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CHAPTER - 10

THREE PHASE INDUCTION MOTORS

(AC motor)

10.1 Introduction:

A three phase induction motor is an a.c. motor. Of all the a.c. motors available, it is extensively used, because of the following advantages:

1. Its construction is simple, rugged and almost unbreakable.
2. Its cost is low and is highly reliable.
3. Its efficiency is high.
4. It works with reasonably good power factor at rated load.
5. Its maintenance is less.
6. Induction motors are self-starting. Hence, motors of smaller ratings do not require a starter. The starting arrangements for larger motors are simple.

The disadvantages are:

1. It is essentially a constant speed motor and the speed cannot be changed easily. The speed variation can be done at the cost of efficiency.
2. The starting torque is inferior to that of a D.C. shunt motor.

10.2 Construction:

A three phase induction motor mainly consists of two parts. (i) *stator* and (ii) *rotor*. The rotor, which is the rotating part, is separated by the stator, which is the static part, by a small air gap, which usually varies from 0.4 mm to 4 mm, depending on the rating of the motor.

(a) Stator:

0.4mm to 4mm depending on the rating of motor

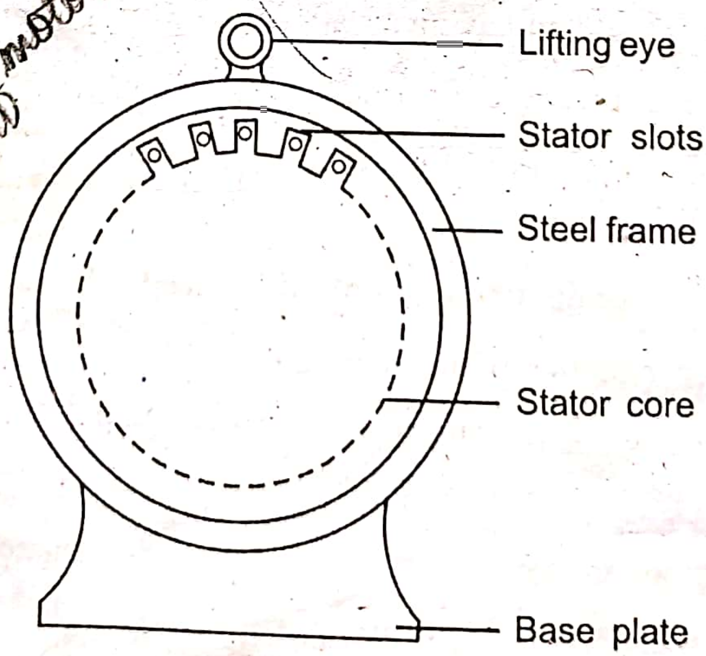


Fig. 10.1

Fig 10.1 shows the stator of the induction motor. It consists of a steel frame, which encloses a hollow, cylindrical core, made up of thin laminations of silicon steel to reduce eddy current loss and hysteresis loss. A large number of uniform slots are cut on the inner periphery of the core. The stator conductors are placed in these slots, which are insulated from one another and also from the slots. These conductors are connected as a balanced three phase star winding or delta winding. The windings are wound for a definite number of poles, depending on the requirement of speed. It is wound for more number of poles, if the speed required is less and vice-versa, according to the relation.

$$\boxed{N_S = \frac{120 f}{P}} \qquad (10.1)$$

No. of poles wound $\propto \frac{1}{\text{speed req.}}$

Where, N_S = synchronous speed in r.p.m.

f = frequency of the supply.

and P = number of poles.

When a three phase supply is given to the stator winding, a magnetic field of constant magnitude and rotating at synchronous speed, given by the equation $N_S = 120\ f/P$ is produced. This rotating magnetic field is mainly responsible for producing the torque in the rotor, so that, it can rotate at its rated speed, which will be explained in detail in the later sections of this chapter.

