THREE PHASE INDUCTION MOTORS.

Synchronous motor - limited applications.
- alternative - asynchronous or induction motor.

Advantages:-

⇒ more rugged
⇒ less maintenance
⇒ less expensive than synchronous or dc motors.
⇒ high efficiency.

Applications :-

* 3ϕ induction motors - lift, cranes, pumps, exhaust fans, lathes etc.

* 1ϕ induction motors - domestic applications - fans, refrigerators, washing machines, hair dryers.

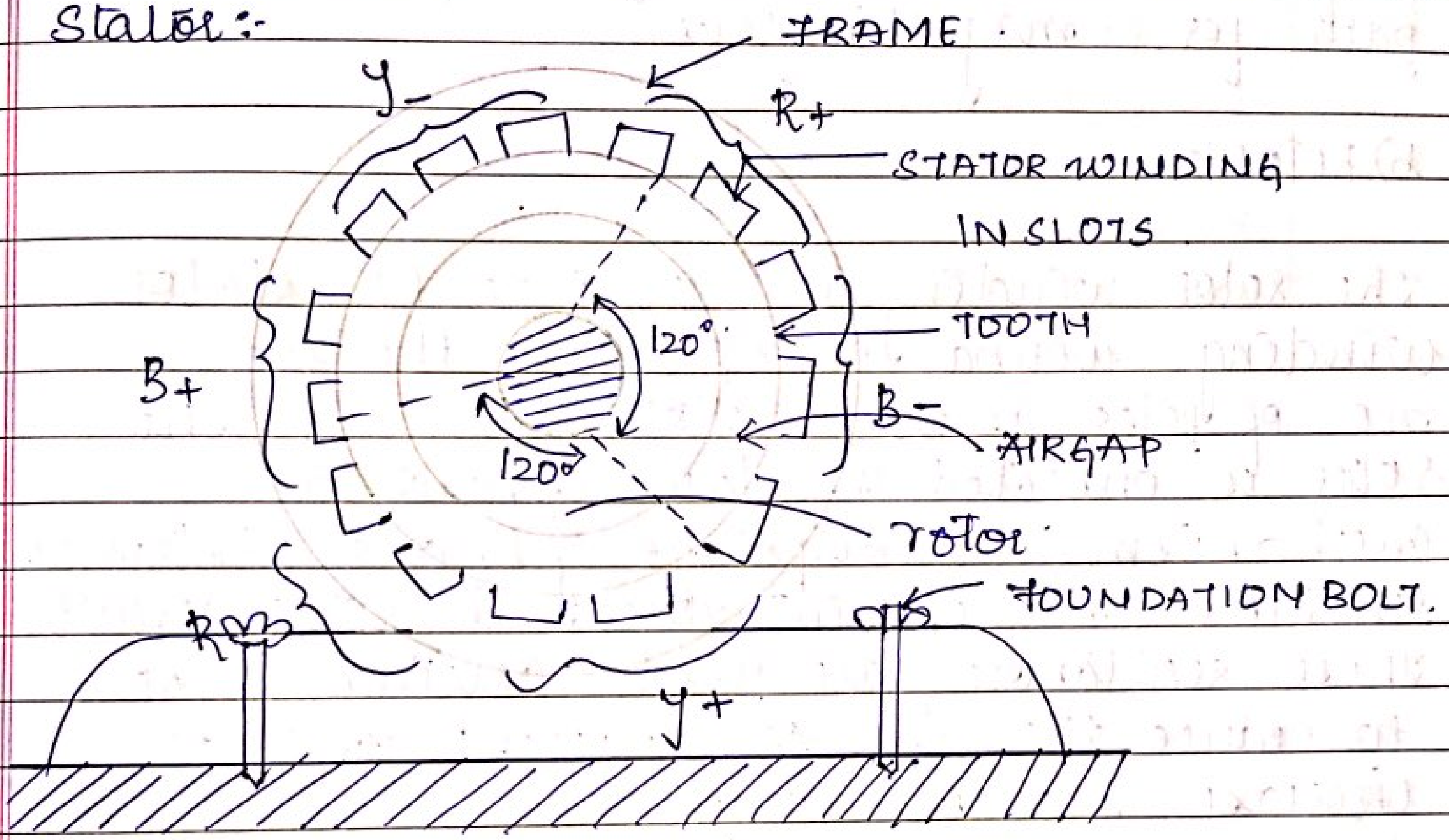
3ϕ Induction motors

↳ constant speed motors (from no load to full load)

