel-cage rotor.

PRINCIPLE OF OPERATION OF A THREE-PHASE INDUCTION MOTOR :

A three-phase induction motor ($3\phi IM$) works on the principle of "Faradays laws of electromagnetic induction". Consider a portion of a $3\phi IM$ with stator and rotor as shown in figure. therefore, the working of a three-phase induction motor can be explained as follows :



: Figure :

When the 3-phase stator windings, are fed by a 3-phase alternating supply, a magnetic field/flux of constant magnitude but rotating at synchronous speed, is set up. Where synchronous speed,

$$\boxed{N_s = \frac{120f}{P}} \text{ (rpm)};$$

$f \rightarrow$ Supply frequency in Hz.
$P \rightarrow$ Number of poles.

The rotating magnetic field (RMF) passes through the air-gap, sweeps over the rotor surface and so cuts the rotor conductors which, as yet, are stationary. Due to the relative speed between the rotating flux and stationary conductors, an e.m.f is induced in the rotor conductors, according to Faraday's laws of electromagnetic induction. The frequency of the induced e.m.f. is the same as the supply frequency. Its magnitude is proportional to the relative speed between the flux and the rotor conductors and its direction is given by Fleming's

right-hand rule. Since the rotor bars & conductors form a
closed circuit, rotor current is produced whose direction is
given by Lenz's law, is such ~~as~~ as to oppose the very cause
producing it. In this case, the cause which produced the
rotor current is the relative velocity between the 'RMF' of
the stator and the stationary rotor conductors. Hence, to redu
-ce the relative speed, the rotor starts running in the same
direction as that of the flux and tries to catch up with
the rotating flux. The setting up of the torque for rotating
the rotor is explained as follows:

As shown in figure (a), the stator field which is assu
-med to be rotating clockwise. The relative motion of the rotor
with respect to the stator is anticlockwise. By applying right-
-hand rule, the direction of the induced e.m.f in the rotor is foun
-d to be outwards. Hence, the direction of the flux due to rotor
current alone, is as shown in figure (b). Now, by applying
left-hand rule, & by the effect of combined field (as shown
in figure (c), it is clear that the rotor conductors experien
-ce a force tending to rotate them in clockwise direction. Hence
the rotor is set into rotation in the same direction as that
of the stator flux & field i.e. 'RMF'. However, the rotor torque
never attains the synchronous speed of RMF by the stator,
hence the 3ϕIM's are usually called as 'asynchronous motors'.