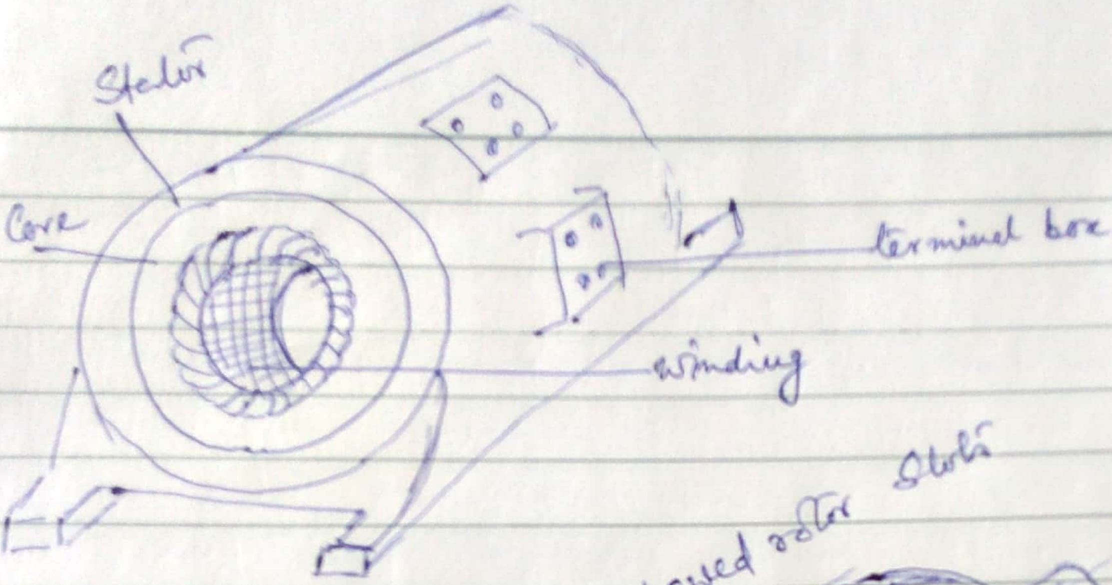
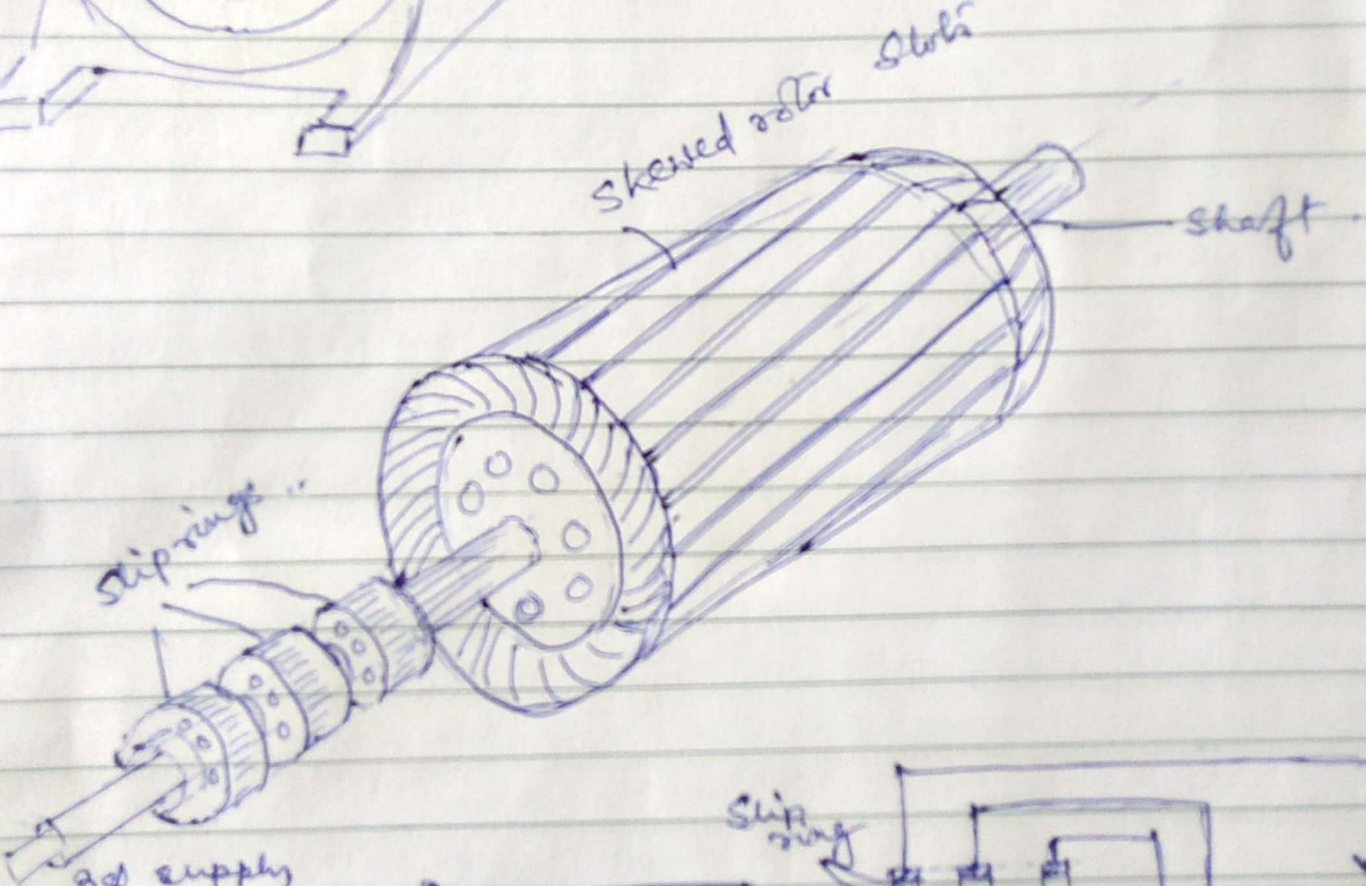
3-ϕ Induction Motor.

