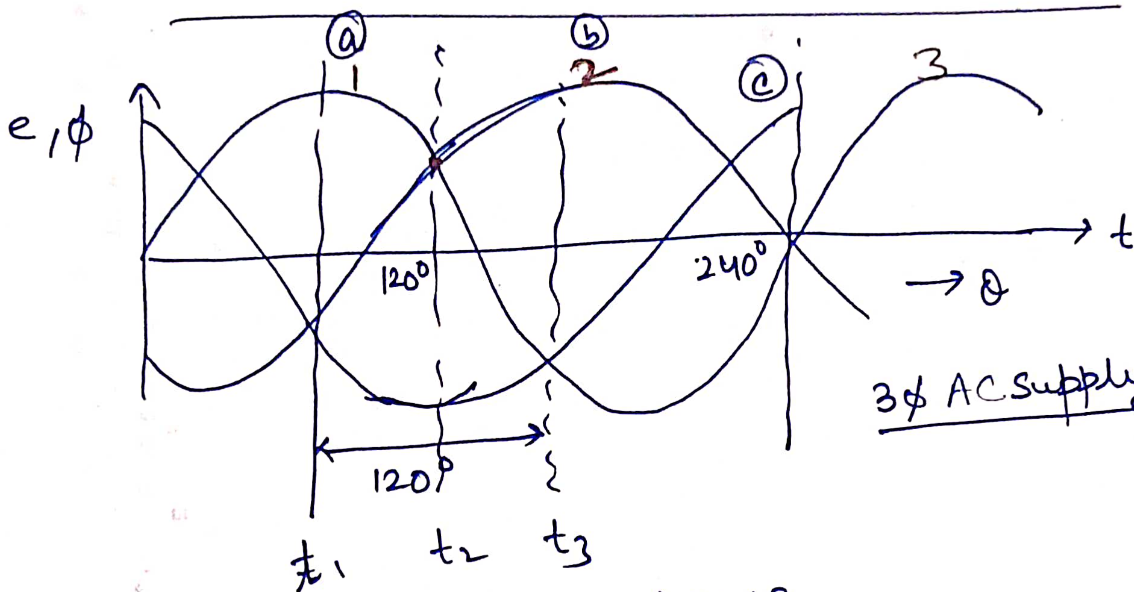
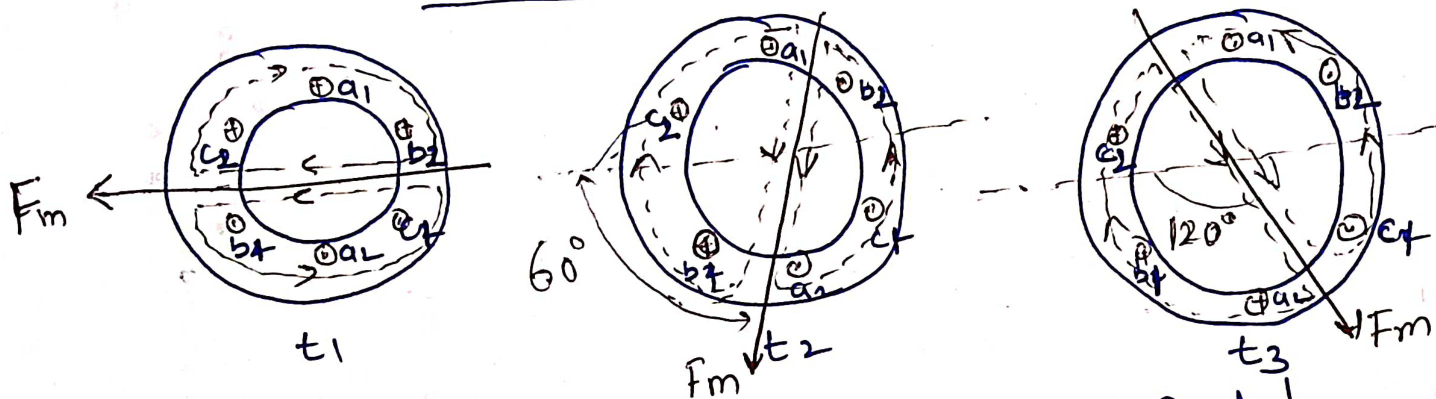
3ϕ Induction motor

assumption.
⊕ +ve direction
⊙ -ve direction

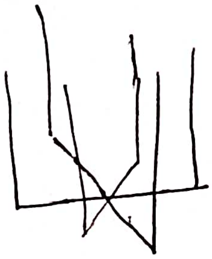


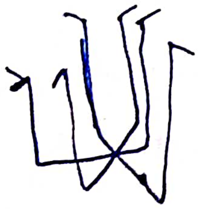
3ϕ AC Supply.

* Concept. of RMF



* Position of Resultant field at different instants.





* when a 3ϕ supply is given to a 3ϕ wound stator, a resultant field is produced which revolves at a constant speed called synchronou speed ; $N_s = 120^{\circ} f/p$

R.M.F.

