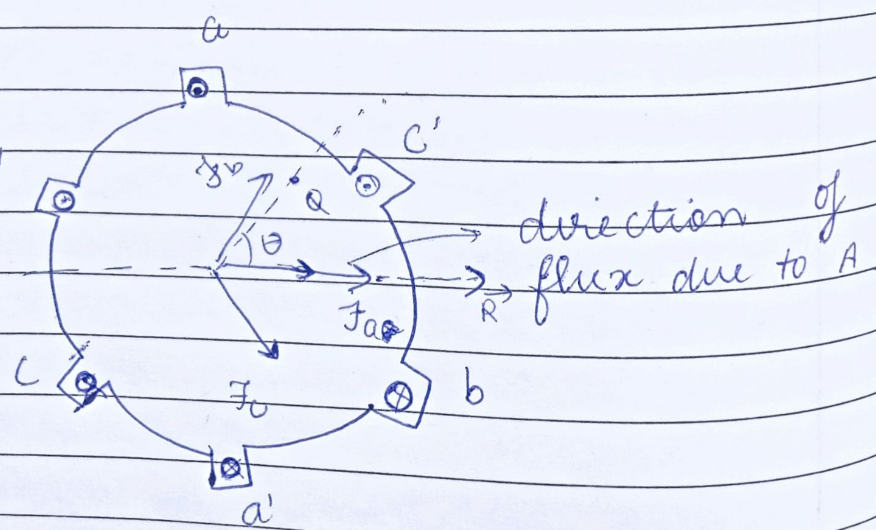
→ ~~Introduction~~ TYPES OF I/M (i) BASED ON CONSTRUCTION)

a) Squirrel cage IM
b) Wound rotor type IM

(ii) Based on no. of phases
a) 1 ϕ I/M
b) 2 ϕ I/M
c) Multiphase I/M.

ROTATING MAGNETIC FIELD



Here, for two pole machine, electrical angle is equal to mechanical angle and we start the phase B winding after 120° electrical angle to phase A.

N = no. of turns in a coil

$i_a = i_m \cos \omega t$

$i_b = i_m \cos(\omega t - 120°)$

$i_c = i_m \cos(\omega t - 240°)$

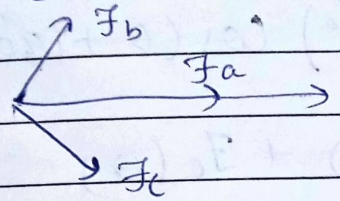
mmf corresponding to these currents.

