UNIT: IV

DC MACHINES AND INDUCTION MOTORS

DC MACHINES: Construction, principle and operation of DC motor, voltage- torque equations - simple problems.

THREE PHASE INDUCTION MOTOR: Construction, principle and working of three phase induction motor, torque-slip characteristics-simple problems.

Single phase induction motor- Working principle.

DC Machine Construction:

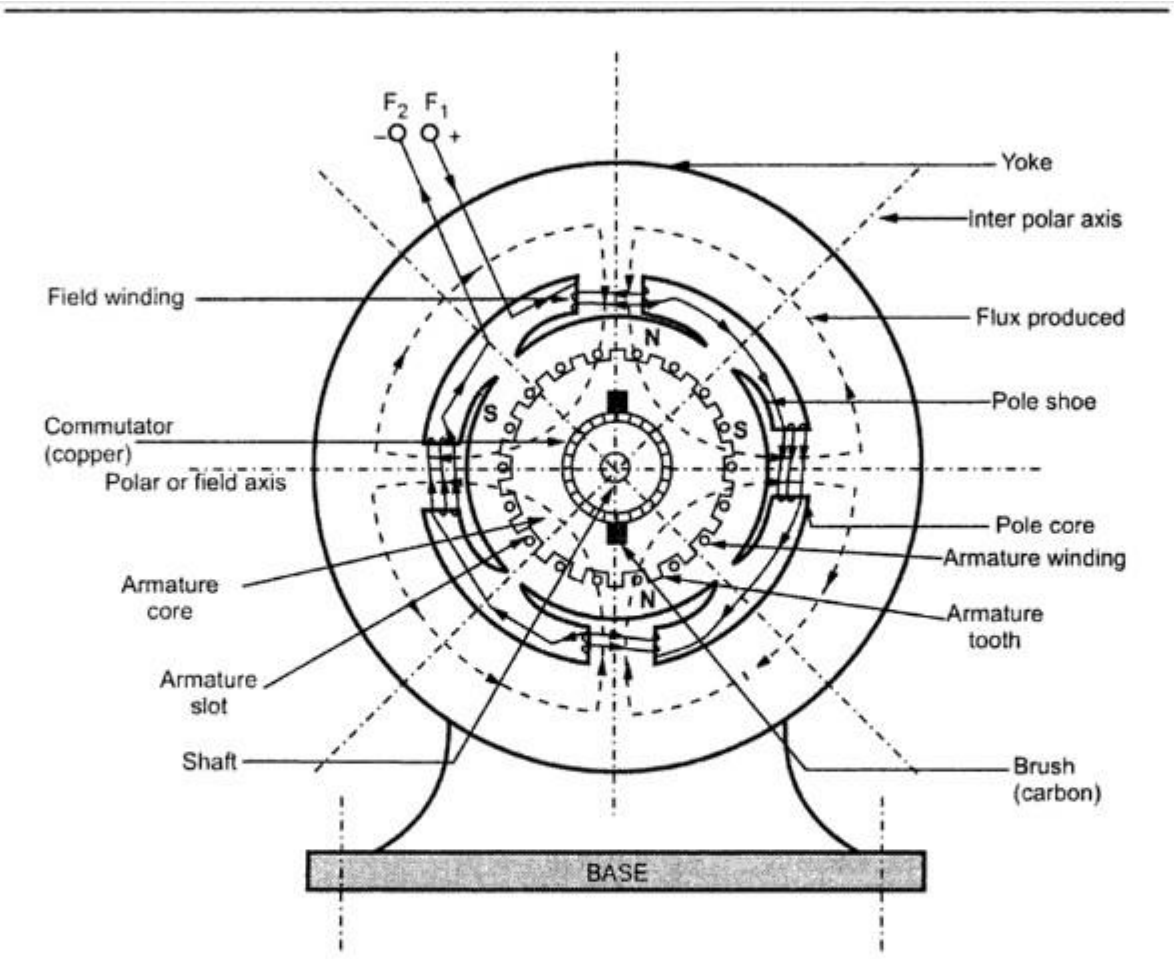


Fig. 1.10 A cross-section of typical d.c. machine

DC machine consists of the following parts:

1. **Yoke and its functions:**

a. It serves the purpose of outermost cover of the d.c. machine. So that the insulating materials gets protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.
b. It provides mechanical support to the poles.
c. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux. The low reluctance path is important to avoid wastage of power to provide same flux, Large current and hence the power is necessary if the path has high reluctance, to provide the same flux.