(b) Rotor:

The rotor is the rotating part of the induction motor and is mounted on the shaft of the motor to which, any mechanical load can be connected. There are two types of rotors (i) *squirrel cage rotor* and (ii) *phase wound rotor*. According to the type of rotor used, three phase induction motors are classified as squirrel cage induction motors and phase wound or slip ring induction motors.

i) Squirrel cage rotor:

Fig.10.2

Nearly 90% of the induction motors are of squirrel cage type, as the rotor is simple and rugged in construction. This type of rotor, shown in Fig. 10.2, consists of a cylindrical laminated core with parallel slots, for carrying rotor conductors. The rotor conductors are

Cu, Al → rotor conductors

heavy bars of copper or aluminium. One bar is placed in each slot. All the bars are brazed or welded at both ends to two copper end rings, thus short circuiting them at both ends. As the rotor bars are short circuited on themselves, it is not possible to add any external resistance in series with the rotor circuit during starting. The slots are slightly skewed, which helps in two ways (i) it reduces the noise due to magnetic hum and makes the rotor to run quietly and (ii) it reduces the locking tendency between the rotor and the stator.

ii) Phase Wound Rotor:

This rotor is a laminated, cylindrical core having uniform slots on its outer periphery. A three phase winding, which is star connected is placed in these slots. The open ends of the star winding are brought out and connected to three insulated slip rings, mounted on the shaft of the motor, with carbon brushes resting on them.

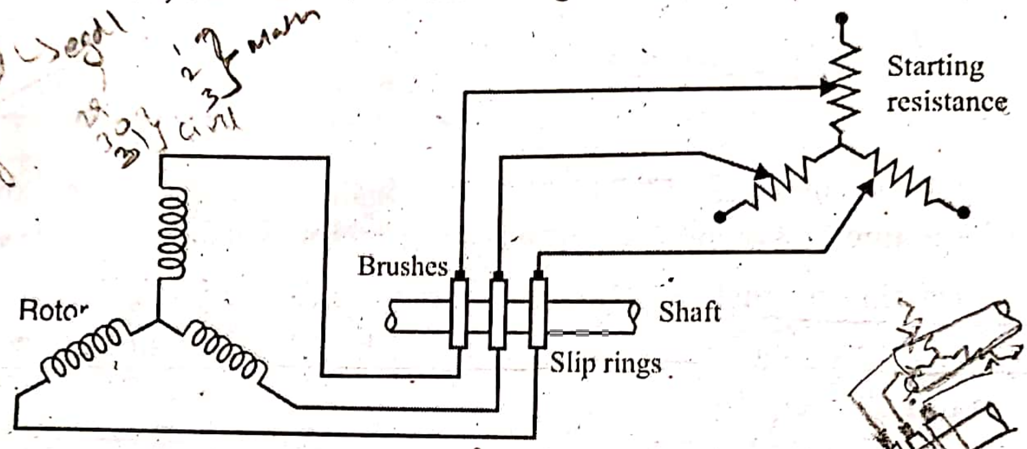


Fig.10.3

The three brushes are externally connected to a three phase star connected rheostat, which is used as a starter during the starting period. When running under normal conditions, the slip rings are automatically short circuited by means of a metal collar, which is pushed along the shaft and connects all the rings together. Next, the brushes are automatically lifted from the slip rings, to reduce the frictional losses, wear and tear. The equivalent circuit diagram of a phase wound induction motor along with the rotor connections to the starting resistance is as shown fig.10.3.

Squirrel Cage Induction Motor:

i) Advantages

suitable. rough use.

1. It is simple in construction, rugged and can withstand rough handling.
2. Cost of maintenance and repairs is less.
3. It has better efficiency and power factor

4. A simple star-delta starter is sufficient to start the motor
5. It is explosion proof as there are no slip rings, brushes and their assembly.

ii) Disadvantages:

1. It has low starting torque.
2. The p.f. at starting is lower.
3. The starting current is high and it has no smooth running.

Applications of squirrel cage induction motors:

centrifugal pumps, blowers, fans, lathes, agricultural & industrial pumps

The squirrel cage induction motors are used for loads which require normal starting torque such as lathes, agricultural and industrial pumps, blowers, fans, centrifugal pumps etc.

Slip-ring Induction Motor:

i) Advantages:

1. It has external resistance in the rotor circuit which can be used as a starter, especially with load, with higher starting torque and lower starting current.
2. The external resistance can be used to control the speed and also to improve the power factor.
3. The motor is smooth running.
4. Slip-ring induction motors of very high capacity can be built.