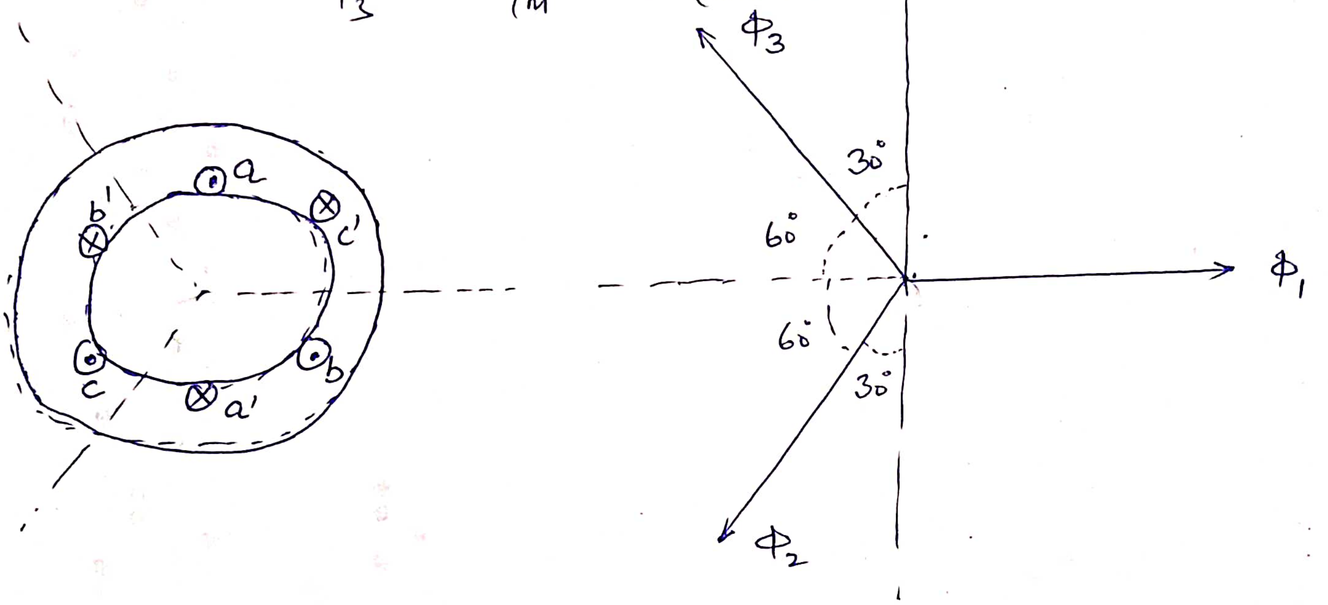
Consider three identical Coils located 120° physically apart.

Let flux generated by Coils are

$$\Phi_1 = \Phi_M \sin \omega t$$

$$\Phi_2 = \Phi_M \sin (\omega t - 120^\circ)$$

$$\Phi_3 = \Phi_M \sin (\omega t + 120^\circ)$$



The resultant flux established by this system Can be obtained by resolving the Component in their horizontal & vertical parts.

The resultant horizontal Component of flux.

$$\Phi_h = \Phi_1 - \Phi_2 \cos 60^\circ - \Phi_3 \cos 60^\circ = \Phi_1 - \frac{1}{2}(\Phi_2 + \Phi_3)$$

$$= \Phi_m \sin \omega t - \frac{1}{2}\left[\Phi_M \sin (\omega t - 120) + \Phi_M \sin (\omega t + 120^\circ)\right]$$

$$= \Phi_m \sin \omega t - \frac{\Phi_M}{2}\left[\sin \omega t \cos 120^\circ - \cancel{\cos \omega t \sin 120^\circ} + \sin \omega t \cos 120^\circ + \cancel{\cos \omega t \sin 120^\circ}\right]$$

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

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

Vertical Component:

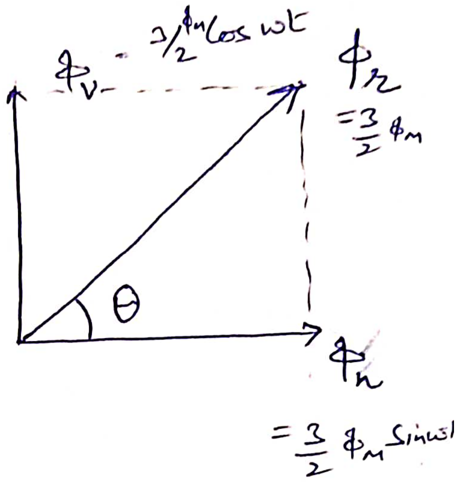
$$\Phi_V = 0 + \Phi_3 \cos 30^\circ - \Phi_2 \cos 30^\circ$$

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

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

$$= \frac{\sqrt{3}}{2}\Phi_M\, 2 \times \frac{\sqrt{3}}{2} \times \cos\omega t$$

$$= \frac{3}{2}\Phi_M \cos\omega t$$



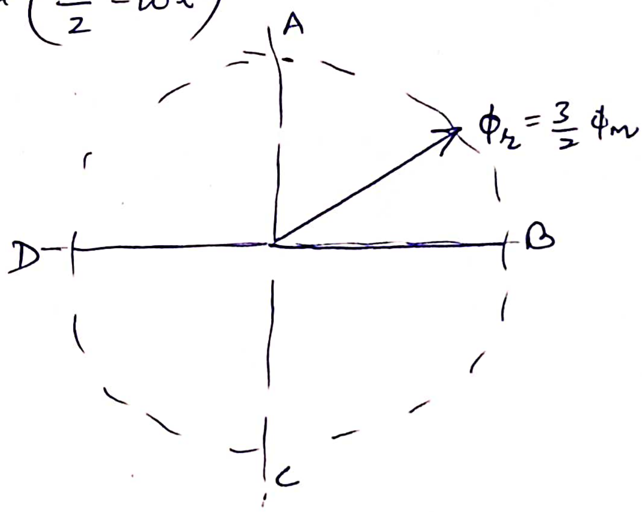
$$\Phi_R = \left(\Phi_h^2 + \Phi_V^2\right)^{1/2}$$

$$= \frac{3}{2}\Phi_m \sqrt{\sin^2 \omega t + \cos^2 \omega t}$$

$$\boxed{\Phi_R = \frac{3}{2}\Phi_M}$$ Magnitude

$$\tan\theta = \frac{\Phi_V}{\Phi_h} = \cot \omega t = \tan\left(\frac{\pi}{2} - \omega t\right)$$

