UNIT-IV

Electrical Machines

DC-Machines:-

Two types ─┬─ DC-Generator
           └→ DC-Motor.

* DC-motors are classified into two types

① Separately excited DC-motor

② Self excited dc motor

(i) DC - series motor

(ii) DC - shunt motor

(iii) DC - compound motor

Construction of DC-Machine:-

The construction for DC-motor and DC-generator is same, it consists of the following parts.

① Yoke on Magnetic frame

② Pole core and pole shoes

③. Field winding

4. Armature core and windings

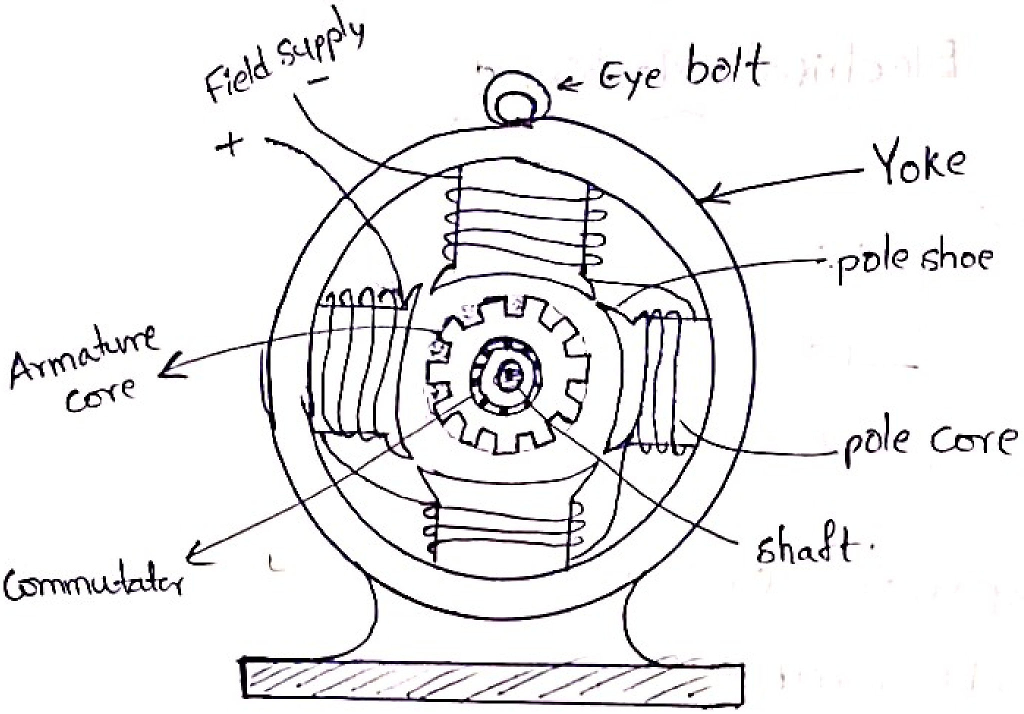
5. Commutators

6. Brushes

7. Bearings

8. End covers

9. Shaft.



① Yoke (or) Magnetic frame :- It is outer frame of DC-machine.

It provides the mechanical support to the poles ~~and~~ core and pole shoes of machine. In large machines it is made up of cast steel and in small machines it is made up of cast iron. The important fuctions of this yoke is

→ It provides support to pole core and pole shoe.

→ It provides low reluctance path for the flux of field

→ It protects inner parts of the machine.

②. Pole core and pole shoes:-

The pole core and pole shoe's are fixed to the magnetic frame ~~or~~ Yoke with the help of bolts. The thin cast steel

~~or~~ iron with ~~or~~ without laminations is used to make pole core and pole shoes.

→ The pole core carries the field winding and pole shoe gives a particular shape to enlarges the area of armature core to come across fluxes.

3. Field winding :-

→ It is the exciting winding, which is placed on pole core to produce the required magnetic field. ~~ks~~ ~~co~~ It always requires a relatively small DC-power to produce the required strong magnetic field. It is ~~o~~ wound on all pole cores in a series connection.

4. Armature core and windings

The rotating component of the DC-motor is called "Armature" and it consists of a liminated cylinder called "Armature core" placed over the shaft.

→ Armature core is the drum (or) cylindrical component fixed to the rotating shaft in a DC-motor.

→ it provides a place for conductor in slots

→ Provides a low reluctance path for ~~to~~ the magnetic flux.

It is made up of "Silicon steel material

→ The armature windings ~~is~~ are the insulated conductors made up of steel wire are placed in the armature slots.

→ This armature windings are two types

(i) Lap winding

(ii) Wave winding.

⑤ Commutators :-

→ Commutator is a cylindrical - wedge shaped hard-drawn copper bars (or) segments, which rotates along with the armature. It performs particular functions

(i) It collects currents from armature conductors and also supplies current to them

(ii) It converts alternating current to direct current in generators

(iii) It converts direct current to ~~d~~ alternating current in motors.

⑥. Brushes :-

It is set of carbon brushes attached to rotating armature via commutator, connecting the external circuit. The main purpose of brushes is to tap the electrical power generated in the rotating machine.

7. **Bearings :-**

Fitting a high carbon steel ball or roller bearings in the machine to make machine smooth rotation and reducing frictional losses.

8. **End covers :-** It is components attached to the yoke ends and which provide support to the bearings is called "end covers.

9. **Shaft :-** It is madeup of a mild steel which is having maximum breaking strength. It is transfers mechanical power to mechanical loads.

Working principle of DC-~~machine~~ motor

Motor works on Lorentz principle, it states that" whenever current carrying conductor placed in a magnetic field it experiences mechanical force (i.e torque), then it starts to rotates.

For understanding of working of dc-motor, consider a 2-poles (N & S), and a conductor which is carrying ~~condu~~ the current (I), placed in a magnetic field as shown below.

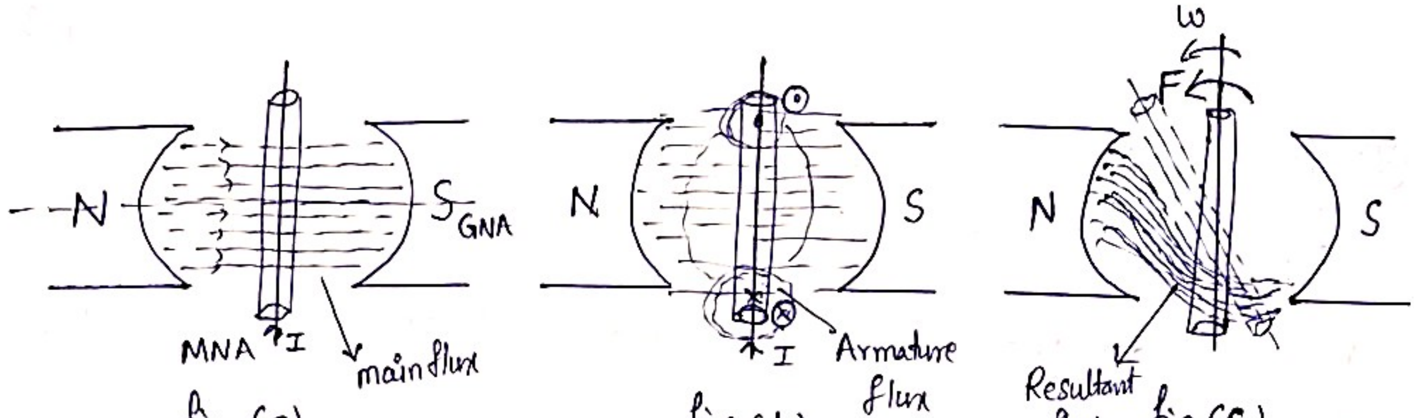
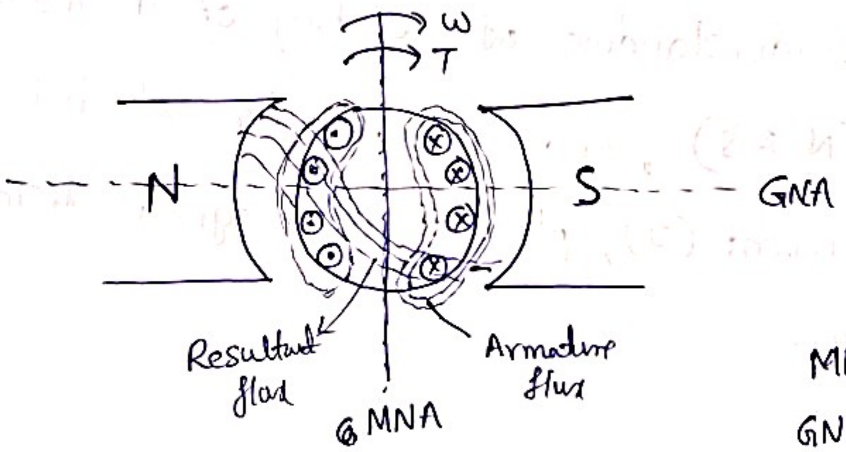


fig (a) fig (b) fig (c)

When the field windings wound on the poles are excited by a dc-source, the poles get magnetized and a strong magnetic field is produced. In that field, if conductor is placed, it creates the own magnetic field i.e weak magnetic field. Here due to the interaction between these two fields resultant field is produced as shown in fig(C).