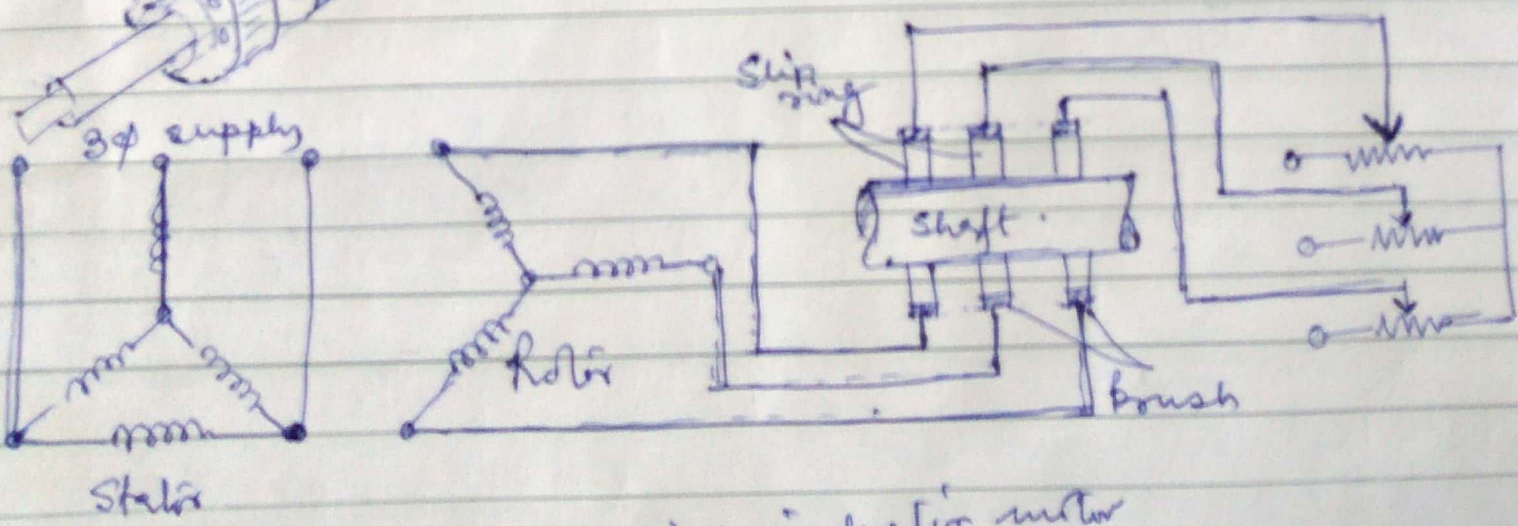
Construction: essentially consists of two parts: the stator and the rotor.
The stator is built up of high-grade alloy steel laminations to reduce eddy current losses.