$$\boxed{\theta = \frac{\pi}{2} - \omega t}$$



at $\omega t = 0^\circ$, $\theta = 90^\circ$; A

$\omega t = 90^\circ$ $\theta = 0^\circ$; B

$\omega t = 180^\circ$ $\theta = -90^\circ$; C

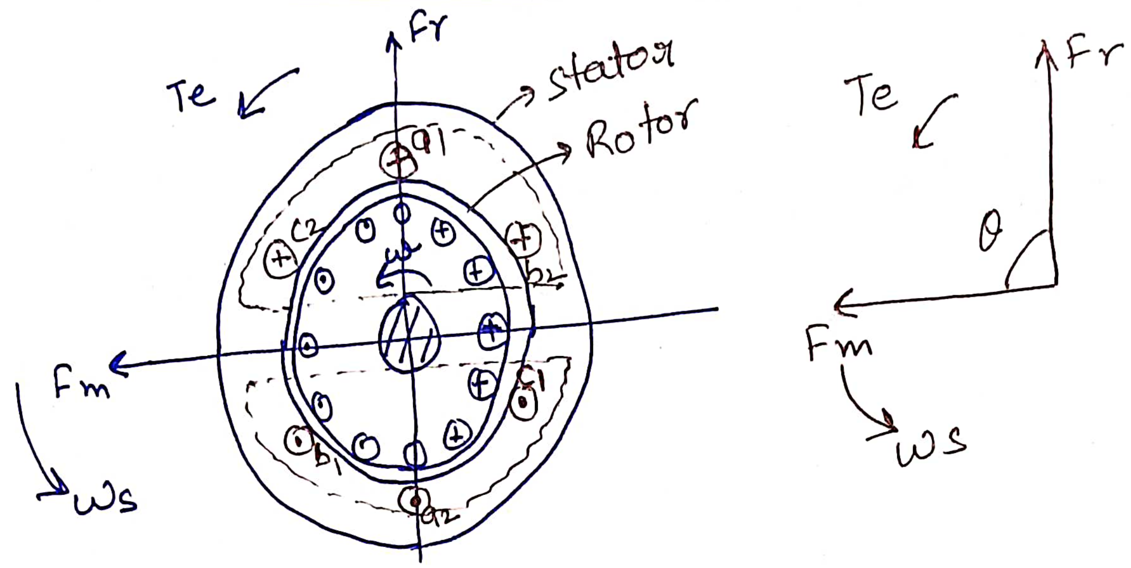
$\omega t = 270^\circ$ $\theta = -180^\circ$; D

$\omega t = 360^\circ$ $\theta = -270^\circ$

$\omega \rightarrow$ ac supply freq.

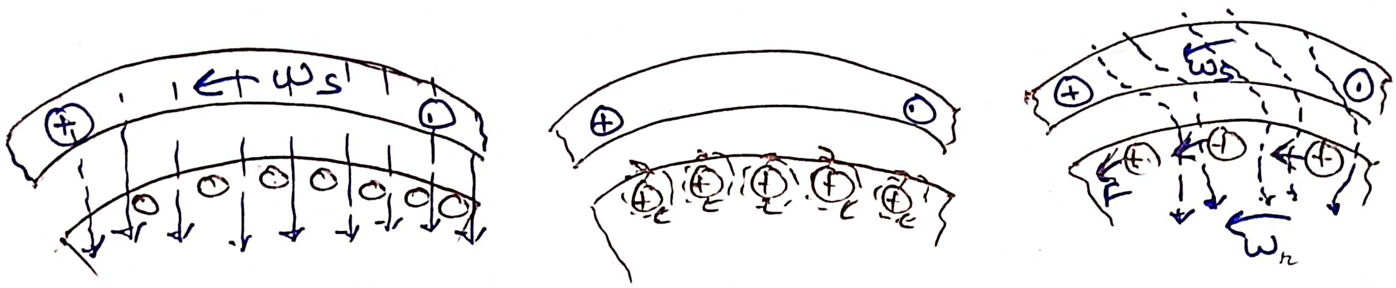
θ

3ϕ Induc^n Motor: Principle of operation:



* 3ϕ spply is given to the stator of a 3ϕ wound I.M.
→ This develops a "Revolving Field" or RMF
→ RMF = Rotating Mag. field.
→ Fm → mag. field set up. $\overleftarrow{Fm}$

Let
→ Fm rotate in anticlockwise direction at an angular speed ωs rad/s.
→ ωs = Synchronous Speed.
→ stationary rotor conductors cut the RMF and due to EMI an emf is induced in the rotor conductors.
→ As Rotor conductors are short ckted, current flows through them.
→ Rotor current carrying conductors set up a resultand field 'Fr'. This tries to come in line with the stator main field Fm.
→ Due to this, an Electromagnetic Torque 'Te' is developed in the ↺ direction.
→ ∴ Rotor starts rotating in the same direction in the 'Fm' is rotating.



slip: The difference between rotor speed & Stator magnetic field.

$$\% \text{ Slip} = \frac{N_s - N_r}{N_s} \times 100 = \underline{\qquad\qquad}$$

	P
N_s = 3000	2
= 1500	4
= 1000	6
= 750	8
= 600	10
= 500	12

⇒ slip. $N_s = \frac{120 f_s}{P}$

Rotor induced emf freq.