Choice of material: To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is cheapest. For large machines rolled steel, cast steel, silicon steel is used which provides high permeability i.e. low reluctance and gives good mechanical strength.

2. **Poles: Each pole is divided into two parts mainly.**

(i). Pole core and (ii). Pole shoe

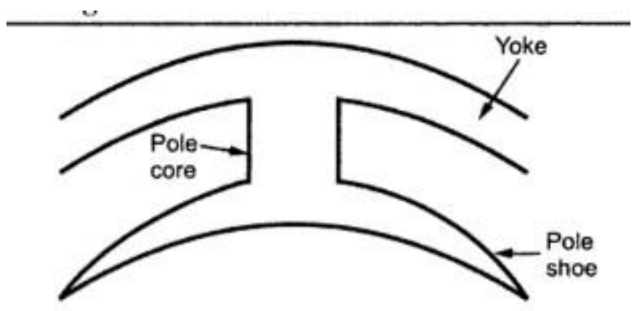


Fig. 1.11 Pole structure

Functions of pole core and pole shoe :

1. Pole core basically carries a field winding which is necessary to produce the flux.
2. It directs the flux produced through air gap to armature core, to the next pole.
3. Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf. To achieve this, pole shoe has given a particular shape.

Choice of material: It is made up of magnetic material like cast iron or cast steel.

3. **Field Winding:** The field winding is wound on the pole core with a definite direction.

a). Functions: To carry current due to which pole core, on which the field winding is placed behaves as an electromagnet, producing necessary flux.

As it helps in producing the magnetic field i.e. exciting the pole as an electromagnet it is called Field winding or exciting winding.

b). Choice of material: It has to carry current hence obviously made up of some conducting material. So aluminium or copper is the choice.

4. Armature: It is further divided into two parts namely,

(i). Armature core and (ii). Armature winding

(i). Armature Core: Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

a). Functions:

1. Armature core provides house for armature winding i.e. armature winding.
2. To provide a path of low reluctance to the magnetic flux produced by the field winding.

b). Choice of material: As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.

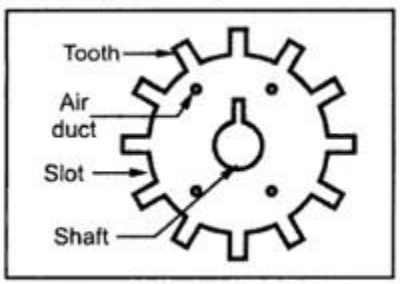


Fig. 1.12 Single circular lamination of armature core

(ii). Armature winding: Armature winding is nothing but the interconnection of the armature conductors, placed in the slots provided on the armature core periphery. When the armature is rotated, in case of generator, magnetic flux gets cut by armature conductors and emf gets induced in them.

a). Functions :

1. Generation of emf takes place in the armature winding in case of generators.
2. To carry the current supplied in case of d.c. motors.
3. To do the useful work in the external circuit.

b). Choice of material: As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

5. **Commutator:** The basic nature of emf induced in the armature conductors is alternating. This needs rectification in case of d.c. generator, which is possible by a device called commutator.

a). Functions:

1. To facilitate the collection of current from the armature conductors.
2. To convert internally developed alternating emf to unidirectional emf.
3. To produce unidirectional torque in case of motors.

b). Choice of material: As it collects current from the armature, it is also made up of copper segments.