The stator winding draws a current, from the 3-ϕ ac supply, which sets up a flux in the air-gap. Since the stator is subjected to an alternating flux, it is made of laminations of high permeability steel such as silicon steel, so as to minimise hysteresis & eddy-current losses. The laminations are slotted on the inner periphery & insulated from each other.

The rotor is built up of thin laminations of the same material as stator. The laminated cylindrical core is mounted directly on the shaft carried by the shaft. These laminations are slotted on their outer periphery to receive the rotor conductors. There are two types of induct motor rotors:
a) Squirrel cage rotor or simply cage rotor.
b) phase wound or wound rotor. Motors using this type of rotor are also called slip-ring rotor



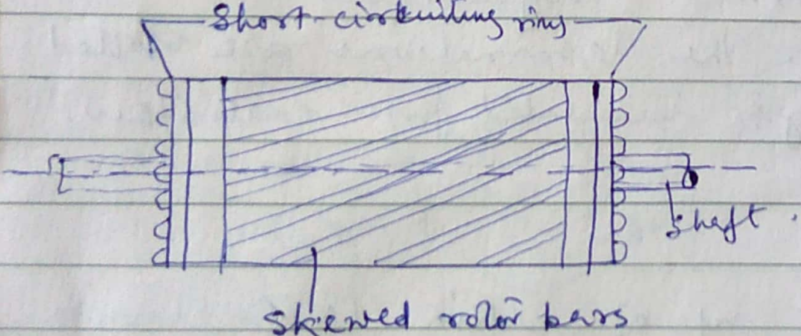




Slip-ring induction motor

Squirrel-cage rotor.

It consists of a cylindrical laminated core with slots nearly parallel to the shaft axis, or skewed. Each slot contains an uninsulated bar conductor of aluminium or copper. At each end of the rotor, the rotor bar conductors are short-ckted by heavy rings of the same material.
[The conductors and the end rings form a cage of the type which was once commonly used for keeping squirrels; hence its name.]



The skewing of cage rotor conductors offers the following advantages:

1. More uniform torque is produced and noise is reduced during operation.

2. The locking tendency of the rotor is reduced. During locking, the rotor & stator teeth attract each other due to magnetic action.

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rotor bars are skewed in Induction Motor.

This is done to prevent cogging. Cogging is magnetic locking. When an induction motor refuses to start even if full voltage is applied to it, this is called as cogging. This happens when the rotor slots and stator slots are same in number or they are integer multiples of each other, due to this the opposite poles of stator & rotor come infront of each other and get locked.