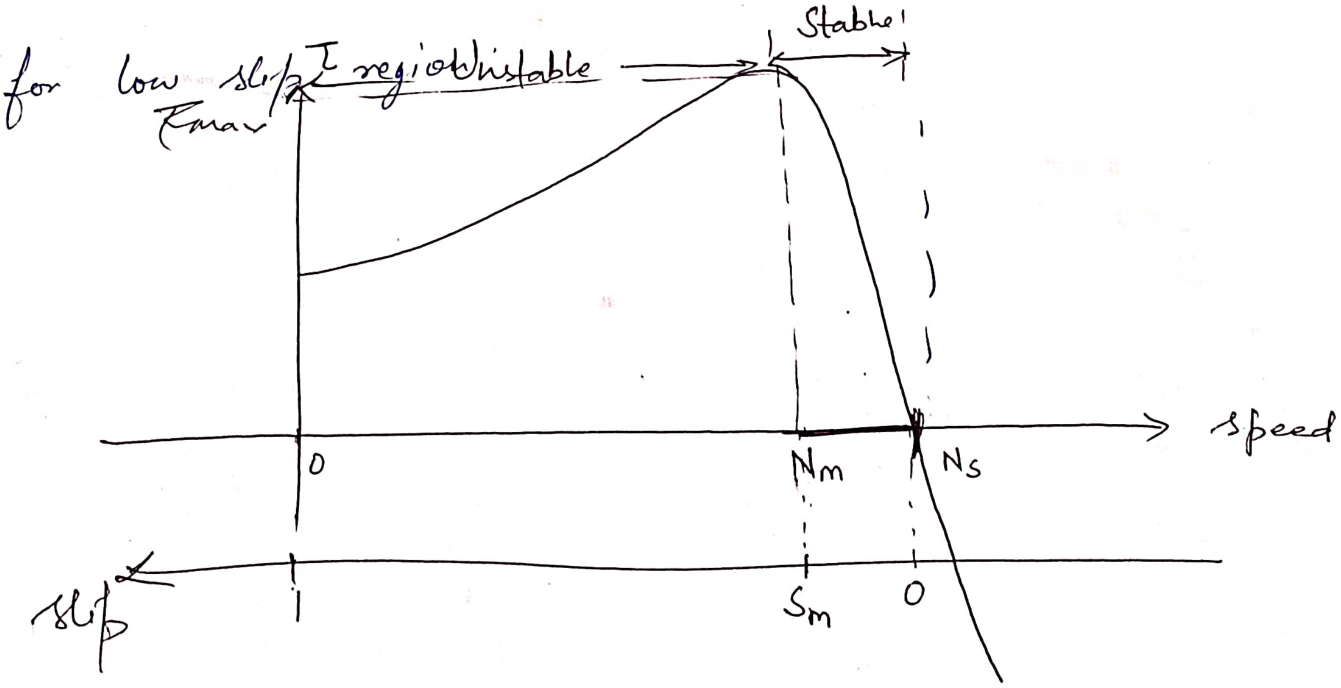
⇒ → $f_r = s f_s$ ↳ supply freq.

Rotor induced emf at any slip

⇒ $E_{2s} = s E_{20}$ ↳ at stationary.

⇒ Torque Eqn:

$$T_e = \frac{K s E_{20}^2 R_2}{R_2^2 + s^2 X_{20}^2}$$



$S = \frac{N_s - N_r}{N_s}$

$N_r = N_s(1-S)$

Slip speed $= N_s - N_r$

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

$f_r = Sf$

$S = \frac{f_r}{f}$

* E_1 = ~~Rotor emf~~ $= 4.44 \times K_{w1} \times T_1 \times f \times \phi_m$

* E_1 = Stator induced emf per phase
  K_{w1} = winding factor = coil span factor (K_c) × distribution factor (K_d)
  T_1 = No. of turns/phase of stator winding
  f = stator or supply freq.
  ϕ_m = maximum value of flux.

* E_2 = Rotor Induced emf per phase
  $E_2 = 4.44 \times K_{w2} \times T_2 \times f_r \times \phi_m$
  $f_r \to$ rotor freq.

* At standstill: $E_{2S} = 4.44 \times K_{w2} \times T_2 \times f \times \phi_m$ $\{f_r = f\}$

$$\frac{E_{2S}}{E_1} = \frac{4.44 \times K_{w2} \times T_2 \times f \times \phi_m}{4.44 \times K_{w1} \times T_1 \times f \times \phi_m} \propto \frac{T_2}{T_1} = K = \text{Transformation Ratio}$$

* Under running condition,
  $$\boxed{E_2 = 4.44 \times K_{w2} \times T_2 \times (S \times f) \times \phi_m = S \times E_{2S}}$$

* ~~Torque developed by Induction motor~~:

* Rotor Resistance and Reactance:
  Rotor Resistance → made up of Cu or Al. $R = \frac{\rho l}{A} \to R_2$

Reactance: → Total flux produced by rotor currents does not link with the stator winding.
The part of rotor flux that links with the rotor conductors but not with the stator winding is called leakage inductance L_2.

Rotor reactance $= X_2 = 2\pi f_r L_2 = 2\pi S f L_2 = S \times 2\pi f L_2$

at standstill: $S=1 \Rightarrow X_{2S} = 2\pi f L_2 \Rightarrow \boxed{X_2 = S X_{2S}}$

∴ Rotor impedance:

$$Z_2 = R_2 + jX_2 = R_2 + jSX_{2S}$$

$$Z_2 = \sqrt{R_2^2 + (SX_{2S})^2}$$

* Torque developed by an Induction motor

* Electrical power of 3ϕ Induction motor converted into mechanical power is given by:

$$P_0 = 3I_2^2 R_2 \left(\frac{1-S}{S}\right) = \omega T$$

$\omega \rightarrow$ angular speed of rotor in rad/sec.
$T \rightarrow$ Torque developed by an induction motor in Nm.

$$T = \frac{3I_2^2 R_2}{S} \times \frac{1-S}{\omega}$$

$$\because \omega = \omega_S(1-S) \Rightarrow T = \frac{3}{\omega_2} \times \frac{I_2^2 R_2}{S}$$

as $I_2 = \dfrac{SE_{2S}}{\sqrt{R_2^2 + (SX_{2S})^2}}$; ∴ $T = \dfrac{3}{\omega_2} \times \dfrac{S^2 E_{2S}^2}{R_2^2 + (SX_{2S})^2} \times \dfrac{R_2}{S}$

or

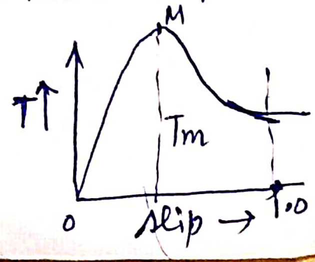
$$\boxed{T = \frac{3}{\omega_S} \cdot \frac{SE_{2S}^2 R_2}{R_2^2 + (SX_{2S})^2} = \frac{3}{\omega_S} \times \frac{E_{2S}^2 R_2/S}{(R_2/S)^2 + (X_{2S})^2}}$$

↳ Full load torque.