The resultant field causes rotation of armature conduction, the direction of ~~of~~ conductor can be found by Flemming Left Hand Rule (FLHR).

The working of DC-motor can be explained by DC-motor mmf devoloped by these two magnetic fields as shown



MNA → magnetic Neutral axis
GNA → Geometrical neutral axis

As shown above figure, if the DC-motor having 'z' no.of conductors and produces resultant flux, it causes "mmf" i.e resultant mmf, which developes resultant force (F_r), which rotates the armature conductors.

The electromagnetic torque developed in the armatur conductors will be continouous if the direction of current in each conductor (or) coil side changes when i crosses the magnetic neutral axis (MNA). This reversal of direction of current can be achieved by using a commutator and it helps in developing a continuous torque.

** Back Emf in a DC-Motor

When a DC-source is used to excite the armature conductor, which is placed in the main magnetic field, a electromagnetic torque is developed, then DC-motor starts rotating. Due to the rotation of armature, the armature conductors cut the magnetic flux of the main magnetic field, hence an emf induced in armature conductors. This emf opposes the cause produces, this induced emf known as "Back emf (E_b)".

This emf is induced in the armature due to the generator action, its magnitude is given by the same expression as that of the generated emf in a DC-generator, i.e

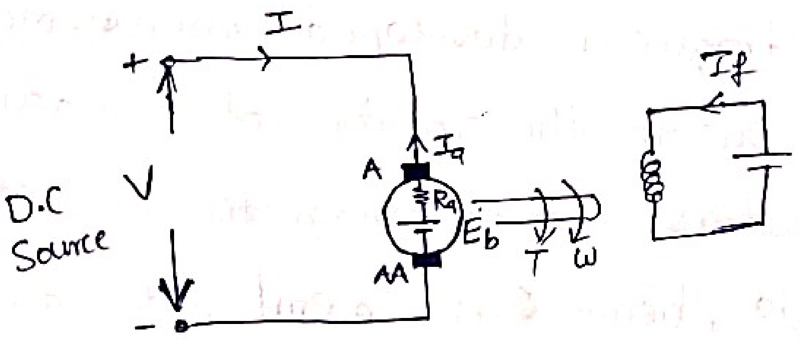
$$\boxed{E_b = \frac{\phi Z N}{60} \times \frac{P}{A}}$$

where ϕ = magnetic flux
Z = Total no. of conductors
N = Speed of motor
P = No. of poles
A = No. of parallel paths

if $A = P$ for lap winding
$A = 2$ for wave winding.

Equivalent circuit of DC-motor

The equivalent circuit of a DC-motor armature is shown as



In a DC-motor, the current flows from the line into the against the voltage generated in the armature, using KVL in circuit, then

$$V = E_b + I_a R_a + V_b$$

If the drop across the brushes is negligible, we get

$$V = E_b + I_a R_a$$

$$\Rightarrow \boxed{E_b = V - I_a R_a}$$

Multiplying with 'I_a', then

$$V I_a = E_b I_a + I_a^2 R_a$$

where $P_i = V I_a \rightarrow$ input power

$P_m = E_b I_a \rightarrow$ Mechanical power

$P_c = I_a^2 R_a \rightarrow$ copper loss in the armature.

Characteristics of separately excited DC-motor

We have ~~two~~ different types of characteristics

- → Torque (T_a) and Armature current (I_a) } Electrical characteristics
- → Speed (N) and Armature Current (I_a) } Electrical characteristics
- → Torque (T_a) and Speed (N) → Mechanical characteristics.

We have the relations

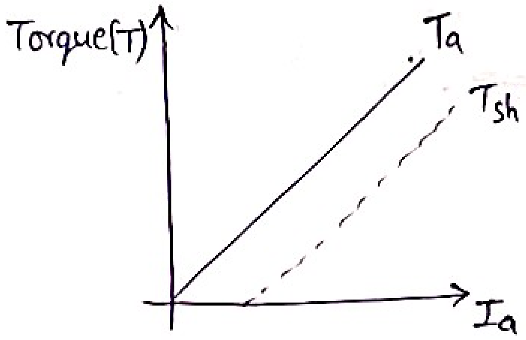
Torque $T = 9.55 \times \dfrac{E_b I_a}{N} \rightarrow T \propto I_a$

and $E_b = \dfrac{\phi Z N P}{60 A} \rightarrow T \propto \dfrac{1}{N}$

& $N \propto \dfrac{V - I_a R_a}{\phi} \Rightarrow N \propto \dfrac{1}{I_a}$

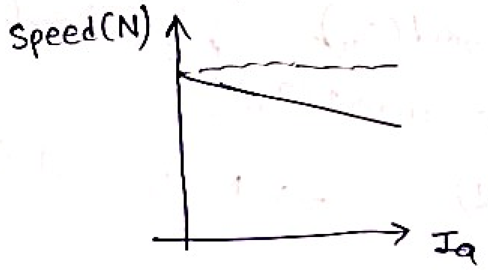
(i) T Vs I_a characterstics:-

Since the field winding in a DC-motor is excited by the constant supply voltage 'V', the current through the field winding I_{sh} constant, w.r.to that torque constant with change the constant armature current 'I_a'



(ii) N Vs I_a Characterstics :-

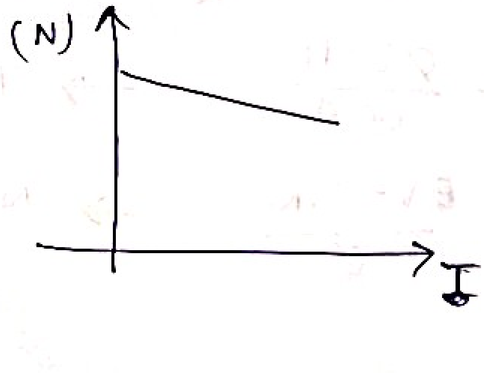
We know that $N \propto E_b$, so $N \propto V - I_aR_a$, when I_a increases, then 'I_aR_a' drop increases, then automatically Speed decreases, so



drooping Characterstics.

(iii) T Vs N characterstics:- From the torque equation

$T \propto \frac{1}{N}$, so that



Speed control of DC-motors

The speed equation of a DC-motor is given by

$$N = \frac{V - I_a R_a}{\phi} \times \frac{60A}{P}$$

i.e $N \propto \frac{V - I_a R_a}{\phi}$

→ The speed control of DC-shunt motors, we have the methods

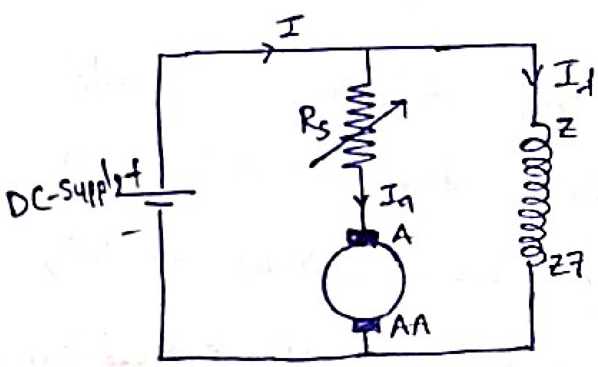
ⓐ Armature Resistance control method

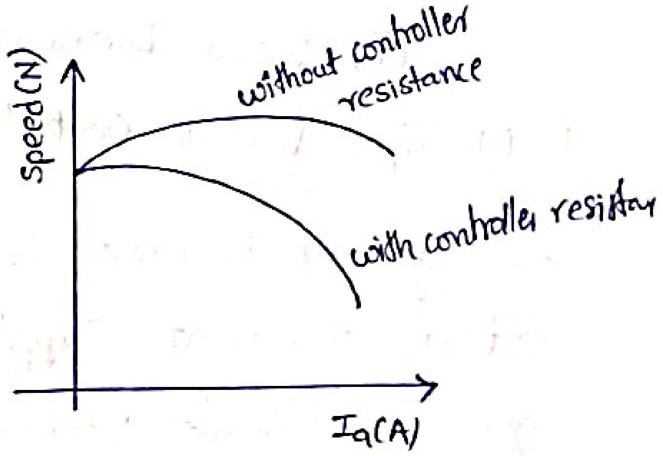
ⓑ Flux control method

ⓒ Applied Voltage ~~[illegible]~~ method

ⓐ Armature Resistance control method:-

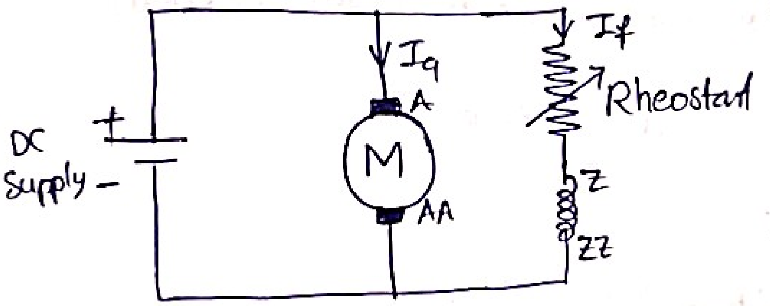
In this method, connecting a series resistance (R_s) to the motor, we can control speed of DC-shunt motor, as shown in fig.