Wound Rotor or slip ring rotor:

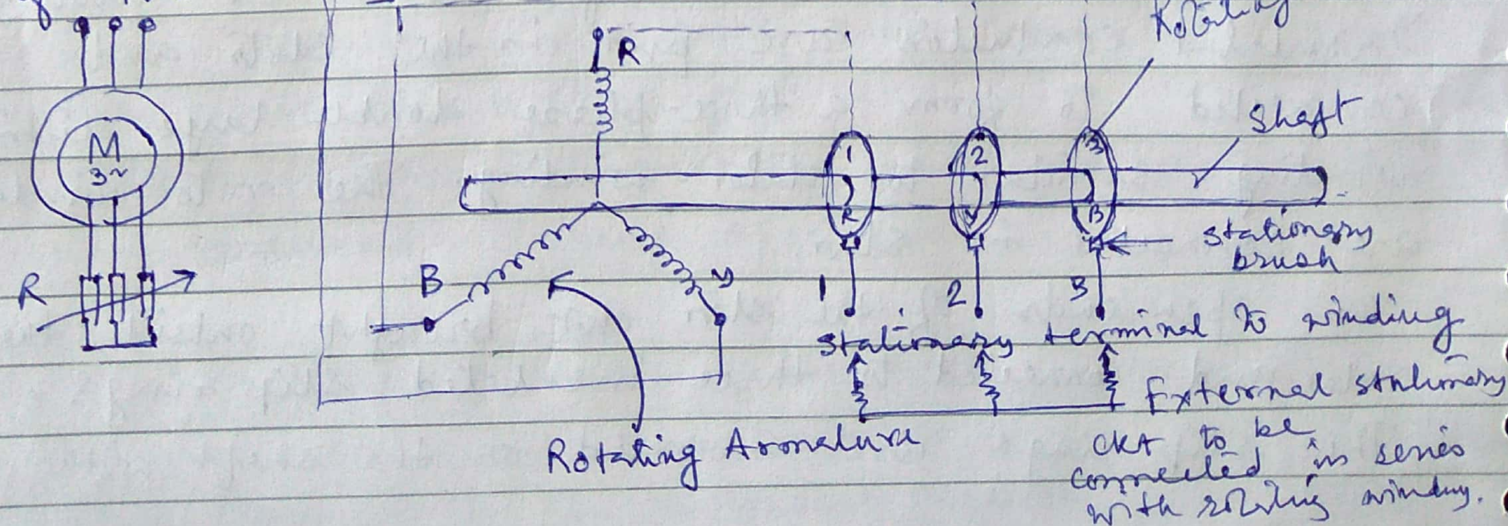
The wound rotor consists of slotted armature. Insulated conductors are put in the slots and connected to form a three-phase double layer distributed winding similar to stator winding. The rotor winding are connected in star.
The open ends of the star ckt brought outside the rotor and connected to three insulated slip rings.
The slip-rings are mounted on the shaft with

resting on them. The brushes are connected to ~~three~~ three variable resistors connected in star.

The resistors enable the variation of each rotor phase resistance to serve ~~each~~ two purposes:

1) to increase the starting torque & decrease the starting current from the supply.
2) to control the speed of the motor.

[A wound-rotor motor, also known as slip ring-rotor motor, is a type of induction motor where the rotor windings are connected through slip-rings to external resistance. Adjusting the resistance allows control of the speed/torque characteristic of the motor.]



Comparison of cage and wound rotors.

The advantages of the cage rotor

1. Robust construction & cheaper
2. The absence of brushes reduces the risk of sparking.
3. Lesser maintenance.
4. Higher efficiency & higher power factor.

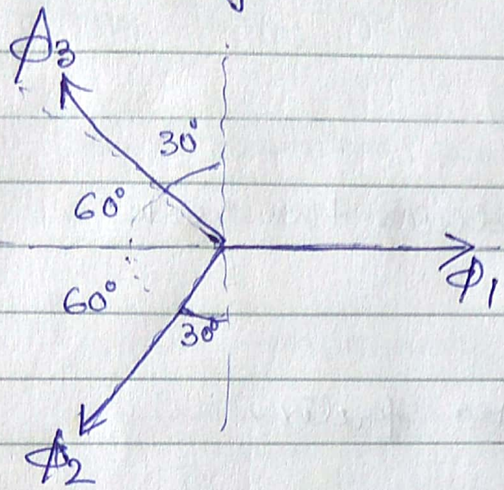
The wound rotors have the following advantages:

1. High starting torque and low starting current.
2. Additional resistance can be connected in the rotor ckt to control speed.