* Starting Torque: $S = 1$

$$T = \frac{3}{\omega_S} \frac{E_{2S}^2 R_2}{R_2^2 + X_{2S}^2}$$

* Torque slip Curve: (1) at synch. speed, $N_S \Rightarrow S = 0$ and Torque $T = 0$
(2) when rotor speed is very near to N_S (i.e. $S \simeq 0$) $\Rightarrow Z = R_2$.
$\Rightarrow T = \dfrac{3}{\omega_S} \dfrac{SE_{2S}^2 R_2}{R_2^2} = KS \propto S \Rightarrow \boxed{T \propto S} \rightarrow$ straight line.
(3) at $S = R/X_{2S} \rightarrow$ Torque is maximum. ⇒ Breakdown or Pull out Torque.
(4) at high value of $S \Rightarrow S^2X_{2S}^2 >> R_2^2 \Rightarrow R_2^2$ neglected.
$\Rightarrow T = \dfrac{3}{\omega_S} \dfrac{SE_{2S}^2 R_2}{S^2 X_{2S}^2} = K' \cdot \dfrac{1}{S}$ or $T \propto S^{-1} \rightarrow$ inverse relation.



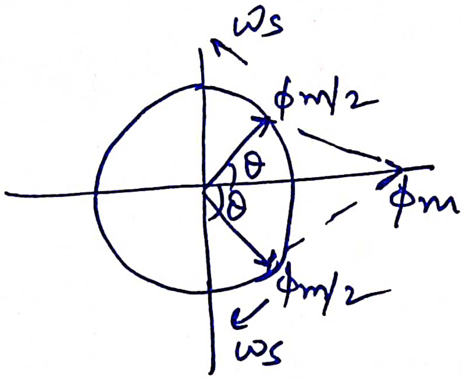
Single Phase Induction Motor

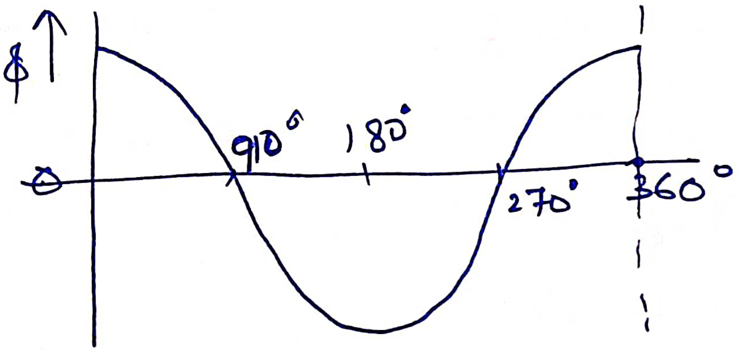
Field Produced in a 1ϕ Induction motor

Double Revolving Field Theory:

Ferraris Principle: Pulsating Field produced in a $1-\phi$ motor can be resolved into two components of half the magnitude and rotating in opposite direction at same synchronous speed.

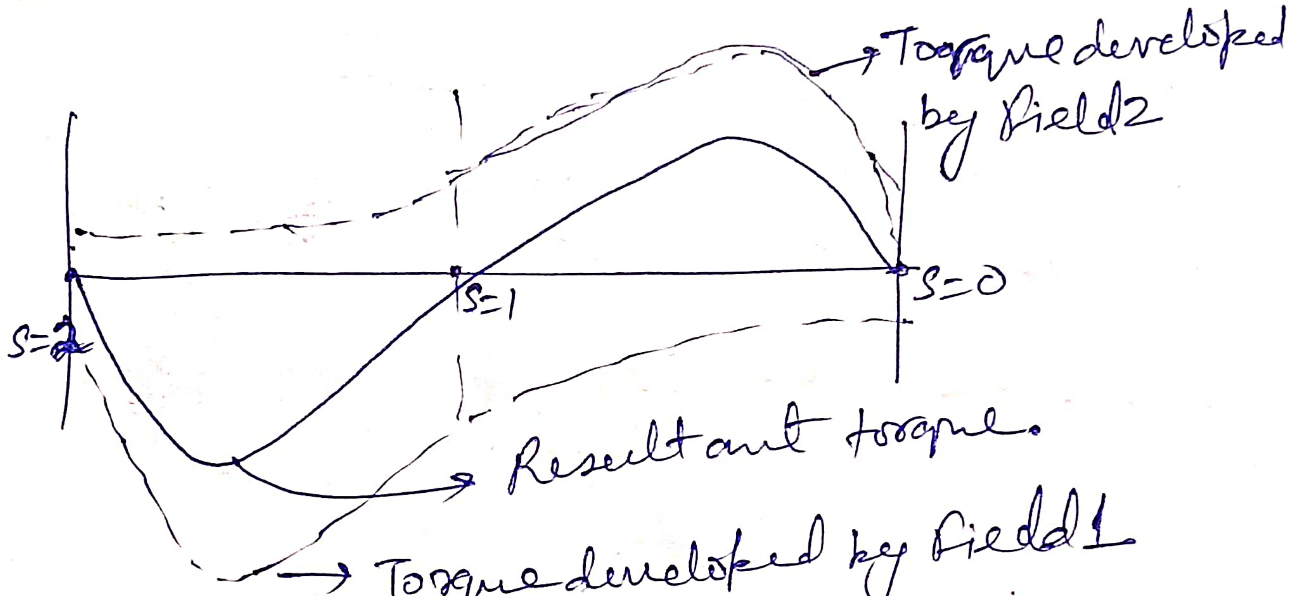
The alternating flux that passes through the air gap of $1-\phi$ Induction motor at standstill consists of combination of two fields of same strength which are revolving with same speed, one in clockwise and other in anticlockwise direction. The strength of each one of these fields will be equal to one half of the maximum field strength of the actual alternating field.