Working principle - "mutual induction" - similar to transformer - ∴ induction motors are also known as "rotating transformers"

∴ refer slides for constructional details, types, adv and dis adv, application of squirrel cage and slip-ring IM

Stator:-



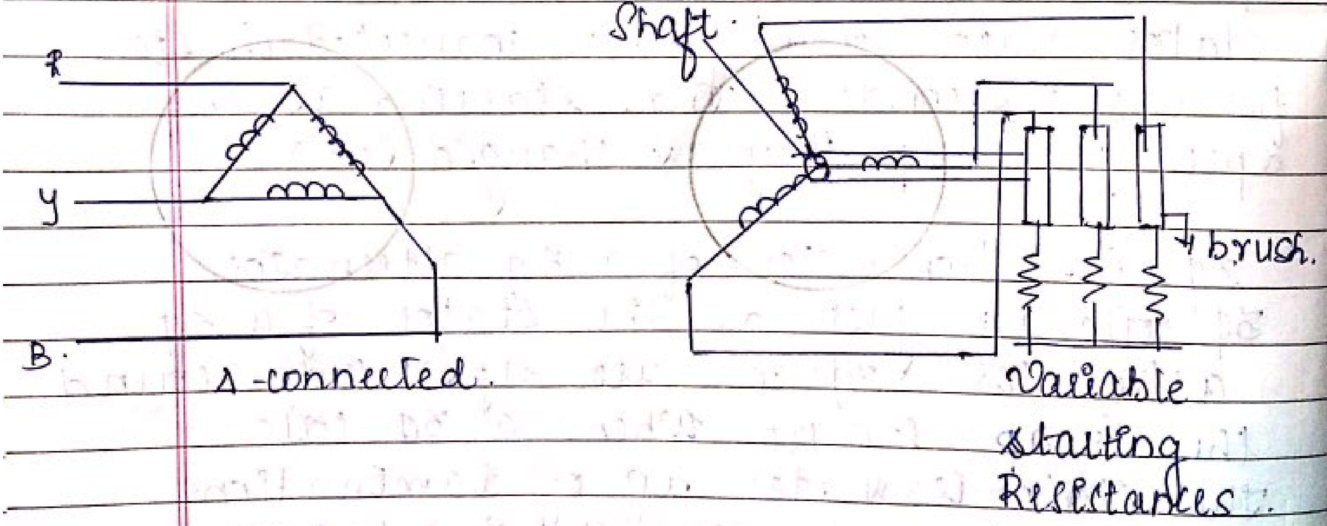
3φ induction motor stator has a star-delta stator. Stator winding are connected in star for a few seconds during starting as the speed picks up they are changed to Δ.

3φ induction motor of a 3φ alternator. 3φ coils are just as the stator of a 3φ alternator. 3φ coils are seperated around the airgap by 120°. When a 3φ coils
The stator is made up of laminations with thin layer of varnish insulation on both sides and with slots cut in them. The laminations are stacked together and fit in frame of stator.

The 3ϕ windings are placed in stator slots. The terminals of the phase coils, are taken out of the machine, to be connected to external loads. The base of frame is, fastened to foundation by means of foundation slots. The frame provides the path for magnetic flux.