Production of rotating field.

When 3-ϕ windings displaced in space by 120° are supplied by 3ϕ currents displaced in time by 120°, a magnetic flux is produced which rotates in space.

Analytical Method. Let each coil be supplied from one phase of a balanced 3-ϕ supply. Each coil will produce an alternating flux along its own axis.



$\phi_1 = \phi_m \sin \omega t$

$\phi_2 = \phi_m \sin(\omega t - 120°)$

$\phi_3 = \phi_m \sin(\omega t - 240°)$

or $\phi_m \sin(\omega t + 120°)$

The resultant horizontal component of flux is given by

$$\phi_h = \phi_1 \cos 0° - \phi_2 \cos 60° - \phi_3 \cos 60°$$

$$= \phi_1 - \cos 60° (\phi_2 + \phi_3)$$

$$= \phi_1 - \frac{1}{2}(\phi_2 + \phi_3)$$

$$= \phi_m \sin \omega t - \frac{1}{2}\left[\phi_m \sin(\omega t - 120°) + \phi_m \sin(\omega t + 120°)\right]$$

$$= \phi_m \sin \omega t - \frac{\phi_m}{2}\left[\sin \omega t \cos 120° - \cos \omega t \sin 120° + \sin \omega t \cos 120° + \cos \omega t \sin 120°\right]$$

$$= \phi_m \sin \omega t - \phi_m \sin \omega t \left(-\frac{1}{2}\right)$$

$$= \frac{3}{2} \phi_m \sin \omega t$$

$$\boxed{\phi_h = \frac{3}{2} \phi_m \sin \omega t}$$

The resultant vertical component of flux is given by

$$\phi_v = \phi_1 \cos 90^\circ - \phi_2 \cos 30^\circ + \phi_3 \cos 30^\circ$$

$$= 0 - \cos 30^\circ . \phi_m \sin(\omega t - 120^\circ) + \cos 30^\circ . \phi_m \sin(\omega t + 120^\circ)$$

$$= \cos 30^\circ \left[-\phi_m \sin(\omega t - 120^\circ) + \phi_m \sin(\omega t + 120^\circ) \right]$$

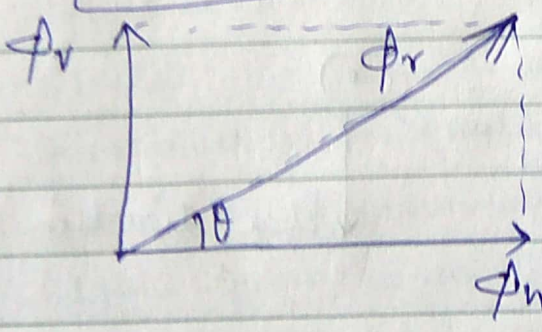
$$= \frac{\sqrt{3}}{2} \phi_m \left[-(\sin \omega t \cos 120^\circ - \sin 120^\circ \cos \omega t) + (\sin \omega t \cos 120^\circ + \cos \omega t \sin 120^\circ) \right]$$

$$= \frac{\sqrt{3}}{2} \phi_m \left[-\sin \omega t \cos 120^\circ + \sin 120^\circ \cos \omega t + \sin \omega t \cos 120^\circ + \cos \omega t \sin 120^\circ \right]$$

$$= \sqrt{3} \phi_m . \sin 120^\circ . \cos \omega t$$

$$= \sqrt{3} \phi_m \frac{\sqrt{3}}{2} . \cos \omega t = \frac{3}{2} \phi_m \cos \omega t .$$

$$\boxed{\phi_v = \frac{3}{2} \phi_m \cos \omega t}$$



Resultant Flux.

$$\phi_r = \sqrt{\phi_h^2 + \phi_v^2}$$

$$= \sqrt{\left(\frac{3}{2} \phi_m \sin \omega t\right)^2 + \left(\frac{3}{2} \phi_m \cos \omega t\right)^2}$$