Pulsating field can be considered ~~as~~ to be composed of two fields, equal in magnitude but rotating in opposite directions with synch speed.

field 1 → clockwise torque → +ve
field 2 → anticlockwise torque. → -ve



S=1 → Standstill → Both torques are equal
⇒ Motor does not move.

* Synchronous speed in clockwise direction will give condition of zero slip for field 1 (S=2 for field 2)
* Synchronous speed in anticlockwise direction will give condition of zero slip for field 2 or S=2 for field 1.

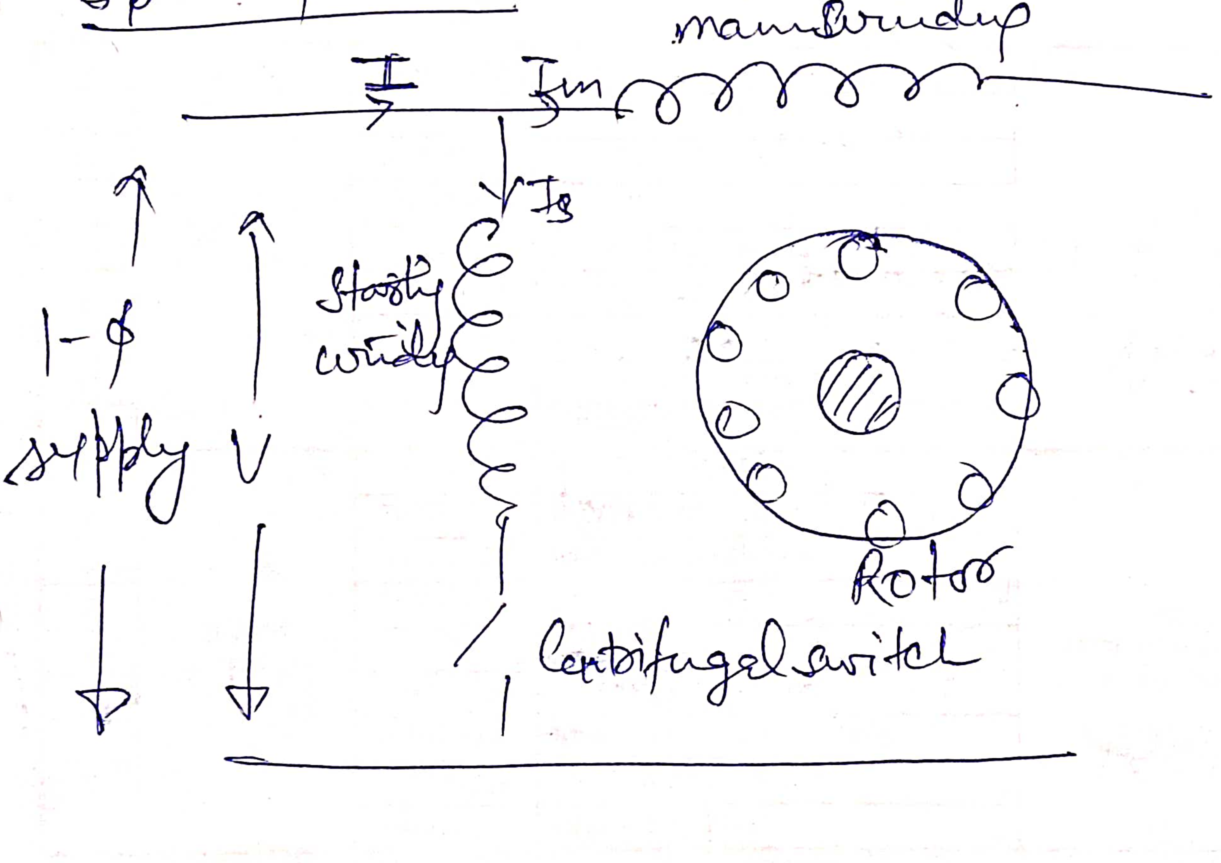
Conclusion: Single phase winding produces no starting torque, but if the rotor is rotated by some auxiliary means, it will ~~not~~ develop torque.

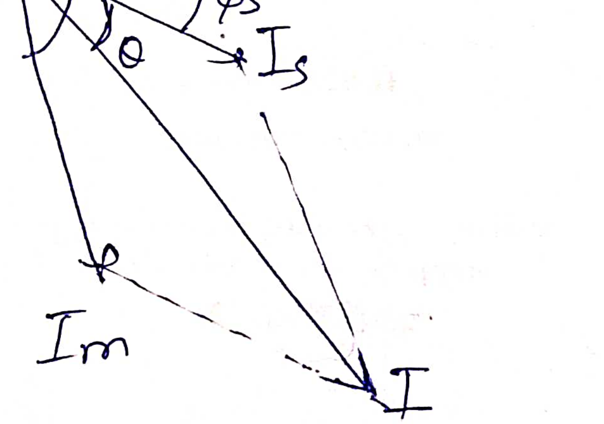
in the same direction in which it has been rotated to start

* **Types of motors:**

(1) Split phase motors
(2) Shaded pole motors
(3) AC series motors.