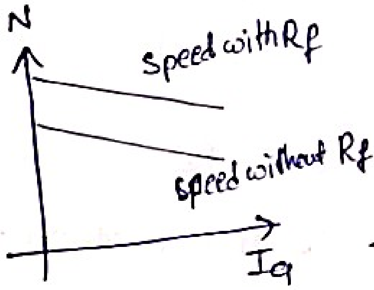


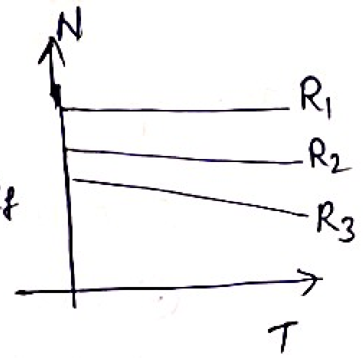


We know that $N \propto (V - I_a R_a)$, from this $N \propto \frac{1}{R_a}$, when R_a increases, then I_a decreases, w.r.to that speed will be reduces.

(b) Flux control method :- This method is used to control of the speed of a DC-shunt motor, above the rated speed, by reducing the field flux, since $N \propto \frac{1}{\phi}$. In this method a variable resistance element called " shunt field rheostart is connected in series with shunt field winding, as shown in fig







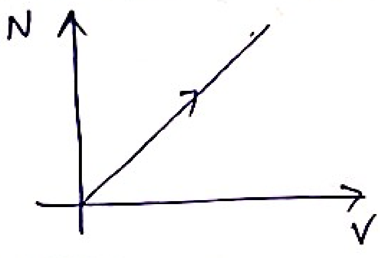
(c). Applied voltage control method :-

We have two different voltage control methods as

(i) Multiple voltage control

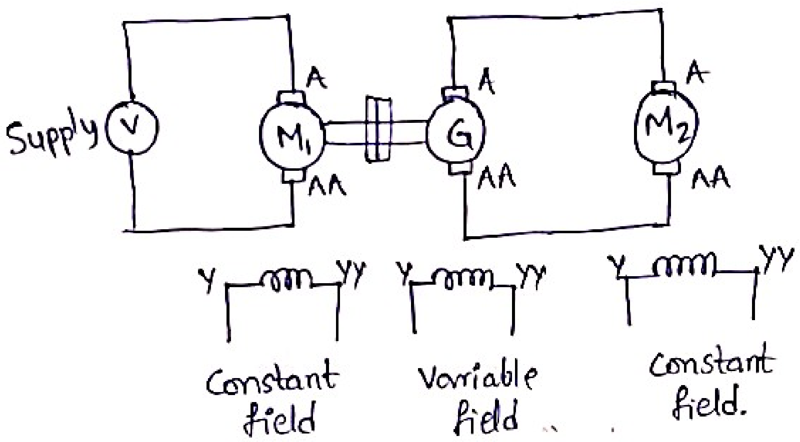
(ii) Ward - Leonard System.

(i) Multiple Voltage Control :- In this method, a suitable arrangement is made in such away that the field winding gets a constant supply voltage and armature winding gets a variable voltage. The different voltages that can be used for exciting armature winding are obtained using a switch-gear. We know that $N \propto V$, so



(ii) Ward-Leonard System :-

The arrangement of ward-leonard system to control the speed of a DC-Shunt motor is shown in figure below.



In this method, M_2 DC-Shunt motor speed has to be controlled, M_1 can be either AC (or) DC-motor with constant speed which is coupled directly to generator "G".

The output of G_1 is fed as the input to the armature of motor M_2. The field winding of M_2 is given by a constant DC-Supply voltage. Therefore, varying the generator output can vary the supply voltage applied to armature of M_2. The generator output can be varied using a field regulator. Smooth controlling can be possible by using this method.

Construction of three phase Induction motor:-

4-①

* The three phase induction motor consists of two main parts, namely.
  1) The part carrying three phase windings, which is stationary called stator.
  2) The part which rotates and is connected to the mechanical load through shaft called rotor.

1. Stator:- The stator has a laminated type of construction made up of stampings which are 0.4 to 0.5mm thick.

* The stampings are slotted on its periphery to carry the stator winding. The stampings are insulated from each other. Such a construction essentially keeps the iron losses to a minimum value.
* The number of stampings are stamped together to build the stator core.
* The slots on the periphery of the stator core carries a three phase winding, connected either in star or delta. This three phase winding is called stator winding. It is wound for definite number of poles.
* The radial duts are provided for the cooling purpose. The fig Q.35.1 shows a stator lamination.

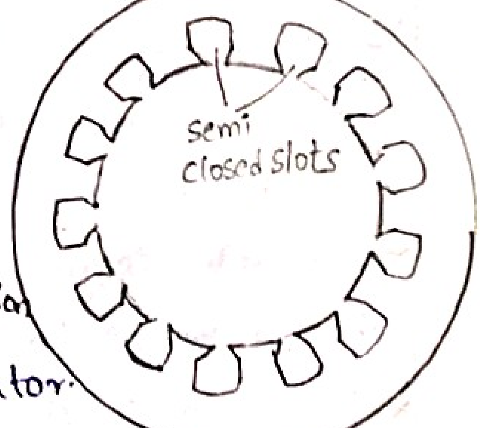


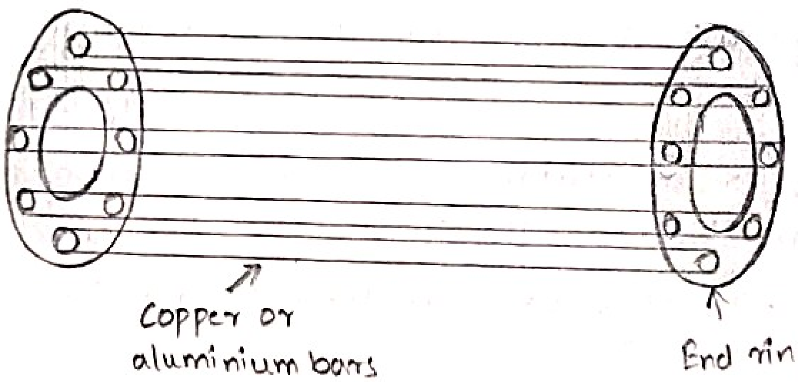
Fig. Q.35.1 Stator lamination

2) Rotor:- The rotor is placed inside the stator.

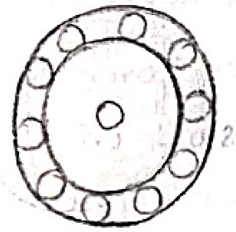
* The air gap between stator and the rotor is 0.4mm to 4mm.
* The two types of rotor constructions which are used for induction motor are, a. squirrel cage rotor and b. slip ring or phase wound rotor.

a) Squirrel cage rotor:-

* The rotor core is cylindrical and slotted on its periphery.
* The rotor consists of uninsulated copper (or) aluminium bars called rotor conductors. The bars are placed in the slots.
* These bars are permanently shorted at each end with the help of conducting copper ring called end ring. The bars are usually brazed to the end rings to provide good mechanical strength.
* The entire structure looks like a cage, forming a closed electrical circuit. so the rotor is called squirrel cage rotor. The construction is shown in the Fig. Q.35.2.