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

Also, $\tan\theta = \dfrac{\phi_v}{\phi_h}$

$$= \frac{3/2 \, \phi_m \cos \omega t}{3/2 \, \phi_m \sin \omega t} = \cot \omega t = \tan(\pi/2 - \omega t)$$

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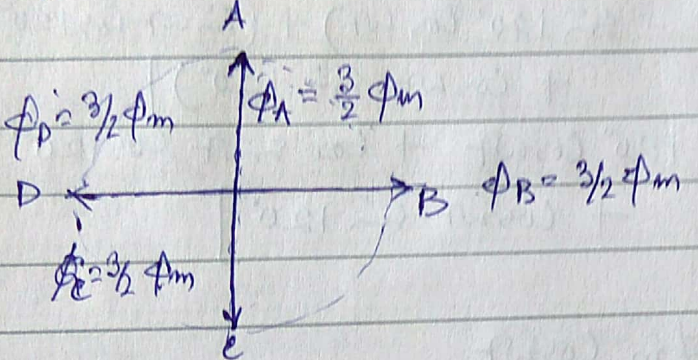
$\theta = \pi/2 - \omega t$

a) at $\omega t = 0^\circ$, $\theta = 90^\circ$ corresponding to position A

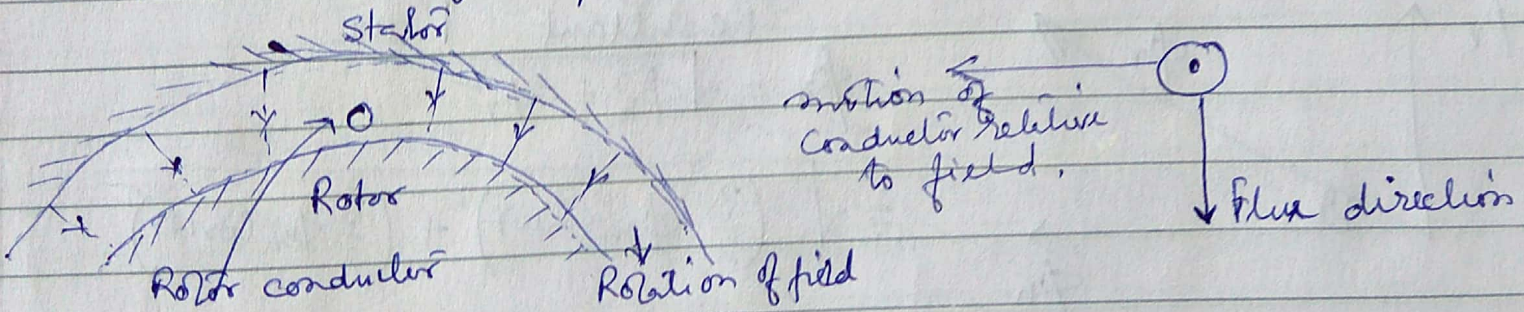
b) at $\omega t = 90^\circ$, $\theta = 0^\circ$ " " " B