(ii) Disadvantages:

1. The size of the slip-ring induction motor of the same capacity is more than that of squirrel cage induction motor.
2. It is costlier as the construction is complicated.
3. The maintenance and repair costs are quite high.

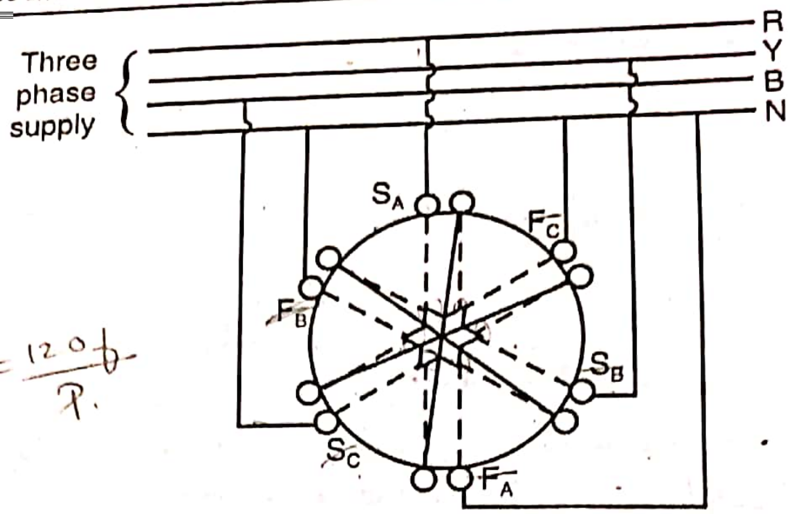
Applications of slip-ring induction motors:

The slip-ring induction motors are used for loads which require high staring torque such as conveyors, crushers, hoists, cranes, elevators, compressors etc.

10.3 Rotating Magnetic Field:

When a three phase supply is given to the three phase winding of the stator, a rotating magnetic field of constant magnitude and rotating with synchronous speed is produced. This fact can be proved as follows.

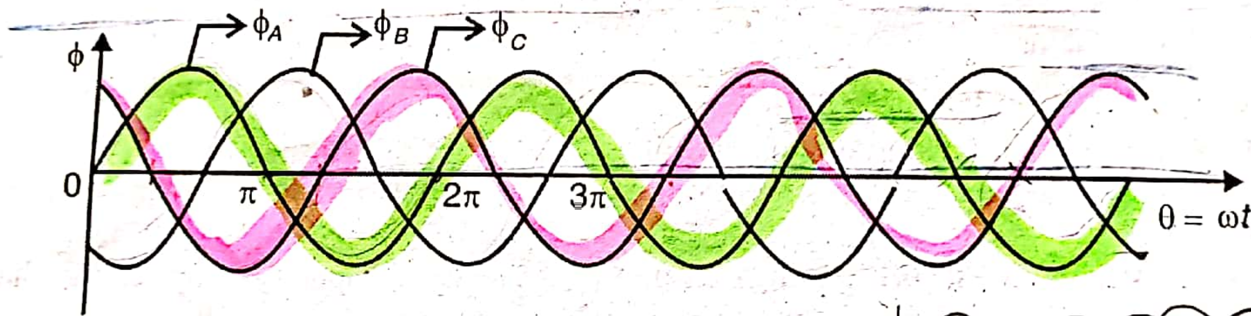
$$\boxed{N_s = \frac{120f}{P}}$$



$N_s = \frac{120f}{P}$

Fig.10.4

The Fig. in 10.4, shows the three phase winding of the stator of an induction motor, which is connected to the three phase supply. The starting points of the windings S_A, S_B and S_C are connected to the three supply lines R, Y and B. The other three ends F_A, F_B and F_C are connected to the neutral N. When the supply is given, the fluxes produced in the three windings are as shown in Fig.10.5.