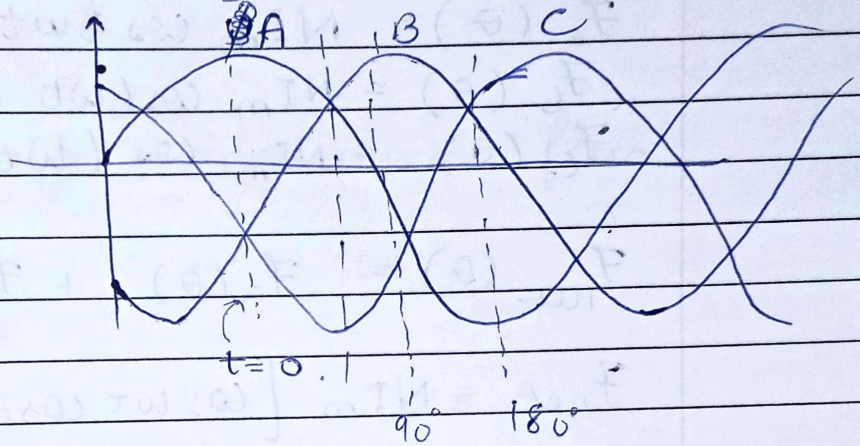
$\mathcal{F}_a = N i_m \cos \omega t$

$\mathcal{F}_b = N i_m \cos(\omega t - 120^\circ)$

$\mathcal{F}_c = N i_m \cos(\omega t + 120^\circ)$

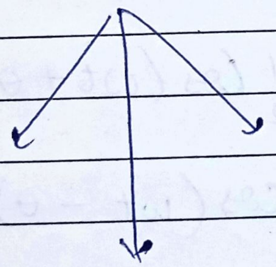
For $\omega t = 0^\circ$





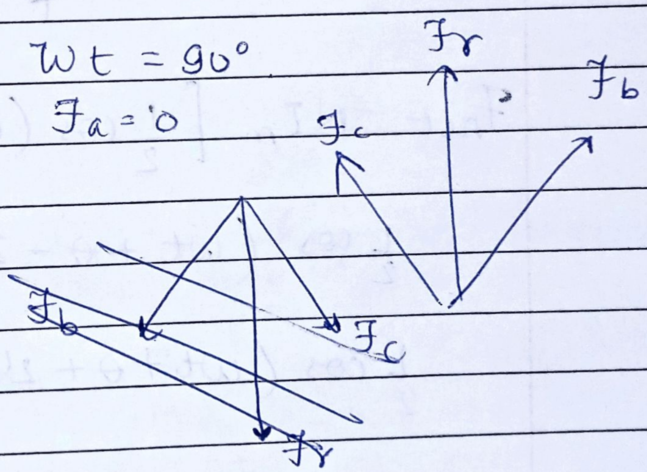
$\omega t = \cancel{90^\circ\ 29}\ 270^\circ$

$\cancel{\mathcal{F}_a = 0}$

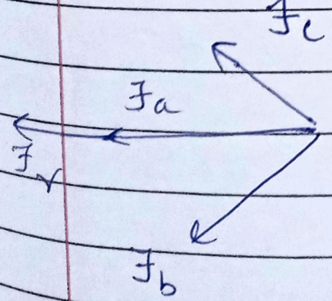


$\omega t = 90^\circ$

$\mathcal{F}_a = 0$



$\omega t = 180^\circ$



Thus the magnetic field appears to be rotating.

θ is the angle of line through Q ~~with~~ and phase A flux line.
Q is the point at which want to find ϕ_R or $\mathcal{F}_r$

$\mathcal{F}_a(\theta) = \mathcal{F}_a \cos\theta$

$\mathcal{F}_b(\theta) = \mathcal{F}_b \cos(\theta - 120^\circ)$

$\mathcal{F}_c(\theta) = \mathcal{F}_c \cos(\theta + 120^\circ)$

$\mathcal{F}_a(\theta) = NI_m \cos \omega t \cos\theta$

$\mathcal{F}_b(\theta) = NI_m \cos(\omega t - 120^\circ)\cos(\theta - 120^\circ)$

$\mathcal{F}_c(\theta) = NI_m \cos(\omega t + 120^\circ)\cos(\theta + 120^\circ)$

$\mathcal{F}_{net}(\theta) = \mathcal{F}_a(\theta) + \mathcal{F}_b(\theta) + \mathcal{F}_c(\theta)$

$\mathcal{F}_{net} = NI_m \left[\cos \omega t \cos\theta + \cos(\omega t - 120^\circ)\cos(\theta - 120^\circ) + \cos(\omega t + 120^\circ)\cos(\theta + 120^\circ)\right]$

$\mathcal{F}_{net} = NI_m \left[\frac{1}{2}\cos(\omega t - \theta) + \frac{1}{2}\cos(\omega t + \theta) + \frac{1}{2}\cos(\omega t + \theta - 240) + \frac{1}{2}\cos(\omega t - \theta) + \frac{1}{2}\cos(\omega t + \theta + 240^\circ) + \frac{1}{2}\cos(\omega t - \theta)\right]$

$\mathcal{F}_{net} = \frac{3}{2} NI_m \cos(\omega t - \theta)$

Peak will occur when $\theta = \omega t$.
θ = position in space.