(a) Cage type structure of rotor



(b) Symbolic representation

b) Slip Ring Rotor (or) phase wound Rotor:-

* In this type of construction, rotor winding is exactly similar to the stator.
* The rotor carries a three phase star (or) delta connected, distributed winding, wound for same number of poles as that of stator.
* The rotor construction is laminated and slotted. The slots contain the rotor winding.
* The three ends of three phase winding, available after connecting the winding in star (or) delta, are permanently connected to the slip rings.
* with the helps of slip rings, the external resistances can be added in series with each phase of the rotor winding. This

arrangement is shown in the Fig Q.35.3

4-②

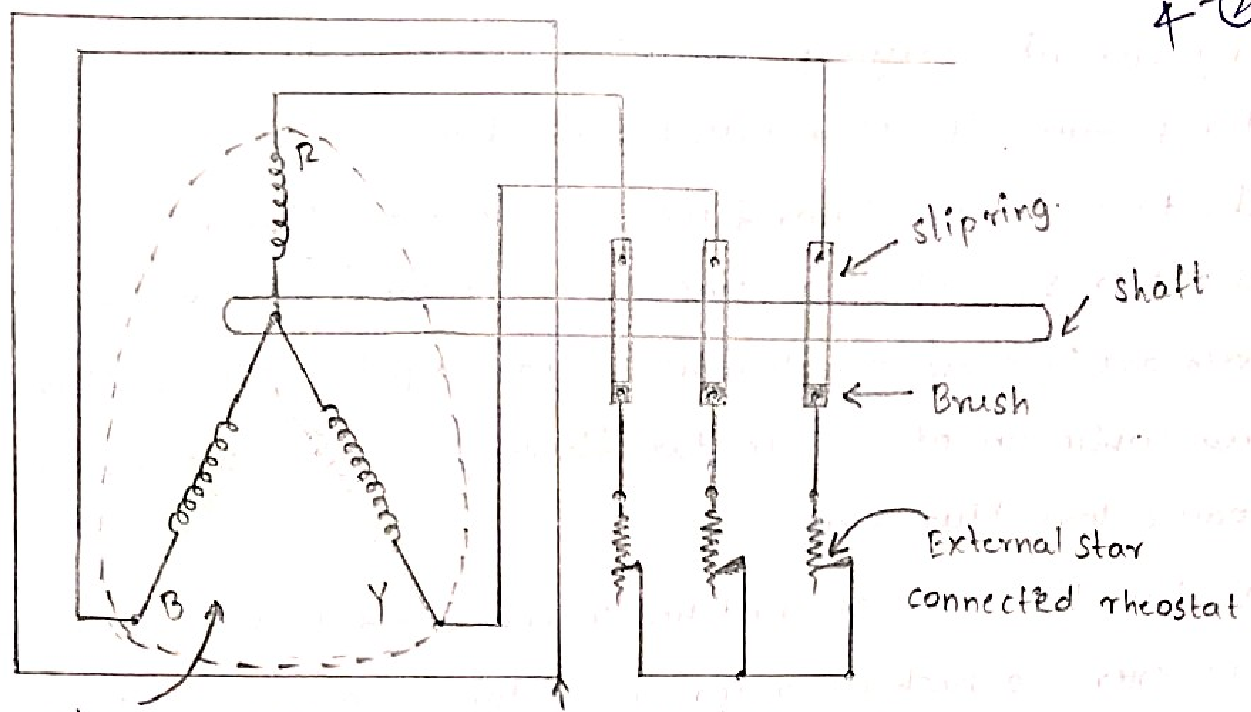


Fig. Q.35.3 Slip rings or wound rotor.

* In the running condition, the slip rings are shorted.

Working principle of three phase induction motor:-

Induction motor works on the principle of electromagnetic Induction.

* When a three phase supply is given to the three phase stator winding, a rotating magnetic field of constant magnitude is produced. The speed of this rotating magnetic field is synchronous Speed, N_s r.p.m.

$N_s = \frac{120f}{P}$ = speed of rotating magnetic field.

* This rotating field produces an effect of rotating poles around a rotor.
* At this instant rotor is stationary and stator flux R.M.F. is rotating. so its obvious that there exists a relative motion between the R.M.F and rotor conductors.
* Whenever conductor cuts of flux, e.m.f gets induced in it. So e.m.f gets induced in the rotor conductors called rotor induced e.m.f
* As rotor forms closed circuit, induced em.f circulates through

rotor called rotor current

* Any current carrying conductor produces its own flux. so rotor produces its flux called rotor flux.

* The two fluxes, stator flux and the rotor flux interact with each other such that on one side of rotor conductor, two fluxes are in same direction hence add up to get high flux area while on other side, two fluxes cancel each other to produce low flux area

* As flux lines act as stretched rubber band, high flux density area exerts a push on rotor conductor toward low flux density area. so rotor conductor experiences a forces due to interaction of the two fluxes.

* As all the rotor conductors experiences a force, the overall rotor experiences a torque and starts rotating.

* According to Lenz's law the direction of induced current in the rotor is so as to oppose the cause producing it.

* The cause of rotor current is the induced e.m.f. which is induced because of relative motion present between the rotating magnetic field and the rotor conductors.

* Hence to oppose the relative motion i.e, to reduce the relative speed, the rotor experiences a torque in the same direction as that of R.M.F. and tries to catch up the speed to rotating magnetic field.

Slip of Induction motor:-

4-③

The differenkebetween the speed of rotating magnetic field and the actual rotor speed is called slip speed i.e. $N_S - N$ = slip speed of the motor.

$$\boxed{\therefore \text{ slip speed} = N_S - N}$$

* slip of the induction motor is defined as the difference between the synchronous speed (N_S) and actual speed of rotor i.e. motor (N) expressed as a fraction of the synchronous speed (N_S). This is also called absolute slip (or) fractional slip and is denoted as 's'.

Thus, $$\boxed{\text{slip, } S = \frac{N_S - N}{N_S} \quad \text{and } \% \ S = \frac{N_S - N}{N_S} \times 100}$$

Torque equation of three phase inductor motor:-

The torque developed by the rotor is directly proportional to

i, rotor current

ii, rotor E.m.f

iii, power factor of the rotor circuit.

$$T \propto E_2 I_2 \cos\phi_2$$

Rotor current $I_2 = \frac{SE_2}{Z_2} = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$

$$\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + (SX_2)^2}} \quad ; \quad T = \frac{KSE_2^2 R_2}{R_2^2 + (SX_2)^2}$$

starting Torque i.e. at $S = 1$ (slip)

$$SE_2 = E_2 \ , \ SX_2 = X_2$$

So starting Torque is given by

$$T_S = KE_2 I_2 \cos\phi_2$$

$$T_S = K E_2 \times \frac{E_2}{\sqrt{R_2^2 + X_2^2}} \times \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$$

$$T_S = \frac{KE_2^2 R_2}{(R_2^2 + X_2^2)}$$

Generally, the stator supply voltage is constant (V), so that flux set up by the stator also fixed, This in turn means that the Emf induced in the Rotor will be constant, so.

$$T_S = \frac{K_1 R_2}{(R_2^2 + X_2^2)}$$

$$T_S = \frac{K_1 R_2}{Z_2^2} \quad (\because K_1 = KE_2^2)$$

Condition for maximum starting Torque :-

Torque Equation is

$$T_S = \frac{K_1 R_2}{(R_2^2 + X_2^2)} \quad \text{—— (1)}$$

Differentiating (1) w.r.t R_2 and Equate to zero

$$\frac{dT_S}{dR_2} = 0$$

$$\text{So} \Rightarrow \quad K_1 \left[\frac{(R_2^2 + X_2^2) - R_2(2R_2)}{(R_2^2 + X_2^2)^2} \right] = 0$$

$$R_2^2 + X_2^2 - 2R_2^2 = 0$$

$$R_2^2 + X_2^2 = 2R_2^2$$

$$R_2^{\cancel{2}} = X_2^{\cancel{2}}$$

$$\boxed{R_2 = X_2}$$

→ This is the condition for maximum starting Torque

Hence, the starting Torque will be maximum when Rotor Resistance / phase = Stand still Rotor Reactance

Torque -slip characteristics:-

The torque slip characteristics are divided mainly into Three region

i, Low slip Region i.e, Lightly Loaded conditions:-

Here Rotor speed (N_r) is almost equal to synchronous speed of Rotating magnetic field (N_s)

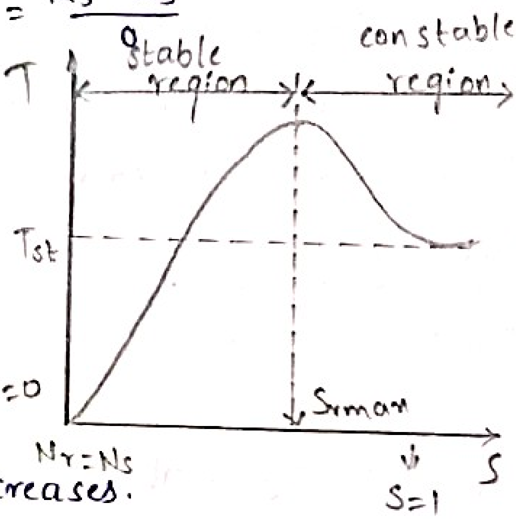
$N_r \simeq N_s$, so slip $s = \frac{N_s - N_r}{N_s} = \frac{N_s - N_s}{}$