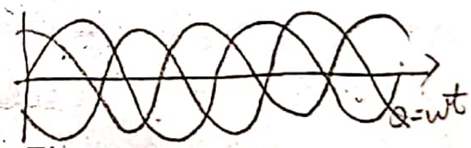


Fig.10.5

The assumed positive directions of fluxes are as shown in Fig. 10.6.

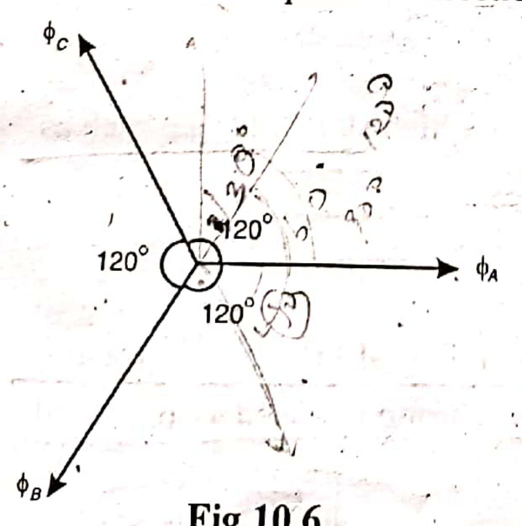


Fig.10.6

The equations for the three fluxes are:

$\phi_A = \phi_m \sin \omega t$

$\phi_B = \phi_m \sin (\omega t - 120°)$ and

$\phi_C = \phi_m \sin (\omega t - 240°)$

The resultant flux of these three fluxes at any instant, is given by the vector sum of the individual fluxes ϕ_A, ϕ_B and ϕ_C.

(i) When $\theta = 0°$, we find from the wave diagram of the fluxes, shown in Fig. 10.5 that

$$\phi_A = 0$$

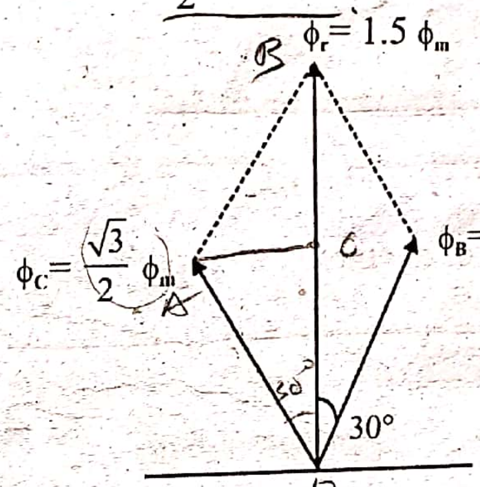
$$\phi_B = \phi_m \sin(-120°) = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_C = \phi_m \sin(-240°) = \frac{\sqrt{3}}{2}\phi_m$$

These values of fluxes at this instant and their resultant are shown in Fig. 10.7. The vector ϕ_B is written opposite to its assumed positive direction, as it is negative. The resultant flux ϕ_r lies along Y–axis and its magnitude is given by,

$$\phi_r = \cancel{2} \times \frac{\sqrt{3}}{\cancel{2}}\phi_m \cos 30° = \frac{3}{2}\phi_m = 1.5\,\phi_m$$

$\phi_r = 2 \times \frac{\sqrt{3}}{2} \cos 30°$



OB = CB + OC
= 2(OC)
= 2 cos 30° OA
= 2

Fig. 10.7

ii) When $\theta = 60°$, the values of the three fluxes are,

$$\phi_A = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_B = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_C = 0$$

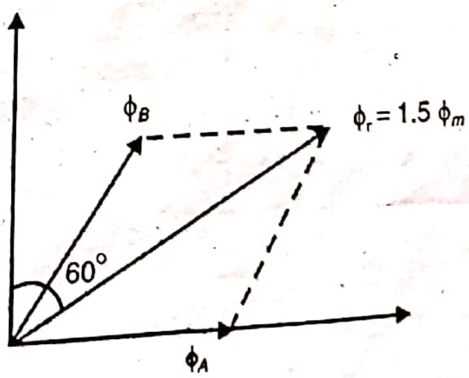


Fig.10.8

The three fluxes at this instant and their resultant are shown in Fig. 10.8. It is observed that, the resultant flux has rotated by 60° in the clockwise direction and its magnitude is $1.5\,\phi_m$.

iii) When $\theta = 120°$, the values of the three fluxes are,

$$\phi_A = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_B = 0 \quad \text{and} \quad \phi_C = -\frac{\sqrt{3}}{2}\phi_m$$

The three fluxes at this instant and their resultant are shown in Fig. 10.9. It is observed that the resultant flux has rotated by another 60° i.e. through 120°, from its original position and its magnitude is 1.5 ϕ_m.