The resultant $\mathcal{F}_r$ covers the same angle as covered by the moving signal

If ω_s = speed of rotating flux, then,
$\omega_s = \omega$, where, ω = electrical speed $= 2\pi f$.

$$\cancel{\mathcal{F}_{net} = \frac{3}{2}\mathcal{F}_m \cos(\omega t - \theta_m)}$$

$$\mathcal{F}_{net} = \frac{3}{2}\mathcal{F}_m \cos\left(\omega t - \frac{P\theta_m}{2}\right)$$

$$\frac{P}{2}\theta_m = \omega t$$, for maximum flux.

$$\Rightarrow \boxed{\theta_m = \frac{2}{P}\omega t}$$

$$\theta_e = \frac{P}{2}\theta_m$$

$$\omega_e = \frac{P}{2}\omega_m$$

$$2\pi f_e = \frac{P}{2} \times 2\pi f_m$$, f_m = mechanical frequency

$$\Rightarrow f_e = \frac{P}{2} f_m$$

If N_m = mechanical speed in rpm.

$$\Rightarrow f_e = \frac{P}{2}\frac{N_m}{60}$$

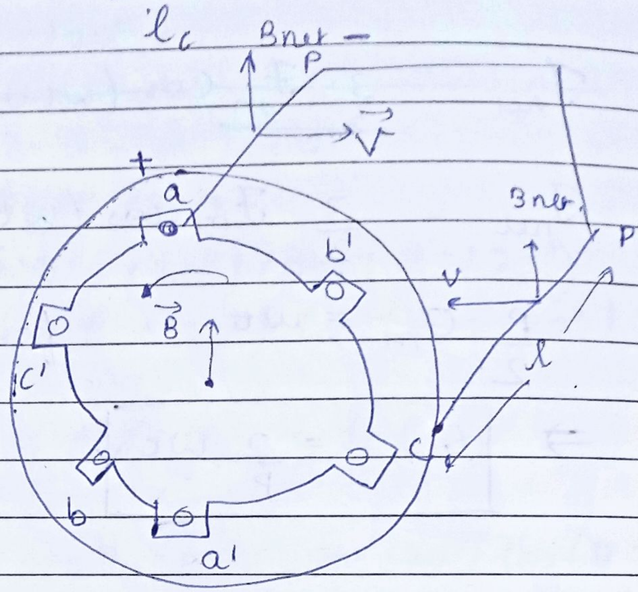
$$\Rightarrow \underset{\text{mechanical speed of rotating flux}}{N_m} = \frac{120 \overset{\rightarrow \text{ electrical frequency}}{f_e}}{P}$$

By changing the phase sequence, we can change the direction of rotation of $\vec{B}$.

Induced emf in stator ring

$H_a l_c = N i_a \Rightarrow H = \frac{Ni}{l_c}$

$\vec{B} = \mu H$



There is some relative velocity b/w flux and conductor

$\vec{B}_{net} = B_m \cos wt$

$e_{ind(ap)} = (v \times B)\, l$

$= vB_m \cos wt \cdot l$

$e_{ind(a'p')} = vB_m \cos wt\, l$

$e_{ind(aa')} = e_{ind(ap)} + e_{ind(a'p')}$

$e_{ind(aa')} = 2 l v B_m \cos wt$

$= 2 l r w_m B_m \cos wt$

$e_{ind(aa')} = (2lr) \frac{2}{P} w_e B_m \cos w$

$= A B_m \frac{2}{P} w_e \cancel{B_m} \cos w_e t$

$\Rightarrow e_{ind(aa')} = \phi_m \left(\frac{2}{P}\right) 2\pi f_e \cos w_e t$

N_{Tph} = No. of turns per phase.

$e_{ind/phase} = N_{Tph}\, \phi \left(\frac{2}{P}\right) 2\pi f_e \cos w_e t$.

For 2 poles,

$e_{ind/phase} = N_{Tph}\,\phi_m\, 2\pi f_e \cos\omega_e t$.

$\cdot\ E_{rms} = \dfrac{e_{ind/phase}}{\sqrt{2}}$

$\Rightarrow E_{rms} = 4.44\, f \phi_m N_{Tph}$

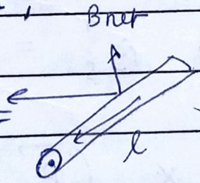
If we have more than one slot for one phase, then, we will have to adds the emf's vectorially to find emf per phase

$E_{rms} = 4.44\, f \phi_m N_{Tph} K_w$, where
K_w = winding factor, $K_w \le 1$.