$S = 0$

So, $Sx_2^2 << R_2^2$

$T_s = \frac{KSE^2 R_2}{R_2^2 + (Sx_2^2)^2}$ $(Sx_2 << R_2)$

So $\boxed{T_s \propto S}$



Torque varies Linearly with slip increases.

ii, Medium slip:- In this Region Torque attain a maximum value i.e at $R_2 = X_2$

iii, High slip Region:- (i.e motor is fully Loaded)

$N_r < N_s$, The slip value increases (0-1)

so $(sx_{20})^2 >> R_2^2$, from Torque Equation

$\boxed{T \propto 1/s}$ → Torque varies Non-Linear i.e decreases with increases in slip(s)

Application of I.M:-

i, squirrel cage Induction motors have "moderate starting Torque" and constant speed characterstics preferred for Driving fans, water pumps, grinders, lalte machines, printing machines, drilling machines.

ii, Slip ring Induction motors have "high starting Torque, hence they are preferred for Lifts, hoists, elevators, cranes, compressors,

Applications of three phase Induction motor:-

i, Squirrel cage type of motors having moderate starting torque and constant speed characteristics preferred for driving fans, blowers, water pumps, grinders, lathe machines, printing machines, drilling machine.

ii, slip ring induction motors can have high starting torque as high as maximum torque. Hence they are preferred for lifts, hoists, elavators, cranes, compressors.

Losses in three phase:-

The various losses taking place in three phase induction motor are,

1) Stater losses:- These include copper losses and iron losses.

2) Roter losses:- In running copper condition, rotor frequency is very small hence iron losses are negligible. Hence only rotor copper losses are considered.

3) Mechanical losses:- These include friction and windage losses.

$$\boxed{\therefore \quad P_{out} = P_m - \text{Mechanical losses}}$$

Types of Single phase Induction motors:-

Name the Starting methods for single phase Induction motors.

Depending upon the methods of producing rotating stator magnetic flux, the single phase induction motors are classified as,

1) split phase induction motor.

2) capacitor start induction motor.

3) capacitor start capacitor run induction motor. 4-5

4) shaded pole induction motor.

~~Stp~~ split phase induction motor:-

This type of motor has single phase stator winding called main winding. In addition to this, stator carries one more winding called auxiliary winding (or) starting winding.

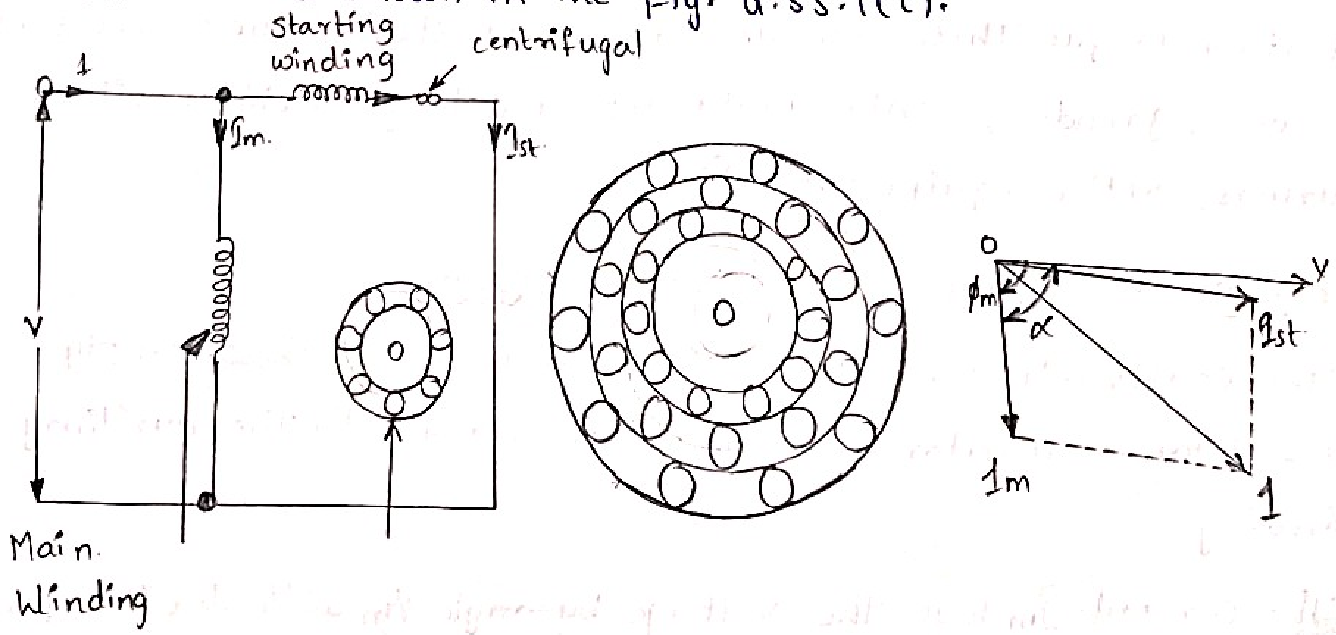
* The auxiliary winding carries a series resistance such that its impedance is highly resistive in nature. The main winding is inductive in nature.

Let I_m = current through main winding.

and I_{st} = current through auxiliary winding.

* As main winding is inductive, current I_m lags voltages V by a large angle ϕ_m while I_{st} is almost in phase in V as auxiliary winding is highly resistive.

* Thus there exists a phase difference of α between the two currents and hence between the two fluxes produced by the two currents. This is shown in the Fig. Q.55.1(c).



(a) Circuit diagram (b) Representation (c) phasor diagram

* The resulant of these two fluxes is a rotating magnetic field. Due to this, the starting torque which acts only in one direction is Produced to make the motor self starting.

* The auxiliary winding has a centifugal switch in series with it. when motor gathers a speed upto 75 to 80%. of the synchronous Speed, centifugal switch gets opened mechanically and in running condition auxiliarly winding remains out of the circuit. so motor runs only on stator winding.

* The torque-speed characteristics of split phase motor is shown in the Fig. Q.55.2.

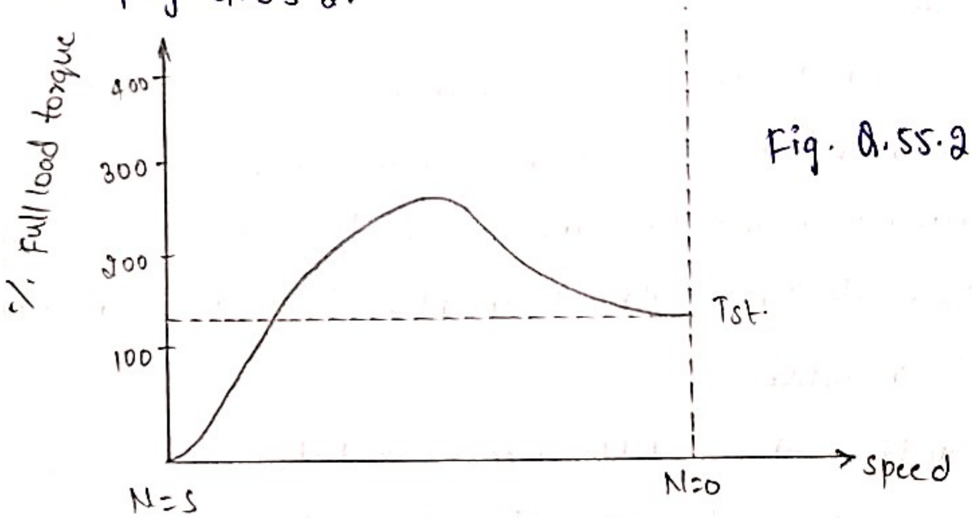


Fig. Q.55.2

Applications:- These motors have low starting current and moderate starting torque. These are used for easily started loads like fans, blowers, grinders, centrifugal pumps, washing machines, oil burners, office equipments etc.