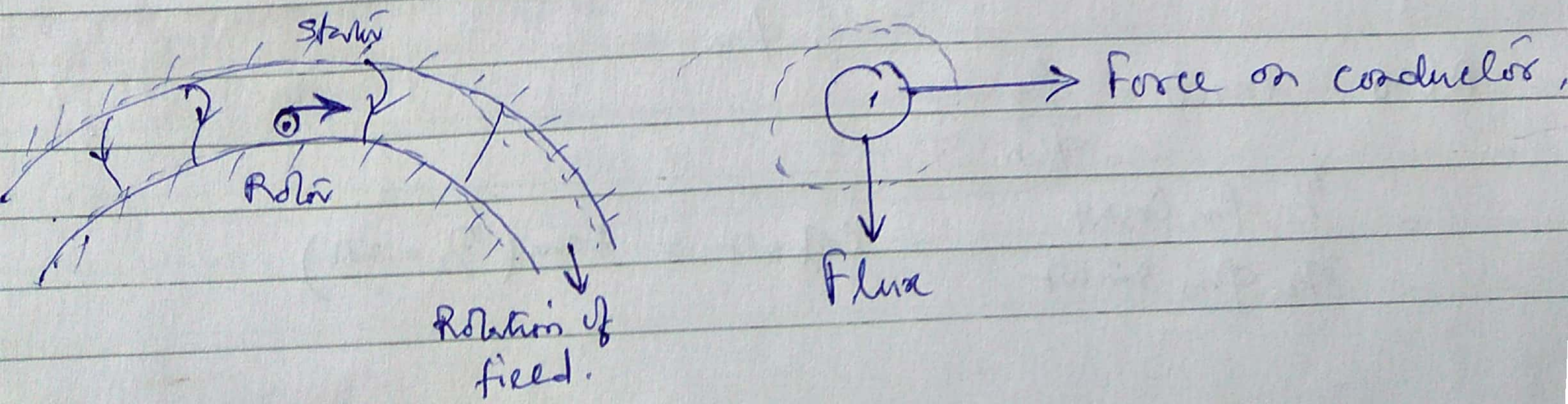
c) at $\omega t = 180^\circ$, $\theta = -90^\circ$ " " " C

d) at $\omega t = 270^\circ$, $\theta = -180^\circ$ " " " D.



Principle of operation of a 3-φ induction motor:



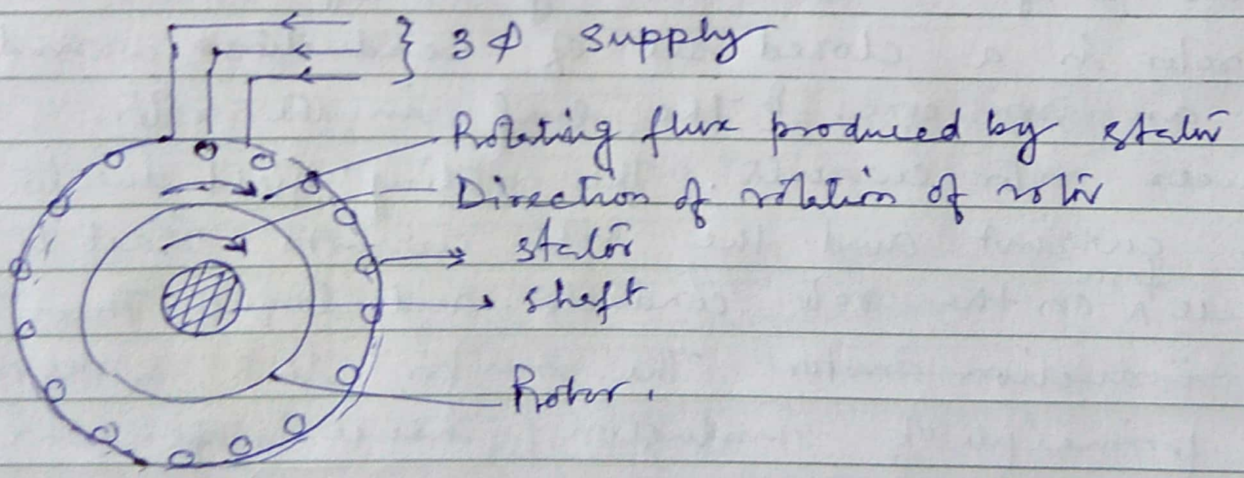


A 3-ϕ inductor motor has a stator winding which is supplied by 3-ϕ alternating voltage and has balanced 3-ϕ currents in the winding. The current produce mmf which is constant in magnitude and rotates in constant at synchronous speed. The rotating mmf produces rotating flux of constant magnitude. A rotating magnetic field is one whose magnitude is constant but whose axis of direction rotates in space. The rotating field caused by the stator current induces emf in the rotor by transformer action. The rotor is a closed set of conductors wound on an iron core. The emf in the rotor produces rotor currents. The rotating field due to stator current and the rotor currents react to produce force on the rotor conductor and torque. ~~Thus the induction motor~~ The motor thus, works on the principle of induction, hence is known as induction motor.