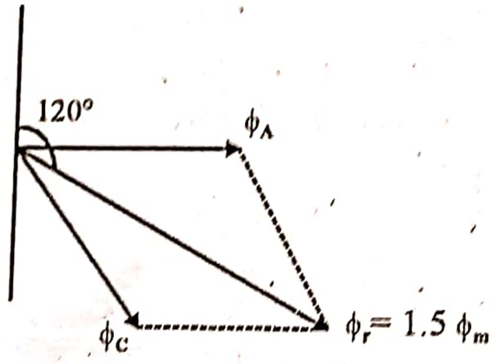


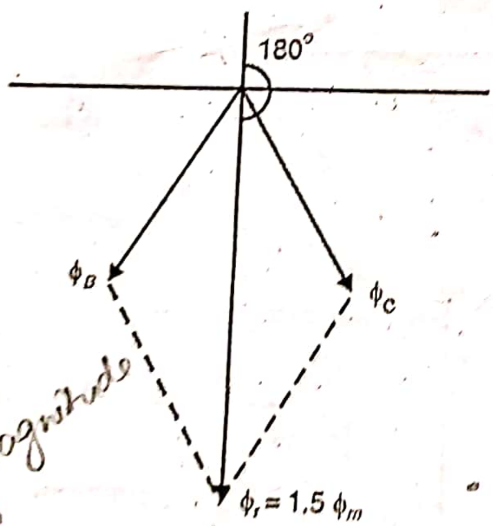
Fig. 10.9

iv) When $\theta = 180°$, the values of the three fluxes are;

$$\phi_A = 0$$

$$\phi_B = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_C = -\frac{\sqrt{3}}{2}\phi_m$$



nstant magnitude 1.5ϕm

Fig.10.10

The three fluxes at this instant and their resultant are as shown in Fig.10.10. It is observed that the resultant flux has rotated by another 60° i.e. through 180°, from its original position and its magnitude is 1.5 ϕ_m.

From the above discussion, we can conclude that as $\theta = \omega t$ varies from $\theta = 0$ to $\theta = 2\pi$, the resultant flux also rotates with the same angular velocity ω and having a constant magnitude of 1.5 ϕ_m. Therefore, when a three phase supply is given to the stator winding, a rotating magnetic field of constant magnitude 1.5 ϕ_m and rotating with synchronous speed $N_S = 120\ f / P$ is produced.

10.4 Working Principle:

When a three phase supply is given to the three phase stator winding, a magnetic field of constant magnitude 1.5 ϕ_m and rotating with the synchronous speed N_s is produced. This rotating magnetic field sweeps across the rotor conductors and hence, an e.m.f. is induced in the rotor conductors. The direction of the induced e.m.f. is such as to oppose the very cause of it i.e. the relative speed between the rotating magnetic field and the static rotor. As the rotor conductors are short circuited on themselves, the induced e.m.f. sets up a current in the rotor conductors in such a direction as to produce a torque, which rotates the rotor in the same direction as the magnetic field, as shown in Fig. 10.11, so that the relative speed decreases. The speed of the rotor gradually increases and tries to catch up with the speed of the rotating magnetic field. But, it fails to reach the synchronous speed, because, if it catches up with the speed of the magnetic field, the relative speed becomes zero and hence, no e.m.f. will be induced in the rotor conductors, the torque becomes zero. Hence, the rotor will not be able to catch up with the speed of the magnetic field, but rotates at a speed slightly less than the synchronous speed.