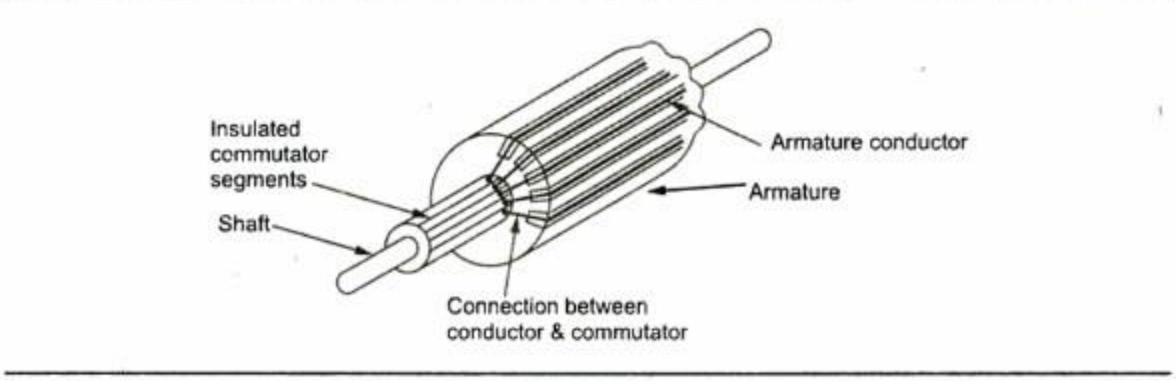


Fig. 1.13 Commutator

6. **Brushes and Brush Gear:** Brushes are stationary and resting on the surface of the commutator.

a). Function: To collect current from commutator and make it available to the stationary external circuit.
b). Choice of material: Brushes are normally made up of soft material like carbon.

Principle of operation of DC Motor:

The principle of operation of a d.c. motor can be stated in a single statement as 'when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force'.

In a practical d.c. motor, field winding produces a required magnetic field while armature conductors play a role of a current carrying conductors and hence armature conductors experience a force.
As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductors acts as a twisting or turning force on the armature which is called a **torque**.

Consider a single conductor placed in a magnetic field as shown in the figure. The magnetic field is produced by a permanent magnet but in a practical d.c. motor it is produced by the field winding it carries a current.

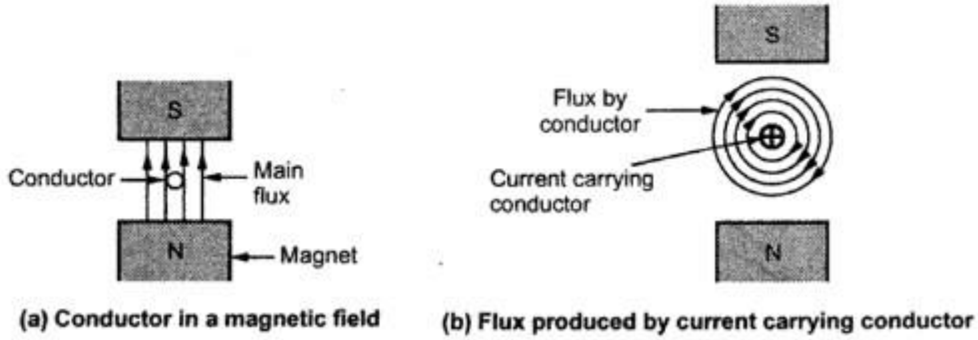


Fig. 4.1

Now this conductor is excited by a separate supply so that it carries a current in a particular direction. Consider that it carries a current away from an observer as shown in the figure.

Any current carrying conductor produces its own magnetic field around it, hence this conductor also produces its own flux, around. The direction of this flux can be determined by right hand thumb rule. For direction of current considered, the direction of flux around a conductor is clockwise.