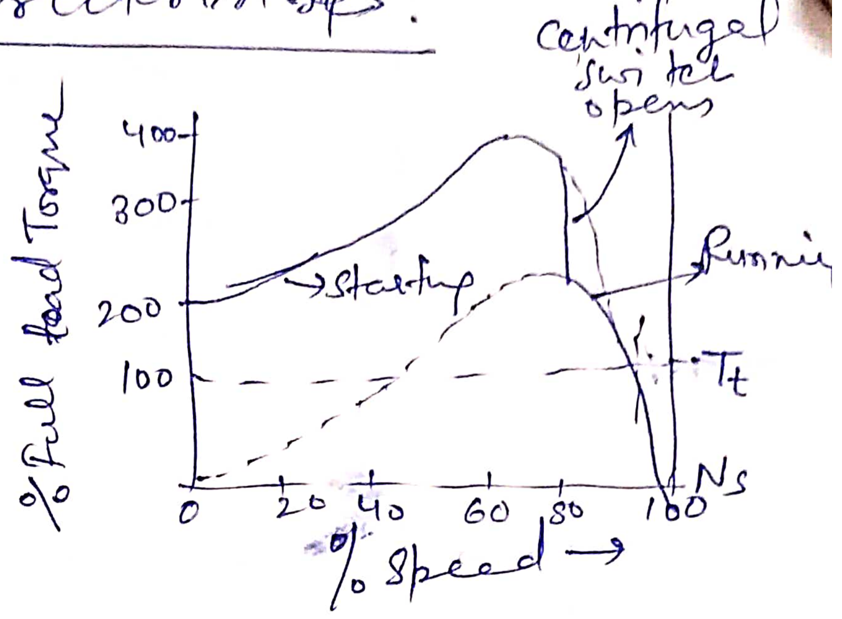
Split phase:





Performance characteristics:

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



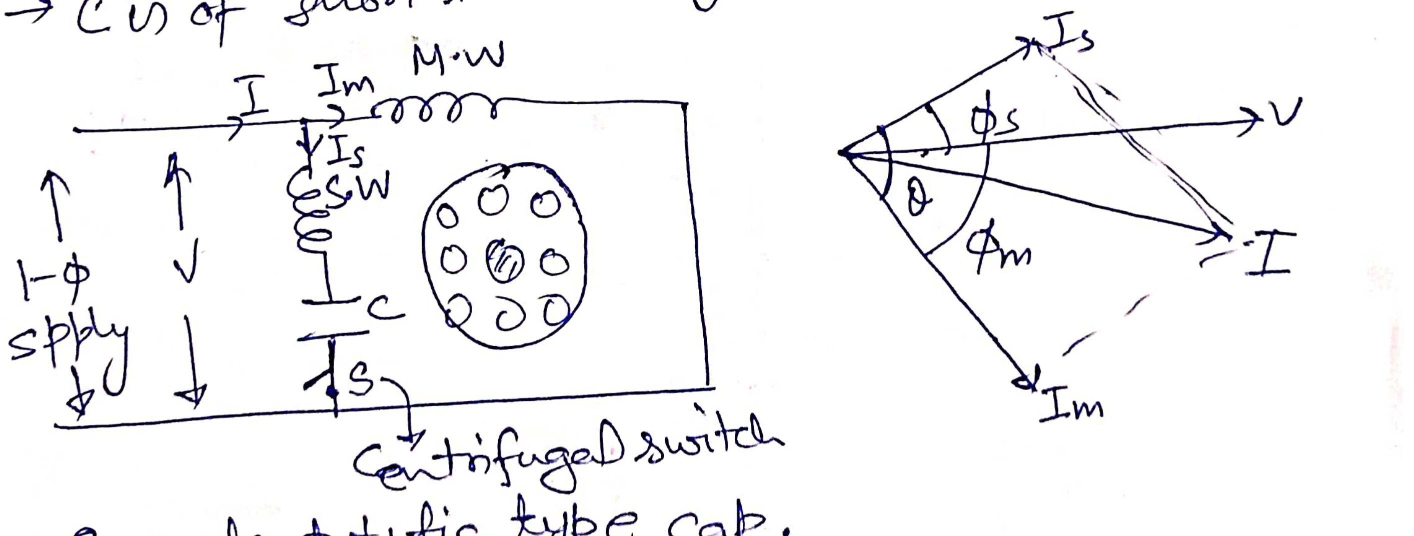
Capacitor motors:

1. Capacitor start motors
2. Capacitor run motors
3. Capacitor start and capacitor run motors

1. Capacitor start motors:

→ Cap. C is of large value such that the motor will give high starting torque.

→ C is of short time duty rating.



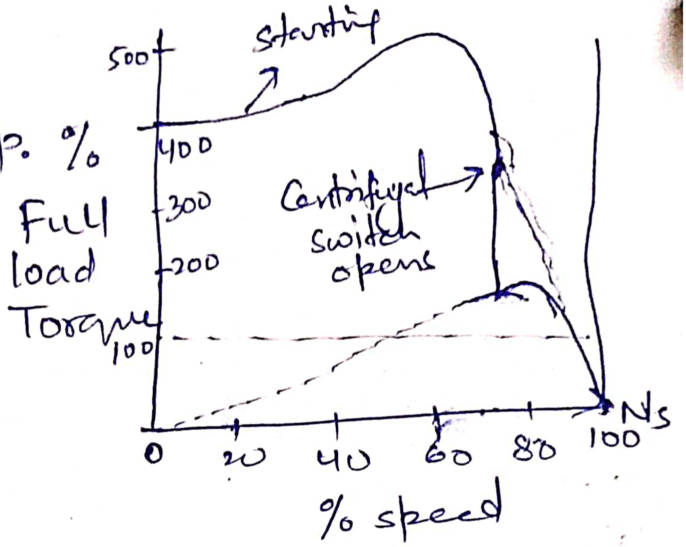
→ C → electrolytic type cap.

→ at 75 % of Ns, starting wndg. is cut off.