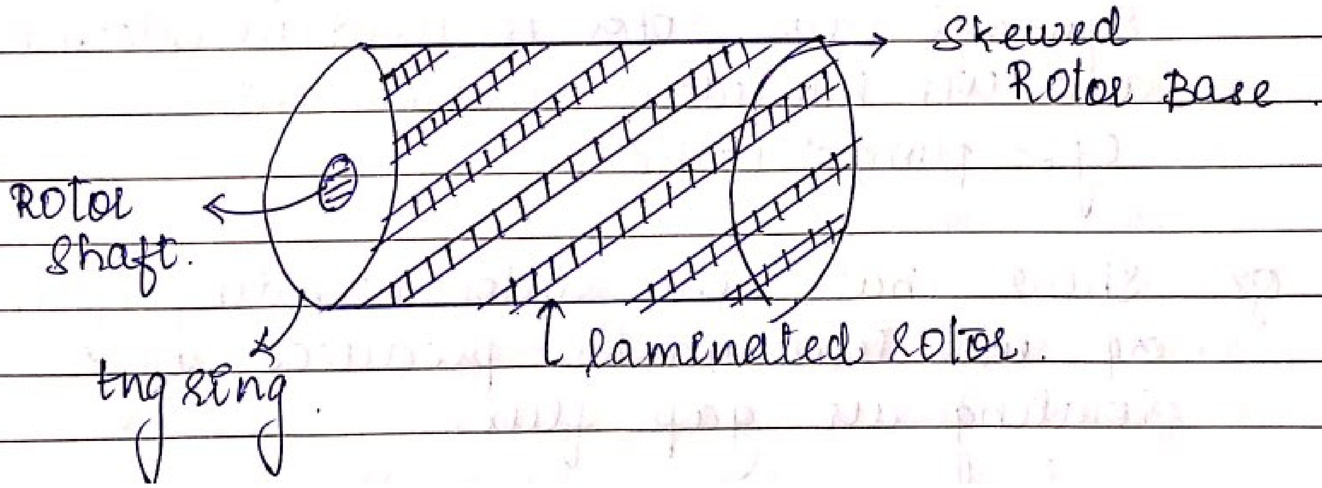
b) Rotor :-

The rotor winding is similar to stator winding, wound for 3ϕ & for the same no of poles as the stator winding. The rotor is connected in star through a mechanism of 3 slip rings & brushes. External resistance may be introduced in rotor circuit. These resistances are used during START to reduce the inrush current and to increase starting torque.



Squirrel Cage Rotor.

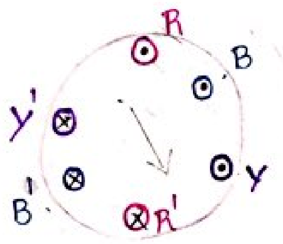
The rotor is made of laminations with slots in them. Rotor bars are inserted in the slots & short circuited at both ends by means of End rings (copper). The rotor bars are skewed. The rotor bars are made up of copper/Aluminium.