Now there are two fluxes present:

1. The flux produced by the permanent magnet called main flux.
2. The flux produced by the current carrying conductor.

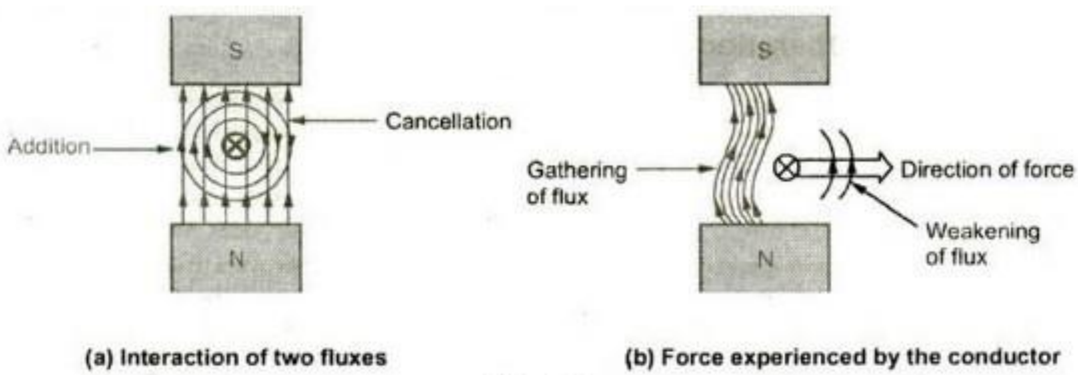
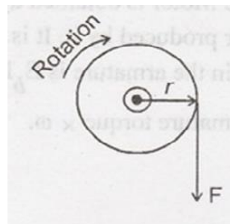


Fig. 4.2

From this, it is clear that on one side of the conductor, both the fluxes are in the same direction. In this case, on the left of the conductor there is gathering of the flux lines as two fluxes help each other. As against this, on the right of the conductor, the two fluxes are in opposite direction and hence try to cancel each other. Due to this, the density of flux lines in this area gets weakened. So on the left, there exists low high flux density area while on the right of the conductor there exists low flux density area as shown in the figure.

TORQUE EQUATION:

Torque is nothing but turning or twisting force about an axis. Torque is measured by the product of force and radius which the force acts. Consider a wheel of radius 'r' meters acted on by a circumferential force 'F' Newton as Figure.



Let the force 'F' cause the wheel to rotate at 'N' rpm. The angular velocity of the wheel is:

$$\omega = \frac{2\pi N}{60} \text{ rad/sec.}$$

Torque, $T = F \times r$ N-m

Work done per revolution = F x distance moved
= F x $2\pi r$ joules.

Power developed, P = Work done / Time
= (F x $2\pi r$) / Time for one revolution
= (F x $2\pi r$) / (60/N)

rps = rpm/60 ; rps = N/60 ; time for one revolution = 60/N

$$P = (F \times r)\, 2\pi N/60$$

$$P = T\,\omega \text{ Watts.}$$

where, T = torque in N – m

ω = angular speed in rad/sec.

The torque developed by a DC Motor is obtained by looking at the electrical power supplied to it and mechanical power produced by it. It is also called armature torque. The gross mechanical power developed in the armature is $E_b I_a$.
Then, power in armature = Armature torque x ω.

$$E_b I_a = T_a \times \frac{2\pi N}{60} \;;$$

$$E_b = \frac{\phi PNZ}{60\,A}$$

$$\frac{\phi PNZ}{60\,A}\, I_a = T_a \times \frac{2\pi N}{60} \;;\; T_a = \frac{\phi I_a}{2\pi}\,\frac{PZ}{A}$$

$$T_a = 0.159\,\phi\, I_a\,\frac{PZ}{A}\ \text{N-m.}$$

The above equation is torque equation of a DC motors.

'T' is proportional to φ Ia. Hence the torque of a given DC motor is proportional to the product of the armature current and the flux.

THREE PHASE INDUCTION MOTOR:

Construction:

Basically, the induction motor consists of two main parts, namely

1. The part i.e. three phase windings, which is stationary called **Stator.**
2. The part which rotates and is connected to the mechanical load through shaft called **Rotor**.