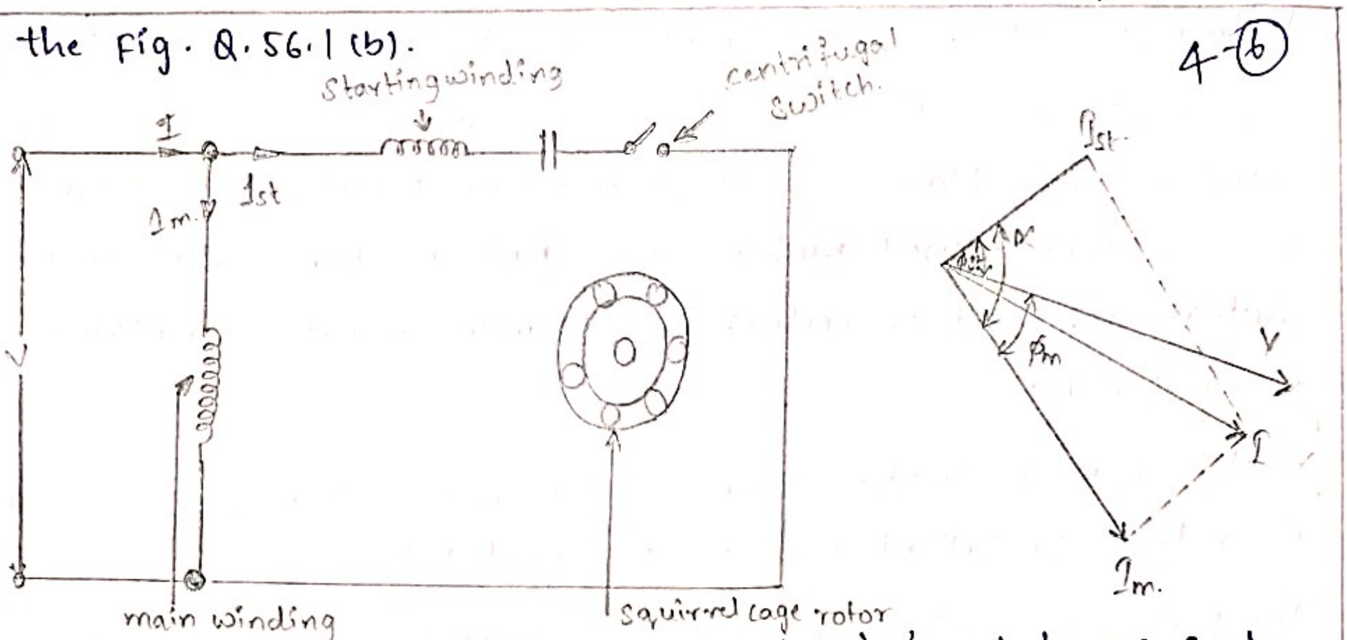
Capacitor start single phase induction motor:-

* The construction of capacitor start motor is shown in Fig Q.56.1 (a) A capacitor is connected in series with the auxiliary winding.

* The current I_m lags the voltage by angle ϕ_m while due to capacitor the current I_{st} leads the voltage by angle ϕ_{st}. Hence there exists a large phase difference between the two currents which is almost $90°$, which is an ideal case. The phasor diagram is shown

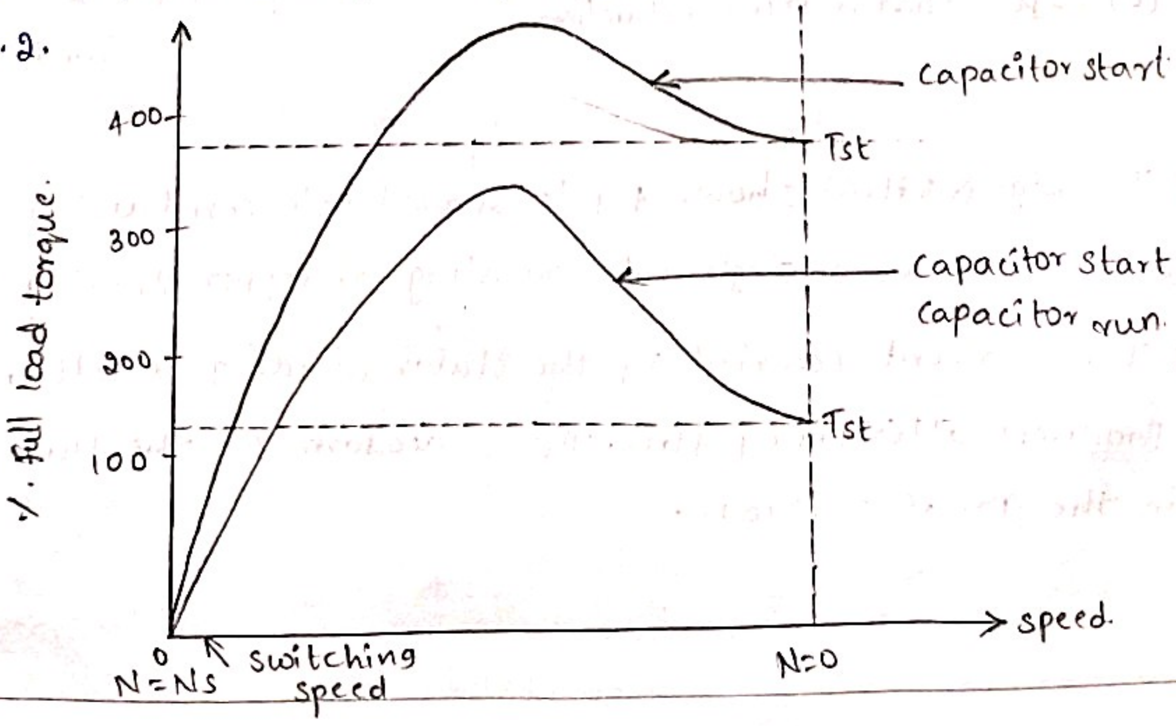
in the Fig. Q.56.1 (b).

4-(b)



* The starting torque is por porportional to 'α' and hence such motors produce very high starting torque.
* When speed approaches to 75 to 80% of the synchronous speed, the starting winding gets disconnected due to operation of the centrifugal switch. The capacitor remains in the circuit only at start hence it is called capacitor start motors.
* In case of capacitor start capacitor run motor, there is no centrifugal switch and capacitor remain parmenently in the circuit. This improves the power factor.

The starting torque available in such type of motor is about 50 to 100% of full load torque. The torque-slip characteristics is shown in the Fig. Q.56.2.

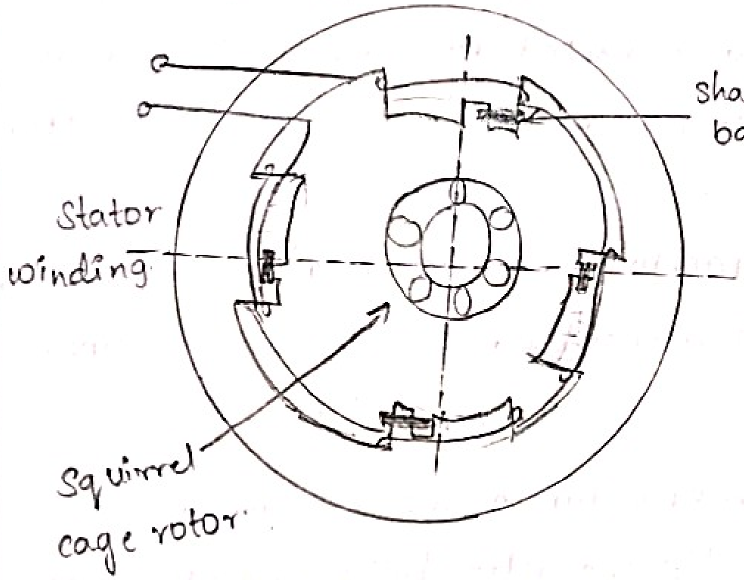


Applications:- These motors have high starting torque and hence are used for hard starting loads. These are used for compressors, conveyors, grinders, fans, blowers, refrigerators, air conditions etc. These are most commonly used motors. The capacitors start capacitor run motors are used in ceiling fans, blowers and air-circulators.

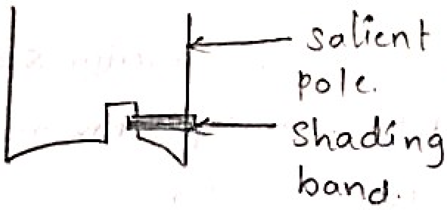
Shaded pole:-

* This type of motor consists of a squirrel cage rotor and stator consisting of salient poles i.e. projected poles.

The poles are shaded i.e. each pole carries a copper band on one of its unequally divided part called shading band.