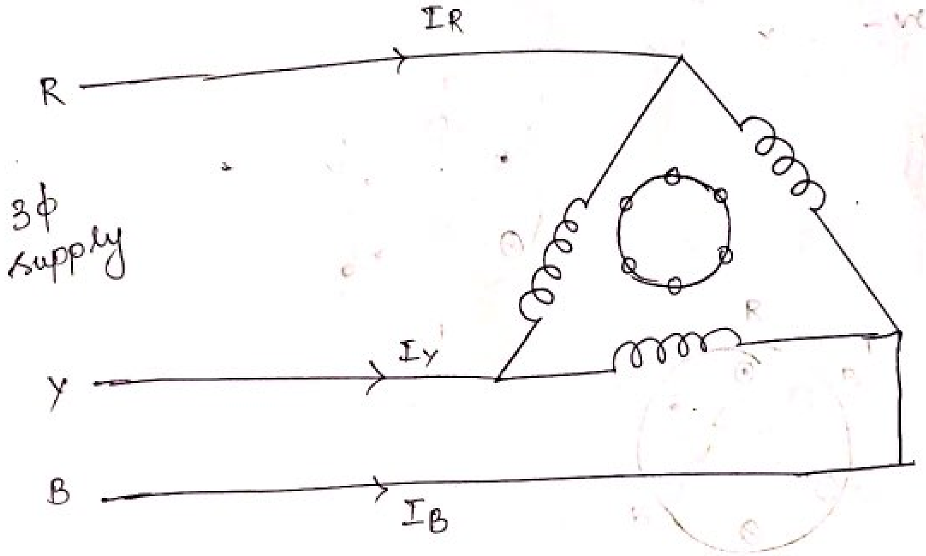
Concept of "rotating magnetic field":-

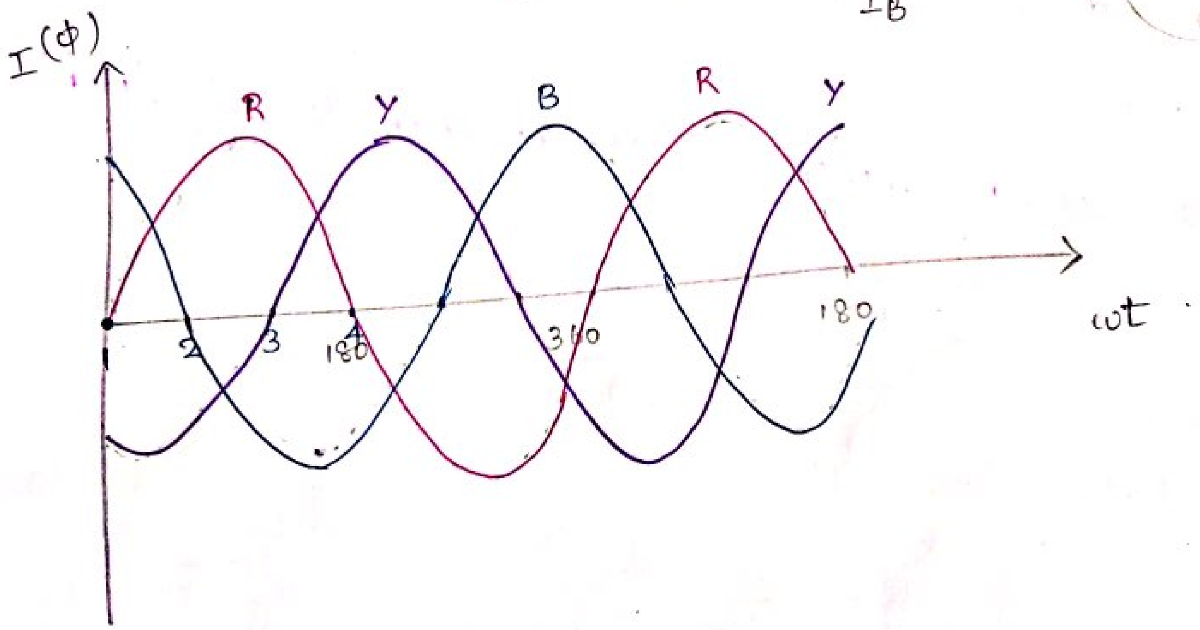
* A rotating magnetic field is produced when 3ϕ winding is energised from 3ϕ supply.
* The produced magnetic field is such that, the poles do not remain in fixed position hence the name, rotating magnetic field.

Consider a 3ϕ winding energized from 3ϕ source.



Position 1.



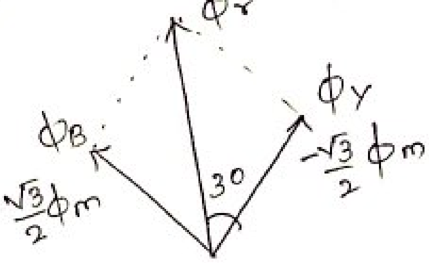


Let ϕ_m be the maximum flux due to any phase,

$$\left.\begin{aligned} \phi_R &= \phi_m \sin \omega t \\ \phi_Y &= \phi_m \sin(\omega t - 120) \\ \phi_B &= \phi_m \sin(\omega t + 120) \end{aligned}\right\} \quad (1)$$