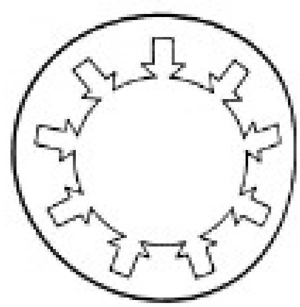


Fig. 5.4.1 Stator lamination

Stator:

1. The stator has a **laminated type of construction** made up of stampings which are 0.4 to .5 mm 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 i**ron losses to a minimum value**.
2. The choice of material for the stampings is generally **silicon steel,** which **minimizes the hysteresis loss**.
3. 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.
4. The choice of **number of poles** depends on the speed of the rotating magnetic field.
5. The **radial ducts** are provided for the **cooling purpose**.
6. In some cases, **all the six terminals** of three phase stator winding are brought out which gives flexiblity to the user to connect them either in star or delta.

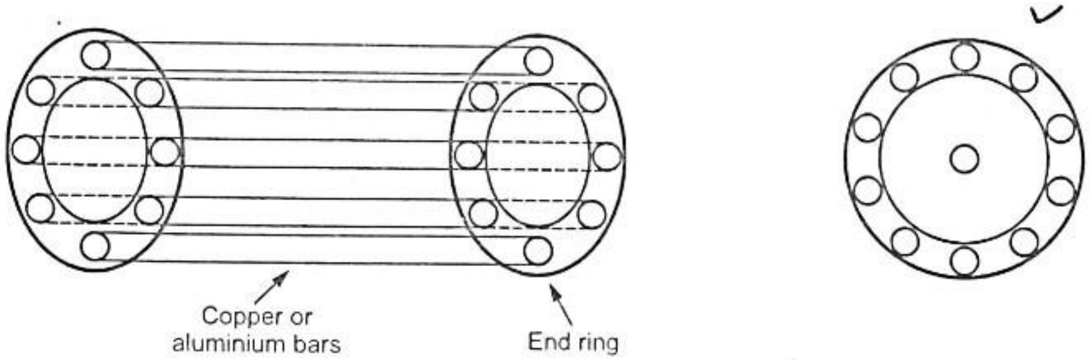
Rotor:

The rotor is placed inside the stator. The rotor core is also **laminated** in construction and uses cast iron. It is **cylindrical**, with slots on its periphery.
The two types of rotor constructions which are used for induction motors are,

1. **Squirrel cage rotor and**
2. **Slip ring or wound rotor**

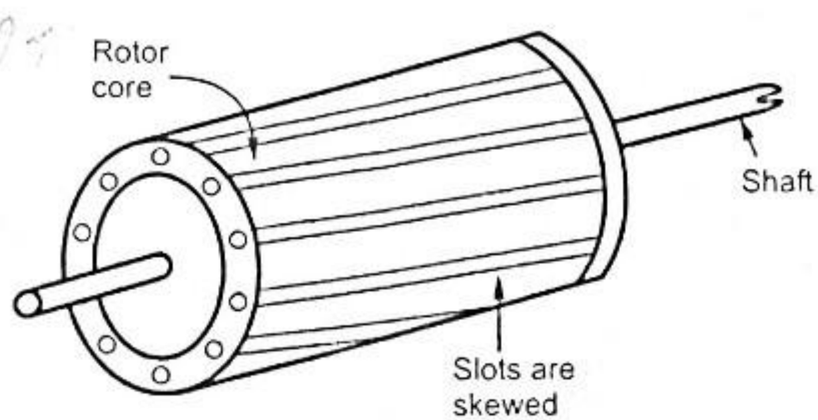
Squirrel cage Rotor:

1. The rotor core is cylindrical and slotted on its periphery. The rotor consists of uninsulated copper or aluminium bars called **rotor conductors.**
2. 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**.
3. 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.



(a) Cage type structure of rotor (b) Symbolic representation

4. As the bars are permanently shorted to each other through end ring, the entire **rotor resistance is very very small**. Hence the rotor is also called **short circuited rotor**.
5. As rotor itself is short circuited, no external resistance can have any effect on the rotor resistance. Hence **no external resistance can be introduced** in the rotor circuit. So **slip ring and brush assembly is not required** for this rotor. Hence the construction is **very simple and robust**.