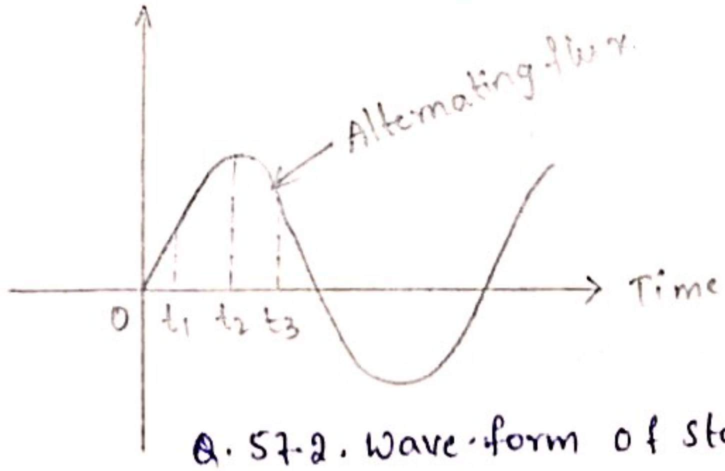


(a) 4-pole shaded pole construction



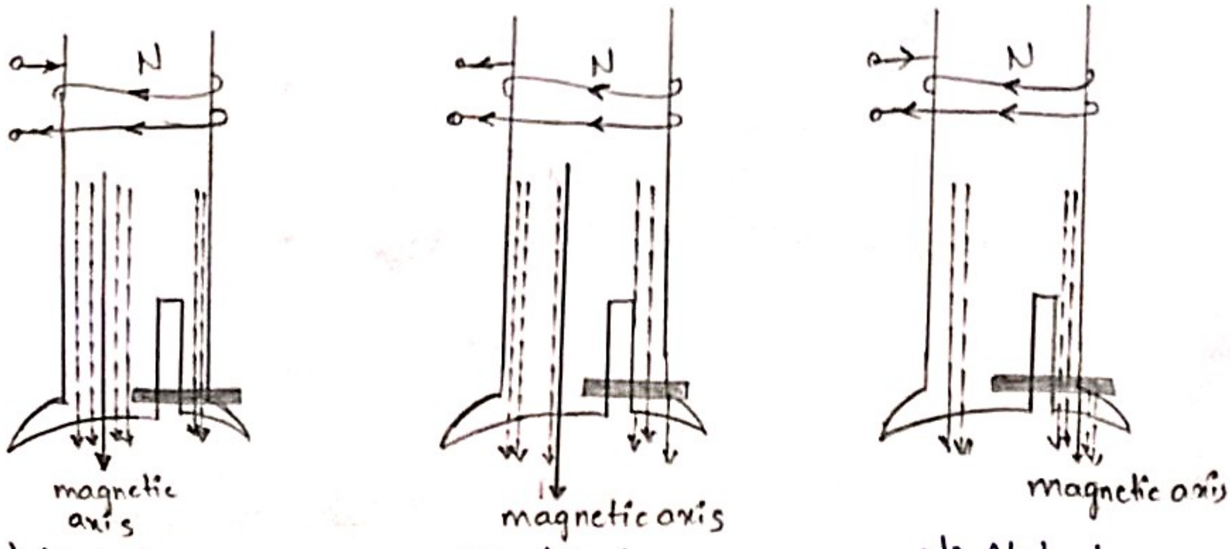
(b) Salient pole with shading band.

* The fig. Q.57.1(a) shows 4 pole shaded pole construction while fig. Q.57.1(b) shows a single pole consisting of copper shading band.
* The current carried by the stator winding is alternating and produces alternating flux. The wave form of the flux is shown in the Fig. Q.57.2(a)



Q. 57.2. Wave-form of stator flux.

* At instant $t = t_1$, rate of rise of current and hence the flux is very high. Due to the transformer action, large e.m.f gets induced in the copper shading band. This circulates current through shading band as it is short circuited, Producing its own flux. According to Lenz's law, the direction of its current is so as to oppose the cause i.e, rise in current. Hence there is crowding of flux in nonshaded part while weakening of flux in shaded part, overall magnetic axis shifts in nonshaded part as shown in the fig Q.57.2(b)
* At instant $t = t_2$, rate of rise of current and hence the rate of change of flux is almost zero. Hence there is very little induced e.m.f in the shading ring. Hence the shading ring flux is also negligible. Hence the main flux distribution is uniform and magnetic axis lies at the centre of the pole face as shown in fig. Q.57.2(c)
* The torque Speed characteristics is shown in the fig. Q.57.3.



(b) At $t = t_1$ (c) At $= t_2$ (d) At $t = t_3$

Applications:-

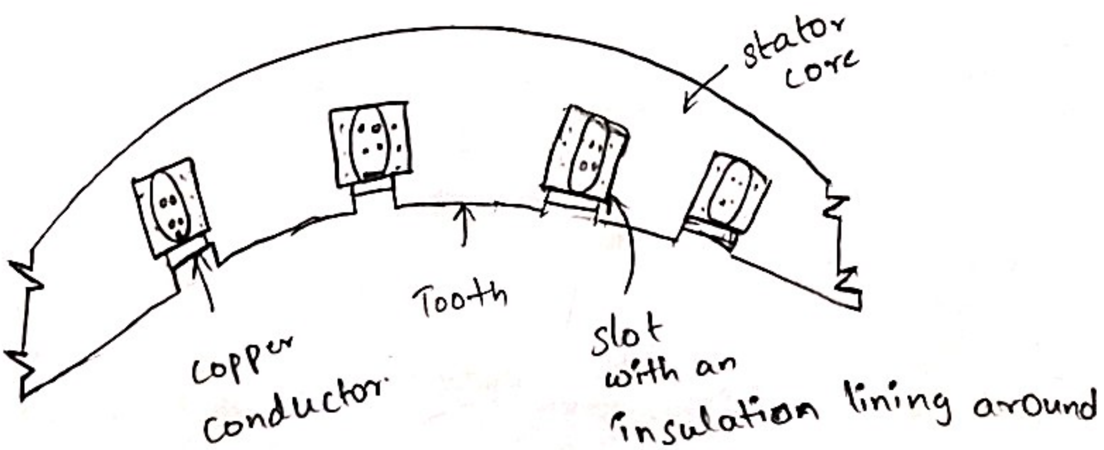
* These motors are cheap but have very low starting torque, low power factor and low efficiency. These motors are commonly used for the small fans, toy motors, advertising displays, film projections, record players, gramophones, hair dryers, photocopying machines etc...

Construction of synchronous generator:-

* In synchronous generators i.e, alternators the stationary winding is called 'stator' while the rotating winding is called 'Rotor'.

1) Stator:- The stator is a stationary armature. This consits of a core and the slots to hold the armature winding.

* The stator core uses a laminated construction. It is built up of special steel stampings insulated from each other with varnish (or) paper. The laminated construction is basically to keep down eddy current looses.
* The entire core is fabricated in a frame made of steel plates. The core has slots on its periphery for housing the armature conductors.
* ventilation is maintained with the help of holes casted in the frame
* The section of an alternator stator is shown in the Fig. Q.61.1.

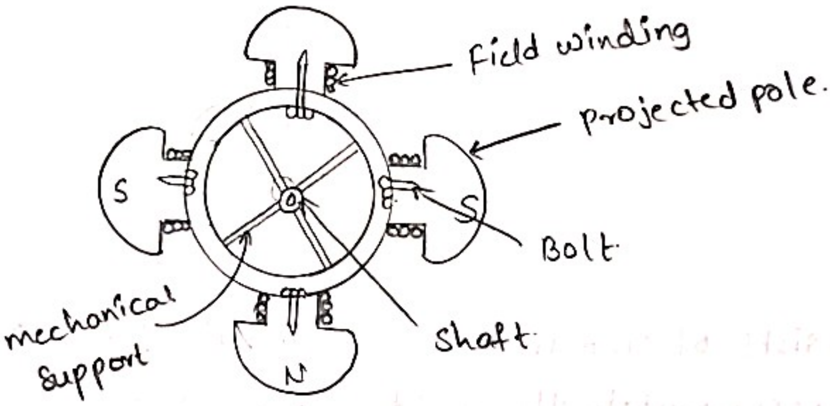


2) Rotor :- There are two type of rotors used in alternators, 4-(8)

i) Salient pole are projected pole type :-

* This is also called projected pole type as all the poles are projected out from the surfaces of the rotor.

* The poles are built up of thick steel laminations. The poles are bolted to the rotor as shown in the fig. Q.61.2



* The pole face has been given a specific shape as discussed earlier in case of d.c. generators. The field winding is provided on the pole shoe.

* These rotors have large diameters and small axial lengths.