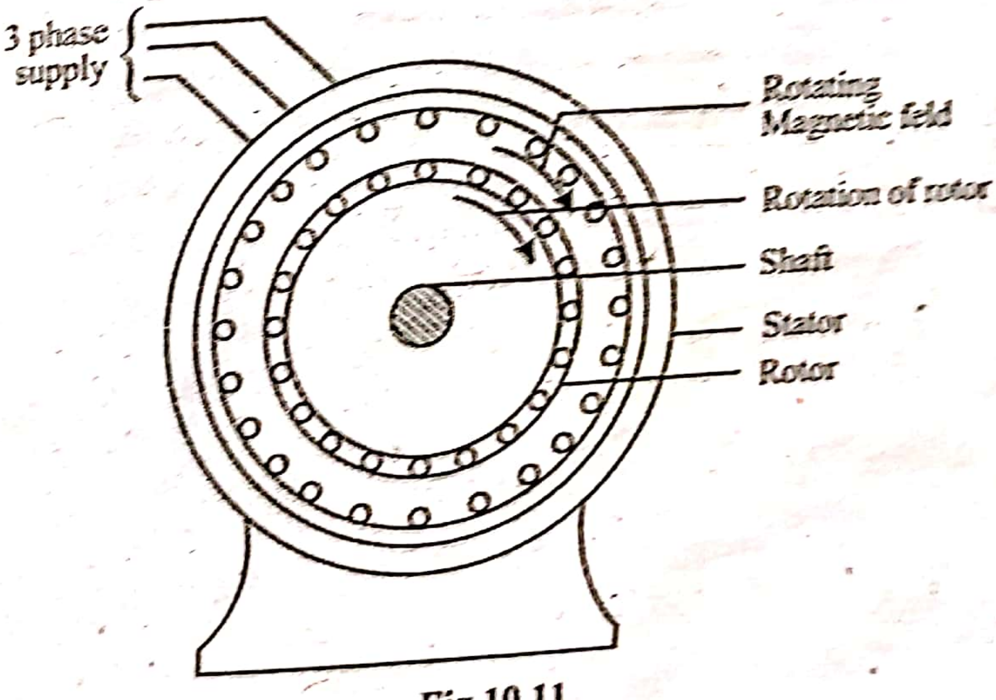


Fig.10.11

The difference between the synchronous speed Ns of the magnetic field and the actual speed of the rotor N is called as the *slip speed*. (10.2)

∴ Slip speed = Ns – N

The *slip* of an induction motor is defined as the ratio of the slip speed to the synchronous speed

$$\text{Slip} = \frac{N_s - N}{N_s}$$

N_s = sp. of
f = freq s.
P = Pole.
N = speed of rotor.
f' = freq of rotor.

$$S = \frac{N_S - N}{N_S} \quad (10.3)$$

The slip of an induction motor is usually expressed as a percentage and the percentage slip is given by,

$$\boxed{\% S = \left[\frac{N_S - N}{N_S}\right] \times 100}$$

10.5 Frequency of Rotor Current:

When the rotor is stationary, the frequency of the rotor current is the same as the supply frequency. When the induction motor is rotating, the frequency of the current induced in the rotor conductors is proportional to the relative speed or slip speed. If f' is the frequency of the induced current in the rotor, then

f' ∝ slip speed

$\boxed{f' \propto N_s - N}$

Rotor current

$$N_S - N = \frac{120\, f'}{P} \quad (10.4)$$

But $N_S = \dfrac{120\, f}{P}$ (10.5)

eqn'

$\frac{120f}{P} - N = \frac{120f'}{P}$

$-PN = 120f - 120f'$

$= 120(f - f')$

$\frac{PN}{120} = f - f'$

$N_S - N = \frac{120f}{P}$

$\boxed{N_S = \frac{120f}{P}}$

Where, f = frequency of the supply

From equation (10.4) and (10.5), we get,

$$\boxed{\frac{N_S - N}{N_S} = \frac{f'}{f} = S}$$

$$\therefore f' = S f \quad (10.6)$$

The frequency of the rotor current is slip times the frequency of the supply.

$S = \frac{f'}{f} = \frac{N_s - N}{N_s}$ $\boxed{f' = Sf}$

$\boxed{f' = Sf}$

$$\boxed{\frac{N_s - N}{N_s} = \frac{f'}{f} = S}$$