6. Fig. 5.4.3 Skewing in rotor construction
7. In this type of rotor, **the slots are not arranged parallel to the shaft axis** but are skewed as shown in the figure.

Advantages of skewing:

- It makes the motor operation smooth.
- The stator and rotor teeth may get **magnetically locked**. Such a tendency of magnetic locking gets reduced due to skewing.
- It increases the **effective transformation ratio** between stator and rotor.
- A magnetic hum i.e. **noise gets reduced** due to skewing hence skewing makes the motor operation quieter.

principle and working of three phase induction motor:

Induction machine works on the principle of electromagnetic induction.

When a 3-phase supply is given to the three-phase stator winding, a rotational magnetic field of constant amplitude is produced.

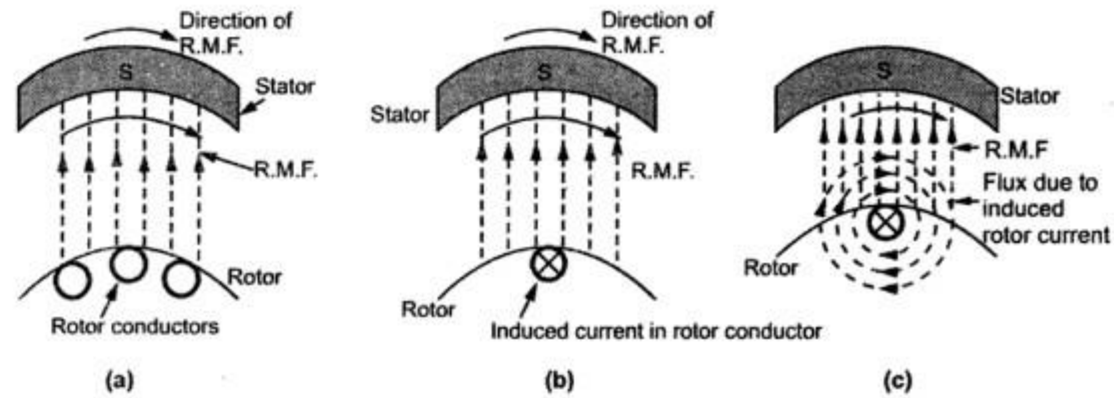
The speed of the rotating magnetic field is synchronous speed, N_s r.p.m.

$N_s = 120\ f / P$

where f = Supply frequency

P = Number of poles for which stator winding is wound.

This rotating field produces an effect of rotating poles around a rotor. Let direction of rotation of this R.M.F. is clockwise as shown in figure.



- Now at this instant rotor is stationery and stator flux is rotating. So it's obvious that there exists a relative motion between the R.M.F. and rotor conductors as R.M.F. sweeps over rotor conductors. Whenever conductor cuts the 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 emf circulates current through rotor called rotor current. Let the direction of this current is going into the paper denoted by a cross as shown in the figure.

- Any current carrying conductor produces its own flux. So rotor produces its flux called rotor flux. For assumed direction of rotor current, the direction of rotor flux is clockwise as shown in the figure. This direction can be easily determined using right hand thumb rule.
- Now there are two fluxes, one R.M.F. and other rotor flux. Both the fluxes interact with each as shown in the figure.

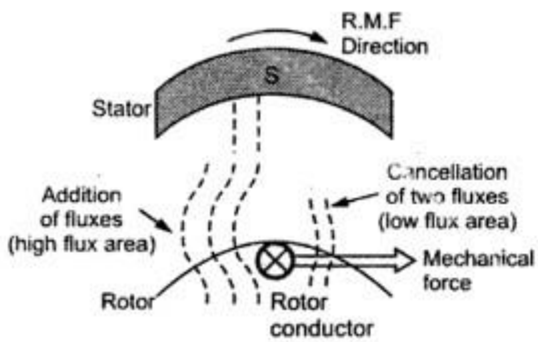


Fig. 5.9 (d)

- On left of rotor conductor, two fluxes are in same direction hence add up to get high flux area. On right side, two fluxes cancel each other to produce low flux area.