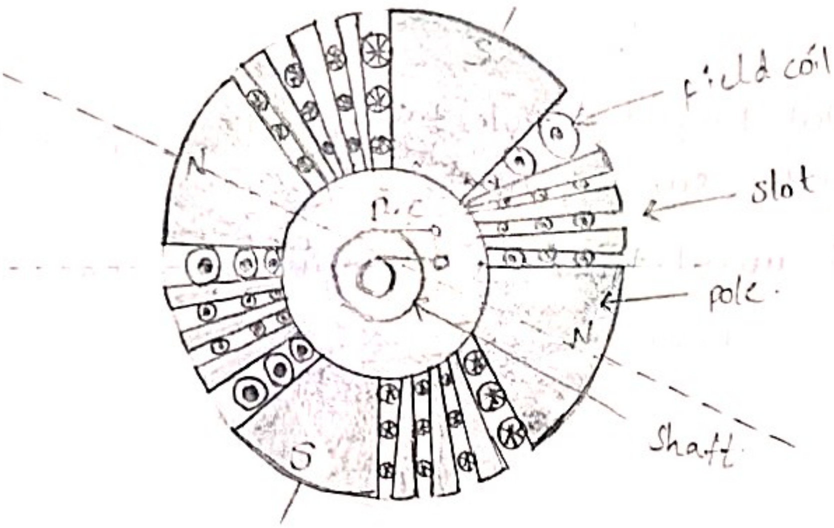
* As mechanical strength of salient pole type is less, this is preferred for low speed alternators ranging from 125 r.p.m to 500 r.p.m

* The prime movers used to drive such rotor are generally water turbines and I.C. engines.

ii) Smooth cylindrical or non salient type :-

* This is also called non salient type (or) non-projected pole type of rotor.

* The Fig. Q.61.3 shows smooth cylindrical type of rotor.



* The rotor consists of smooth solid steel cylinder, having numbers of slots to accommodate the field coil. The slots are covered at the top with the help of steel (or) manganese wedges.

* The unslotted portions of the cylinder itself act as the poles. The poles are not projecting out and the surface of rotor is smooth which maintains uniforms air gaps between stator and the rotor.

* These rotors have small diameters and large axial lengths. This is to keep peripheral speed within limits.

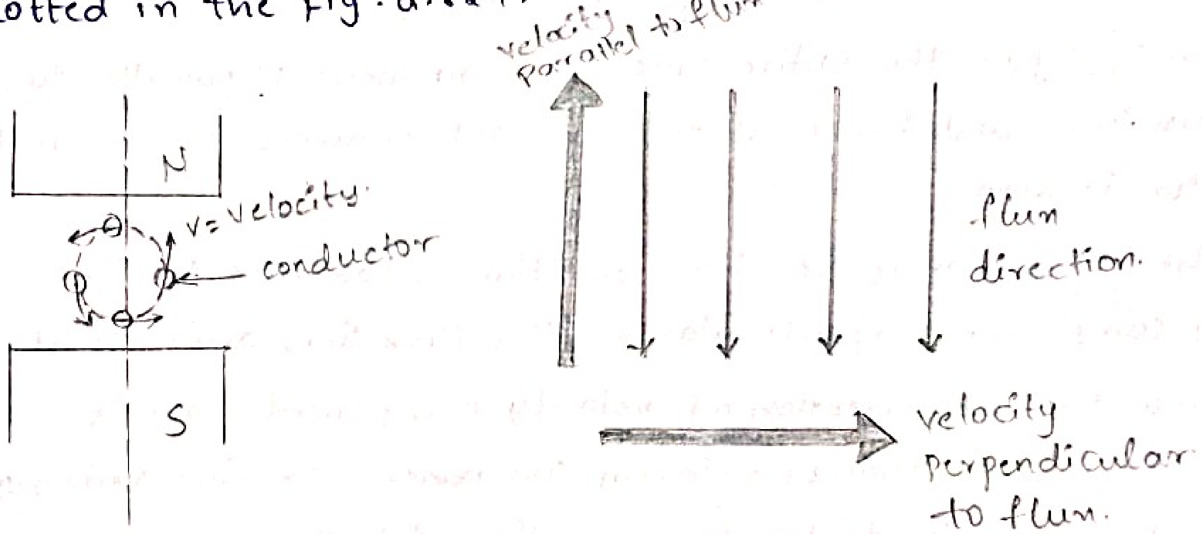
* The main advantage of this type is that these are mechanically very strong and thus preferred for high speed alternators ranging between 1500 to 3000 r.p.m... such high speed alternators are called 'turboalternators'.

* The prime moves used to drive such type of rotors are generally steam turbines, electric motors.

Working principle of Alternators :- 4-(9)

Principle of operation of synchronous generator :-

* The alternators i.e, synchronous generators work on the principle of electromagnetic induction. When there is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors.
* Consider a relative motion of a single conductor under the magnetic field produced by two stationary pole. The magnetic axis of the two poles produced by field is vertical, shown dotted in the Fig. Q.62.1.



* Let conductor starts rotating from position 1. At this instant, the entire velocity component is parallel to the flux lines. Hence there is no cutting of flux lines by the conductor. Hence induced e.m.f. in the conductor is also zero.
* As the conductor moves from position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that, e.m.f gets induced in the conductor. The magnitude of such an induced e.m.f. increases as the conductor moves from position 1 towards 2.
* At position 2, the entire velocity component is perpendicular to the flux lines. Hence there exists maximum cutting of the flux lines. And at this instant, the induced e.m.f in the conductor

is at its maximum.

* As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

* As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

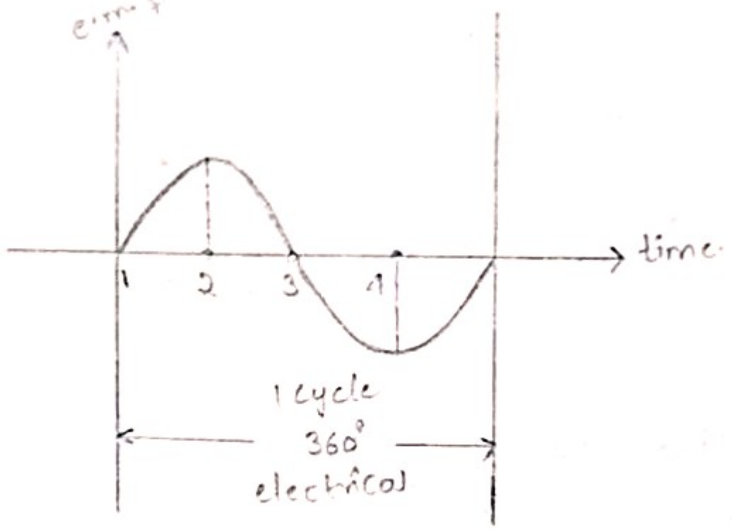
* As the conductor moves from position 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. But the direction of velocity component now is opposite to the direction of velocity component existing during the movement of the conductor from position 1 to 2. Hence an induced e.m.f in the conductor increases but in the opposite direction.

* At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines.

* Again from position 4 to 1, induced e.m.f decreases and finally at position 1, again becomes zero. This cycle continues as conductor rotates at a certain speed.

* So if we plot the magnitudes of the induced e.m.f against the time, we got an alternating nature of the induced e.m.f as as shown in the Fig. Q.62.2.

* Thus for 2 pole alternator, one mechanical revolution corresponds to one electrical cycle i.e. 360° electrical of an induced e.m.f



* In a 4 pole alternator, for one revolution of the conductor, we get the two electrical cycles of the induced e.m.f. due to flux distribution due to 4 poles.

* In general, one mechanical revolution of rotor $= \frac{P}{2}$ cycles of e.m.f. electrically.

* As speed is N r.p.m., in one second, rotor will complete $\left(\frac{N}{60}\right)$ revolutions.

* But electrical cycles / sec = frequency = f

∴ frequency f = (No. of electrical cycles per revolution) X (No. of revolutions per second)

$$\therefore \quad f = \frac{P}{2} \times \frac{N}{60} \quad \text{i.e.,} \quad f = \frac{PN}{120} \text{ Hz}$$

(cycles per sec)

* So there exists a fixed relationship between three quantities, the number of poles p, the speed of the rotor N in r.p.m and f the frequency of an induced e.m.f in Hz (hertz)

* The speed of the alternator at which it produces induced e.m.f. at the rated frequency for p numbers of poles is called synchronous speed N_s

So,
$$\boxed{N_s = \frac{120f}{P} \quad \text{Where } f = \text{Required rated frequency}}$$

Ex:-

* A 12 pole alternator is coupled to an engine running at 500 rpm. It supplies a 3 phase induction motor having full load speed at 1440 rpm. Find % slip and number of poles of the motor.

Ans:- For an alternator, $P = 12$, $N_s = 500$ r.p.m.

$$N_s = \frac{120f}{P} \quad \text{i.e., } f = \frac{500 \times 12}{120} = 50Hz$$

For an Induction motor,

$$N_{FL} = 1440 \text{ r.p.m.}$$

$$\therefore \text{ Nearest } N_s = 1500 \text{ r.p.m} = \frac{120f}{P}$$

$$\therefore \quad P = \frac{120 \times 50}{1500} = 4 \quad \text{.... poles of motor}$$

$$\therefore \quad \% S = \frac{N_s - N}{N_s} \times 100 = \frac{1500 - 1440}{1500} \times 100 = 4\%.$$