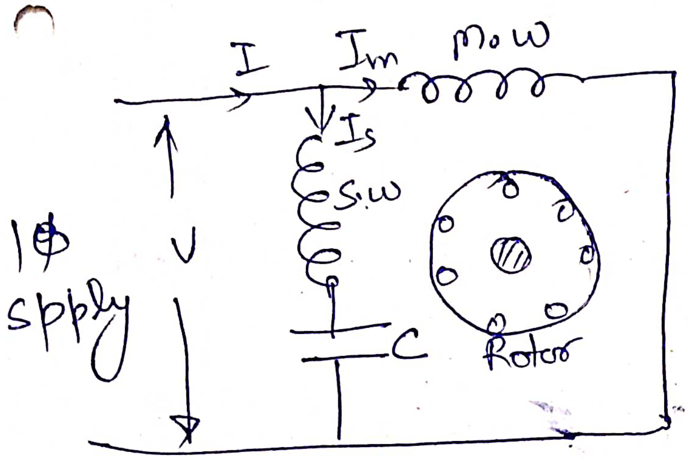
→ Used where high starting torque is required

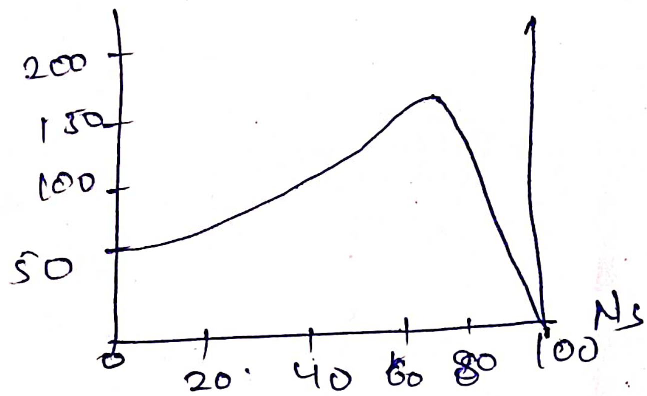
Performance tchs:

→ speed is almost 5% of slip. %
→ High starting torque (400%).
→ low starting current.



* Capacitor Run motors:





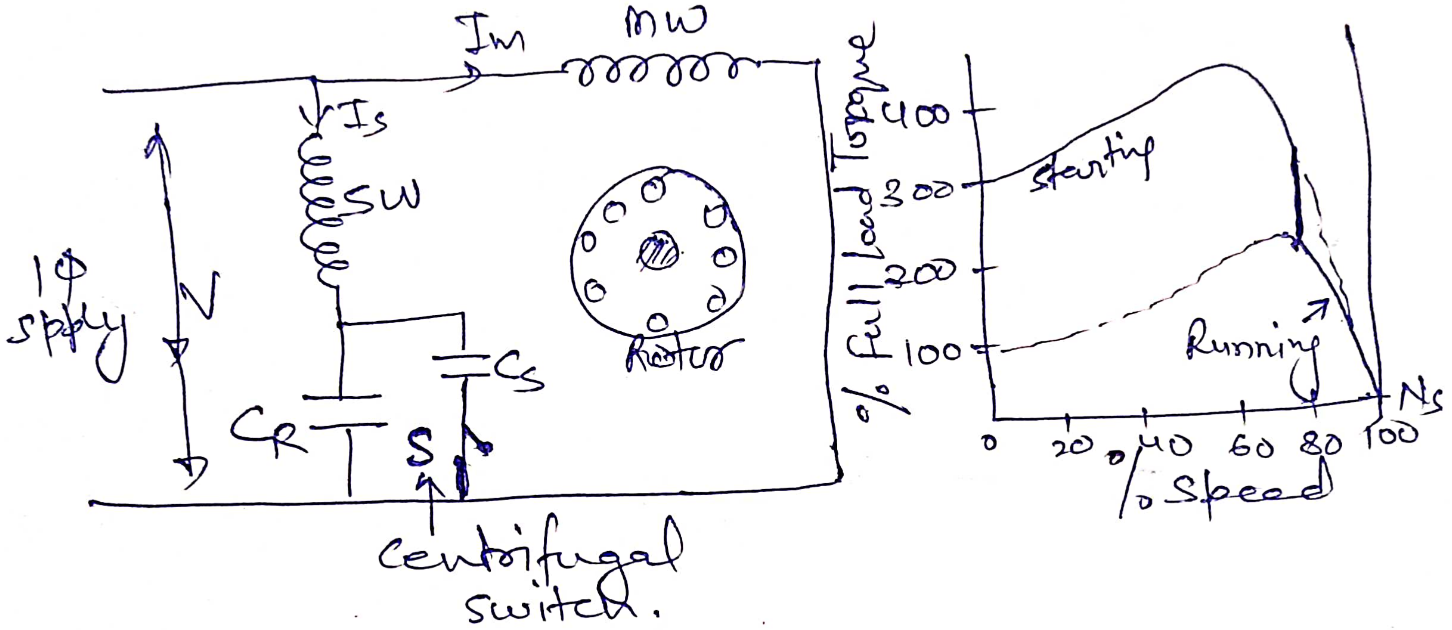
* → Cap. is permanently connected in the S.W.
→ Both M.W. & S.W. are of equal rating
→ Paper Cap. is used and electrolytic cap. not used, ∵ electrolytic cap. is for short duration rating only.

Performance tchs:

→ starting torque is lower about 50 to 100% of full-load ~~torque~~. Power factor is improved about unity.
→ Efficiency improved to about 75%
→ Cieling fans, room coolers, portable ~~tools~~ etc.

* Capacitor Start and Cap. Run motors

→ 2 capacitors used: for starting purpose (C_S) and other for running purpose (C_R)



→ C_S → Electrolytic type and is disconnected when motor attains 75% of N_S with the help of centrifugal switch.

→ C_R → Paper capacitor → remains connected during running.

→ gives best running and starting operation.

→ C_S has higher value than C_R value.

Perf. ch^s:

→ operate as 2ϕ motors
→ gives best performance and noiseless operation.
→ If starting torque is low, starting current is low and give better efficiency and higher p.f.
→ highly expensive.