High flux density area exerts a push on rotor conductor towards low flux density area. So rotor conductor experiences a force from left to right in this case.

- As all the rotor conductors experience a force, the overall rotor experiences a torque and starts rotating. So, interaction of the two fluxes is very essential for a motoring action.
- According to Lenz's law the direction of induced current in rotor is so oppose the cause producing it. The cause of rotor current is the induced emf 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. 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 of rotating magnetic field.

N_s = Speed of rotating magnetic field in r.p.m.
N = Speed of rotro i.e. motor in r.p.m.
N_s – N = Relative speed between the two, Rotating magnetic field and the rotor conductors.

Slip of Induction Motor:

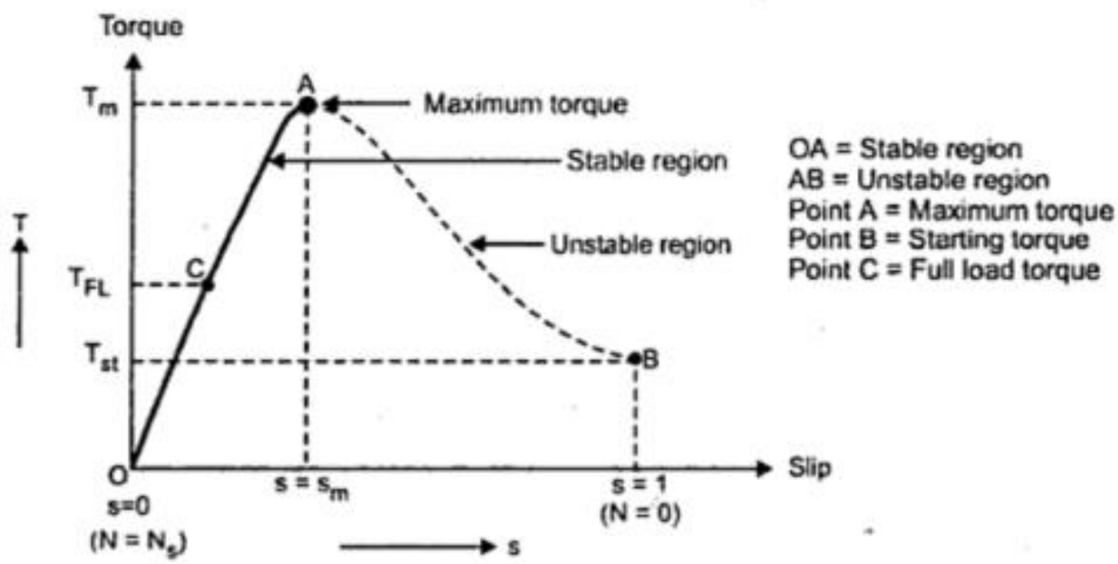
The slip of an induction motor is the difference between the synchronous speed (R.M.F Speed) and the actual speed of the motor (Rotor Speed) expressed as fraction of Synchronous speed.

$$S = \frac{Ns - Nr}{Ns}$$

$$\%S = \frac{Ns - Nr}{Ns} \times 100$$

$$Relative\ Speed = Ns - Nr$$

Torque-slip characteristics:



The behaviour of motor can be easily judged by sketching a curve obtained by plotting torque produced against slip of induction motor. The curve obtained by plotting torque against slip from s = 1 (at start) to s = 0 (at synchronous speed) is called torque-slip characteristics of the induction motor.