Principle:

When the stator winding of a 3-ϕ induction motor is connected to a 3-ϕ a.c supply, a rotating magnetic field is produced which rotates round the stator at synchronous speed ($N_s = \frac{120f}{P}$). The direction of rotation of this field will depend upon the phase ~~eq~~ sequence of the supply voltage. This direction of rotation can be reversed by interchanging the connection to the supply of any two leads of the 3-ϕ induction motor. Here the direction is assumed to be clockwise.

~~and understand how~~



Speed and slip.

If, N_s = synchronous speed* in r.p.m.
N_r = actual rotor speed in r.p.m.

*speed of the stator field.

then, Slip speed = $N_s - N_r$ r.p.m.

The slip speed is expressed as a fraction of the synchronous speed is called the per-unit slip or fractional slip. The per unit slip is usually called the slip.

$$S = \frac{N_s - N_r}{N_s} \text{ per unit (P.u)}$$

$$\text{Percentage slip} = \frac{N_s - N_r}{N_s} \times 100$$

The slip at full load varies from about 5% for small motors to about 2% for large motors.

Frequency of rotor voltage and current.

Frequency of current & voltage in the stator must be the same as the supply frequency given by

$$f = \frac{PN_s}{120}.$$

& The rotor frequency $f_r = \frac{P(N_s - N_r)}{120}$

$$\frac{f_r}{f} = \frac{N_s - N_r}{N_s} \quad \text{But, } \frac{N_s - N_r}{N_s} = s$$

$$\therefore f_r = sf \quad / \quad \boxed{f_2 = sf_1}$$

Speed of the motor, $N = (1-s) N_s$

i.e. rotor current frequency = per unit slip × supply frequency

When the rotor is (stand still) stationary

$N_r = 0$, $s = \frac{N_s - N_r}{N_s} = 1$ and $f_r = f$

When the rotor is driven by a mechanical prime mover at synchronous speed N_s, the $s=0$ and $f_r = 0$.

∴ Frequency of rotor current varies from $f_r = f$ at stand still ($s=1$) to $f_r = 0$ at synchronous speed $s=0$

Ex: A 3ϕ induction motor is wound for four poles and is supplied from a 50 Hz supply. Calculate

a) the synchronous speed

b) the speed of the ~~motor~~ rotor when the slip is 3%.

c) the rotor frequency when the speed of the rotor is 900 rpm

a) $N_s = \frac{120 f}{P} = \frac{120 \times 50}{4} = 1500$ rpm

b) $s = \frac{N_s - N_r}{N_s} = \frac{1500 - \text{rotor speed}}{1500} =$

$0.03 = \frac{1500 - \text{rotor speed}}{1500}$

∴ rotor speed $= -1500 \times 0.03 + 1500 = 1455$ rpm.

c) per unit slip $= \frac{1500 - 900}{1500} = 0.4$

$f_r = sf = 0.4 \times 50 = 20$ Hz.

Ex: A 3-ϕ, 6 pole, 50 Hz induction motor has a slip of 1% at no load, and 3% at full load. Determine:

(a) synchronous speed
(b) no-load speed
(c) full-load speed
(d) frequency of rotor current at stand-still.
(e) frequency of rotor current at full-load.

(a) $N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$ r.p.m.

(b) $N_o = (1-s) N_s = (1 - 0.01) \times 1000 = 990$ rpm

(c) $N_{fL} = (1 - S_{fL}) N_s = (1 - 0.03) \times 1000 = 970$ r.p.m.

(d) frequency of rotor current at standstill:

$f_r = s f_s = 1 \times 50 = 50$ Hz.

(e) frequency of rotor current at full load:

$f_r = S_{fL} f_s = 0.03 \times 50 = 1.5$ Hz.