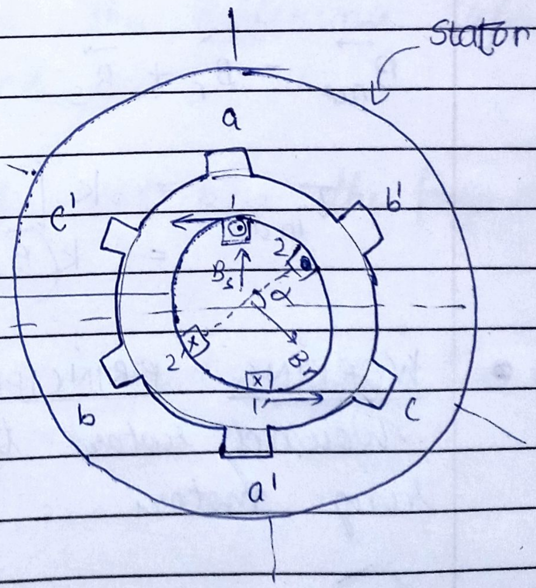
Induced Torque in Induction motor

For conductor 1,

$F = i(l \times B)$
$= ilB$



$T = 2rilB$.



rotor

F_2 = Force experienced by 2nd conductor.
$= i(l \times B^s_{net} \sin\alpha)$

$T = 2r i_r l B_s \sin\alpha$.

$T_{ind} = K(B^r_{net} \times B^s_{net})$

All 3 phases will produce $\vec{B}$ in rotor circuit as well.

B_s = peak of the rotating $\vec{B}$ produced by the stator

What will be speed of rotor flux wrt Stator, Rotor frame?

- **Working Principle of Induction motor**

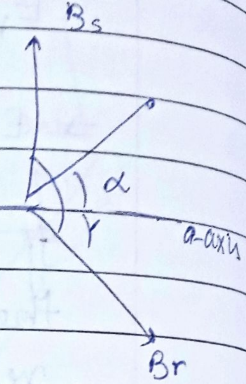
There will be $\vec{B}$ $\vec{B_r}$ which is produced b/as of the current flowing in loop 2.

If γ is the angle b/w B_s and B_r

$\Rightarrow \gamma = 90 + 90 - \alpha$

$= 180 - \alpha$

$\Rightarrow \sin\gamma = \sin\alpha.$



Magnetisation intensity $H_r = k i_r$

$\Rightarrow \vec{B_r} = k i_r \quad (\because \vec{B_r} = \mu \vec{H_r})$

$\Rightarrow T_{ind}$ (coil 2) $= k B_r B_s \sin\alpha$

$= k B_r B_s \sin\gamma$

$= k(\vec{B_r} \times \vec{B_s})$

$\vec{B_{net}} = \vec{B_r} + \vec{B_s} \quad \Rightarrow \vec{B_s} = \vec{B_{net}} - \vec{B_r}$

$T_{ind} = k[\vec{Br} \times (\vec{B_{net}} - \vec{B_r})]$

$= k(\vec{B_r} \times \vec{B_{net}})$

- **WORKING PRINCIPLE OF 3-PHASE INDUCTION MOTOR**

Wound rotor type are also known as slip ring motors.

Squirrel cage rotor has copper bars, both ends of which are shorted.

The rotor is excited with a three-phase supply. This will produce a rotating $\vec{B}$ which interacts with the stator coils and the rotor conductors

$\Rightarrow$ emf will be induced.

Current will start flowing, since they are shorted

⇒ Torque will be produced and rotation starts.

The cause of enduced emf is the relative velocity b/w the rotating $\vec{B}$ and the rotor conductor. Rotor will try to reach the speed of rotating $\vec{B}$. Once the rotor reaches to the speed of rotating $\vec{B}$

⇒ no relative velocity

⇒ ~~Ao~~ $\vec{E}_{ind} = 0 \Rightarrow i = 0 \Rightarrow \tau = 0$

⇒ Rotor decelerates

⇒ Again, there is a relative velocity and the motor will accelerate.

~~The~~ We perceive this as a chang in speed of the rotor during motion. This difference of speed is called slip speed.

Slip speed → Difference of speed b/w the flux and the rotor

$S = N_s - N_r$

N_s = Synchronous speed = speed of flux (in Rpm)

N_r = Rotor speed. (Rpm)

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

Induction motors are also known as asynchronous machines ~~b/as~~ b/as the motor never acquires the synchronous speed.