Torque – slip characteristics has two parts,

1. Straight line called stable region of operation
2. Rectangular hyperbola called unstable region of operation.

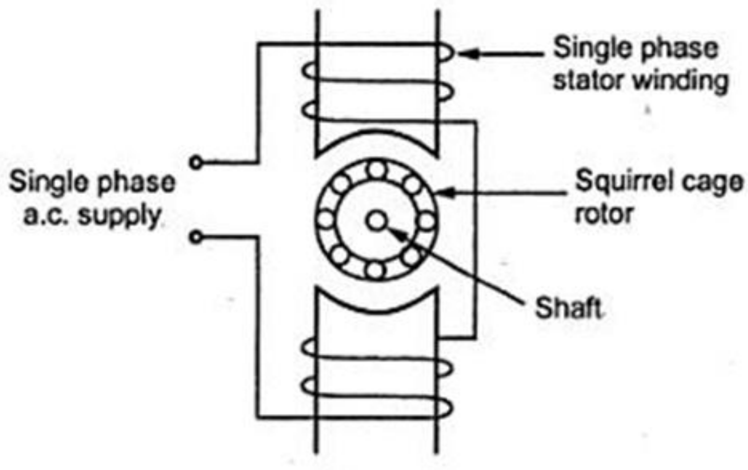
In low slip region, as load increases, slip increases and torque also increases linearly. Every motor has its own limit to produce a torque. The maximum torque, the motor can produce as load increases is T_m which occurs at $s = s_m$. So linear behaviour continues till $s = s_m$.

If load is increased beyond this limit, motor slip acts dominantly pushing motor into high slip region. Due to unstable conditions, motor comes to standstill condition at such a load. Hence i.e. maximum torque which motor can produce is also called breakdown torque or pull-out torque. So, range $s = 0$ to $s = s_m$ is called low slip region, known as stable region of operation. Motor always operates at a point in this region. And range $s = s_m$ to $s = 1$ is called high slip region which is rectangular hyperbola, called unstable region of operation. Motor cannot continue to rotate at any point in this region.

At s = 1, N = 0 i.e. start, motor produces a torque called starting torque denoted as T_{st}.

Single Phase Induction Motor:

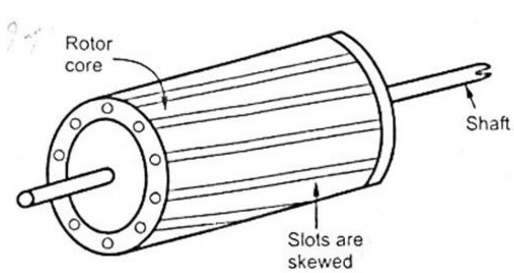
Construction:



Similar to a d.c. motor, single phase induction motor has basically two mains parts.one rotating and other stationary. The stationary part in single phase induction motors is called stator while the rotating part is called rotor.

The stator has laminated construction, made up of stampings. The stampings are slotted on its periphery to carry the winding called stator winding or main winding. This is excited by a single phase a.c. supply. The laminated construction keeps iron losses to minimum. The stampings are made up of material like silicon steel which minimises the hysteresis loss. The stator winding is wound for certain definite number of poles means when excited by single phase a.c. supply, stator produces the magnetic field which creates the effect of certain definite number of poles. The number of poles for which stator winding is wound, decides the synchronous speed of the motor.

The rotor construction is of squirrel cage type. In this type, rotor consists of uninsulated copper or aluminium bars, placed in the slots. The bars are permanently shorted at both the ends with the help of conducting rings called end rings. The entire structure looks like cage hence called squirrel cage rotor. The construction and symbol is shown in the Fig..1



Working Principle of Single-Phase Motors:

In the single-phase induction motors, single phase a.c supply is given to the stator winding. The stator winding carries an alternating current which produces the flux which is also alternating in nature. This flux is called main flux. This flux links with the rotor conductors and due to transformer action e.m.f gets induced in the rotor. The induced e.m.f. drives current through the rotor as rotor circuit is closed circuit. This rotor current produces another flux called rotor flux required for the motoring action. Thus second flux is produced according to induction principle due to induced e.m.f. hence the motor is called induction motor.

Important difference between the two is that the d.c. motors are self-starting while single-phase induction motors are not self-starting.