i) at $\omega t = 0$,

Substituting the value of ωt in (1) and also referring the waveform,



$\phi_R = 0$

$\phi_Y = \phi_m \sin(-120)$

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

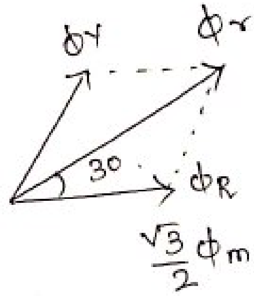
$\phi_B = \phi_m \sin(120)$

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

$\therefore \phi_r = 2 \cancel{\cos} \frac{\sqrt{3}}{2}\phi_m \cos 30$

$\boxed{\phi_r = 1.5\phi_m}$

ii) at $\omega t = 60$,



$\phi_R = \phi_m \sin 60$

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

$\phi_Y = \phi_m \sin -60$

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

$\phi_B = \phi_m \sin 180$

$= 0$

$\boxed{\phi_r = 1.5\phi_m}$

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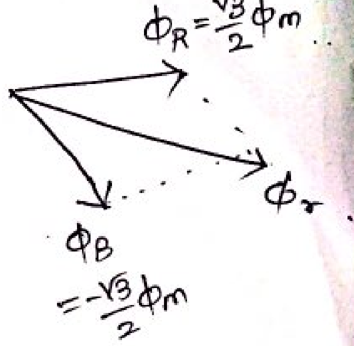
iii) at $\omega t = 120$,

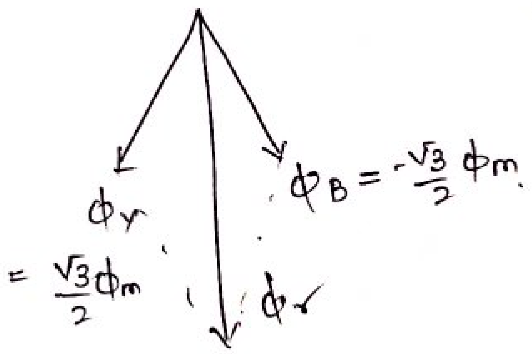
$$\phi_R = \phi_m \sin 120$$
$$= \frac{\sqrt{3}}{2}\phi_m$$
$$\phi_Y = \phi_m \sin 0$$
$$= 0$$
$$\phi_B = \phi_m \sin 240$$
$$= -\frac{\sqrt{3}}{2}\phi_m.$$



$$\boxed{\phi_r = 1.5\phi_m}$$

iv) at $\omega t = 180$.

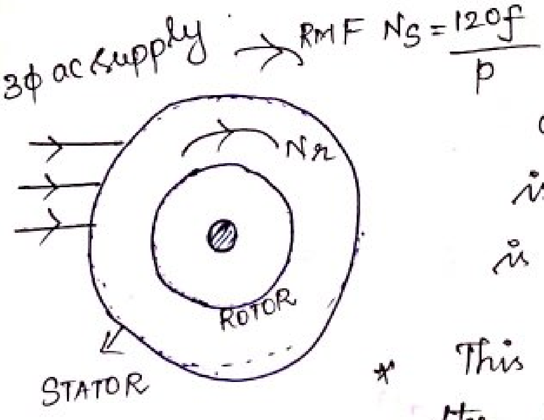
$$\phi_R = \phi_m \sin 180.$$
$$= 0.$$
$$\phi_Y = \phi_m \sin(180-120)$$
$$= \phi_m \sin 60$$
$$= \frac{\sqrt{3}}{2}\phi_m.$$
$$\phi_B = \phi_m \sin(180+120)$$
$$= \phi_m \sin 300$$
$$= -\frac{\sqrt{3}}{2}\phi_m.$$



$$\boxed{\phi_r = 1.5\phi_m.}$$

Thus from above discussion, it is clear that a 3ϕ supply produces a rotating field of const value $1.5\,\phi_m$ rotating at synchronous speed $N_S = \frac{120f}{P}$ - speed of rotating magnetic field

Principle of operation :



* Consider the rotor of IM is at standstill. $N_r = N_{ro} = 0$. When 3φ ac supply is given to stator, RMF is produced in air gap whose speed is given by $N_S = \frac{120f}{P}$.

* This RMF passes thro air gap and cut the rotor conductors (stationary)., due to relative speed b/w rotating flux and stationary rotor, e.m.f s are induced in the rotor conductors. since they are short - circuited current start flowing in the rotor conductors,

* Now the current carrying conductor placed in mag field experiences the force and produces a torque which tends to move the rotor in same direction as that of the rotating magnetic field. (b'coz of Lenz's law - the direction of rotor currents will be such that they tend to oppose the cause producing them). i.e the relative speed b/w rotating field and stationary conductors.

Rotor speed and slip :

In induction motor, the rotor field is always less than RMF Ns. $N_r < N_s$

The difference b/w N_s and N_r is called slip and is usually expressed as a percentage of N_s.

i.e $$\% S = \frac{N_s - N_r}{N_s} \times 100 .$$

... the rotor is stationary, ... at ... 1 phase

(i) $N_R = 0$, slip $= \frac{N_S}{N_S} = 1$ standstill condition

(ii) $N_R = N_S$, slip $= 0$, (never happens in IM)

Frequency of the rotor induced emf:

The frequency of induced voltage (current) due to relative speed b/w rotor winding and magnetic field is given by,

$$\text{Frequency} = \frac{P \times \text{relative speed}}{120}$$

where relative speed b/w magnetic field and the winding.

P - no of poles.

For a rotor speed N, the relative speed b/w the rotating flux and rotor is $N_S - N$,

$\therefore$ Let f' be the rotor current frequency.

$$f' = \frac{(N_S - N) \times P}{120}$$

$$= \frac{S N_S}{120} \times P$$

$\because f = \frac{N_S P}{120}$.

$\because S = \frac{N_S - N}{N_S}$

$$\boxed{f' = Sf}$$

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

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When the rotor is stationary, $s=1$,

Let E_{ro} be the rotor induced emf / phase at standstill.

W.K.T, induced emf / phase in rotor $\propto$ relative speed.

At standstill $(N_r = 0)$ i.e $s=1$,

$$E_{ro} \propto N_s \quad \text{— (1)}$$

Under running conds, $(N_r \neq 0)$

$$E_r \propto N_s - N_r \quad \text{— (2)}$$

$$\frac{②}{①} = \frac{E_r}{E_{ro}} \Rightarrow \frac{N_s - N_r}{N_s} = s$$

$$\therefore \boxed{E_r = sE_{ro}} \quad \text{— ③}$$

i.e the rotor induced emf / phase is equal to slip times the rotor induced emf / phase at standstill.

1) A. 3ϕ, 50Hz, 6-pole induction motor runs at 950 rpm. Calculate (7).

i) the synchronous speed

ii) the slip

iii) frequency of the rotor emf.

i) $N_S = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$ rpm.

ii) $\text{Slip} = \frac{N_S - N}{N_S} \Rightarrow \frac{1000 - 950}{1000} \Rightarrow 0.05$.

% slip = 5%.

iii) $f' = sf = 0.05 \times 50 = 2.5$ Hz.

(2). The frequency of the emf in the stator of a 4-pole induction motor is 50Hz and that in the rotor is 2Hz. What is the slip and at what speed is the motor running?

$f = 50$Hz, $f' = 2$Hz.

$f' = sf$ $\quad \text{slip} = \frac{f'}{f} \Rightarrow \frac{2}{50} \Rightarrow 0.04$

slip = 4%.

$N_r = N_s(1-s)$

$N_S = \frac{120f}{P} \rightarrow \frac{120 \times 50}{4} \Rightarrow 1500$ rpm.

speed of the motor $\Rightarrow (1-0.04) \times 1500 \Rightarrow 1440$ rpm.

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③ A 3ϕ 60Hz induction motor has a no load speed of 890 rpm and a full-load speed of 855 rpm. Calculate i) no of poles ii) slip at no load and full load iii) fre of rotor currents at no load and full load.

No load speed = 890 rpm

full-load speed = 855 rpm.

fre = 60Hz.

∴ The syn speed will be slightly greater than no-load speed.

∴ if n	2	4	6	8	10.
N_S	3600	1800	1200	900.	720.

therefore no. of poles = 8.

$N_S = 900$.

ii) No-load slip, $\left(\frac{900-890}{900}\right) \times 100 = 1.11\%$

full-load slip % $\Rightarrow \left(\frac{900-855}{900}\right) \times 100$

$= 5\%$.

iii) fre of rotor current @ no-load, $f' = sf$

$= 0.0111 \times 60 = 0.66Hz$.

fre of rotor current @ full-load,

$f' = sf$

$= 0.05 \times 60 \Rightarrow 3Hz$.

④ A 3ϕ, 6 pole, 50Hz induction motor has a slip of 1% at no load and 3% at full load. Find i) N_s ii) the no-load speed iii) the full load speed iv) fre of rotor current at standstill and full load.

i) $N_s = \frac{120f}{P} \Rightarrow \frac{120 \times 50}{6} = 1000$ rpm.

ii) No load speed $N_r = (1-s) N_s$

s at no load $= 0.01$

$\therefore N_r = (1-0.01)\, 1000 \Rightarrow 990$ rpm.

iii) full-load speed,

s at full-load $= 0.03$

$N_r = (1-0.03) \times 1000 \Rightarrow 970$ rpm.

iv) at standstill $s=1$,

therefore $f' = sf = f$

$= 50 Hz$.

at full load, $s = 0.03$

$f' = sf$

$= (0.03)\, 50. \Rightarrow 1.5 Hz$.

⑤ A 3ϕ 440V, 50Hz, 4 pole induction motor, the standstill rotor induced emf per phase of 115V. If the motor is running at 1440 rpm, calculate for this speed i) the slip ii) the fre of the rotor induced emf per rotor iii) the value of rotor induced emf per phase.

i) Slip = $\frac{N_s - N_r}{N_s}$

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

$= \frac{120 \times 50}{4} = 1500$ rpm

$\therefore \; S = \frac{1500 - 1440}{1500} \Rightarrow 0.04$.

ii) rotor frequency, $f' = sf$

$= 0.04 \times 50$

$= 2Hz$.

iii) $E_{r0} = 115V$

$E_r = SE_{r0}$

$= 0.04 \times 115$.

$= 4.6V$.

⑤ . A 10-pole IM is supplied by a 6 pole alternator, which is driven at 1400 rpm. If the motor runs with a slip of 2%, What is its speed ?.

$f = \frac{PN_A}{120} \Rightarrow \frac{6 \times 1400}{120} = 70Hz$

$N_s = \frac{120 \times 70}{10} \Rightarrow 840$ rpm.

Now slip, $s = \frac{N_s - N_r}{N_s}$.

$N_r = (1-s) N_s$

$= (1 - 0.02) \; 840 \Rightarrow 823.2$ rpm.

Repeated

(4) A 3ϕ, 6-pole, 50 Hz IM has a slip of 0.8% at no-load and 2% at full load. Calculate i) the syn speed. ii) no load and full load speed iii) the fre of rotor current at standstill and at full load. (8).

i) $N_S = \dfrac{120f}{P} \Rightarrow \dfrac{120 \times 50}{6} \Rightarrow 1000$ rpm.

ii) $\underset{(\text{no-load})}{N_r} = N_S(1-S) = 1000(1-0.008) \Rightarrow 992$ rpm.

$\underset{(\text{full-load})}{N_r} = N_S(1-S) = 1000(1-0.02) \Rightarrow 980$ rpm.

iii) $\cancel{f'(\text{no-load}) = sf \Rightarrow (0.008 \times 50)}$

$\underset{S=1}{f' \text{ at standstill}} = sf \Rightarrow 50\,\text{Hz}$

f' at full load $= f'$
$= sf \Rightarrow 0.02 \times 50 \Rightarrow 1\,\text{Hz}$.