$N_r = N_s$ i.e. $S = 0$ is a hypothetical case

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$f_r = f_s$ (when $N_r = 0$ or $s = 1$)

~~f_s~~ $f_r = 0$ (when $N_r = N_s$) ~~→ no~~

$$\boxed{f_r = sf_s}$$

e.g. 3 phase IM with 4 pole and slip at rated load condition is 3%. The ~~ff~~ supply frequency of the motor is 50 hz.

a) Find the rated speed of the motor.

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}.$$

$$S = 3\% \Rightarrow 0.03 = \frac{N_s - N_r}{N_s}$$

$$\Rightarrow 0.03 \times 1500 = N_s - N_r$$

$$\Rightarrow N_r = 1500 - 45$$

$$= 1455 \text{ Rmp.}$$

Stator flux speed = 1500 rpm.

Rotor flux speed at rated condition = ?

N_s^r = Speed of rotor flux w.r.t rotor frame in rpm

$$N_s^r = \frac{120 f_r}{P}$$

Speed of rotor flux w.r.t stator frame

$$= N_r + N_s^r$$

$$= (1-s\cancel{N_s})N_s + \frac{120\, sf_s}{P} = s\cancel{N}_s$$

$$= (1-s)N_s + sN_s = N_s$$

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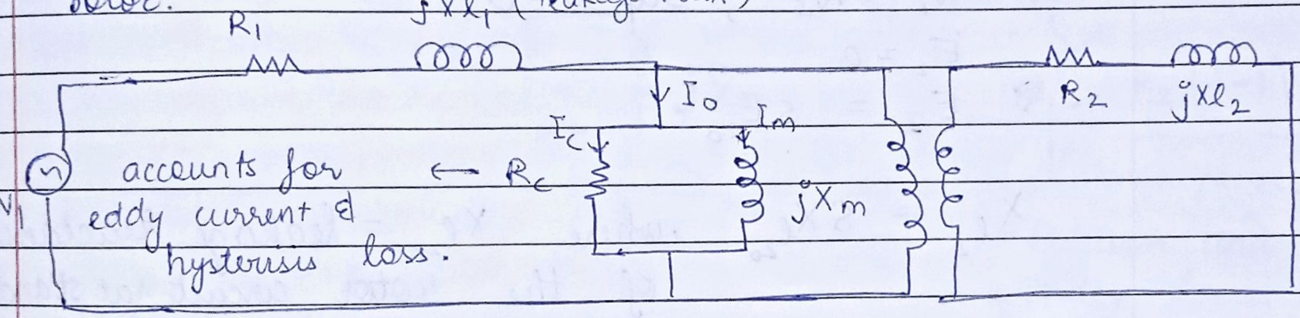
→ rotor flux speed w.r.t stator frame = stator flux speed wrt stator frame.

→ Rotor flux and stator flux both rotate with the ~~sa~~ synchronous speed w.r.t. stator frame

PER PHASE EQUIVALENT CIRCUIT DIAGRAM.

Stator ~~wr~~ circuit ≡ primary circuit.

↳ Has a leakage flux which does not link with rotor.



V_1 = per phase applied stator voltage

R_1 and R_2 = per phase winding resistance of stator and rotor respectively.

jXl_1 and jXl_2 = Per phase leakage reactance of the stator and rotor circuits respectively.

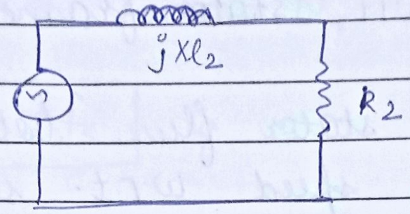
R_c → Core losses (Eddy current + hysteresis losses)

jX_m → Magnetization reactance.

I_0 → No load current → 10 % - 20 % of rated current.

I_m → 5% - 10 % of rated current (greater than that of transformer b/as of air gap)

ROTOR CIRCUIT EQUIVALENT



at $N_r = 0$, slip $s = 1$

$E_2 = E_{20}$ (induced emf at standstill condition)

At $N_r = N_s$, slip $s = 0$,

$E_2 = 0$.

$\therefore E_2 = s E_{20}$

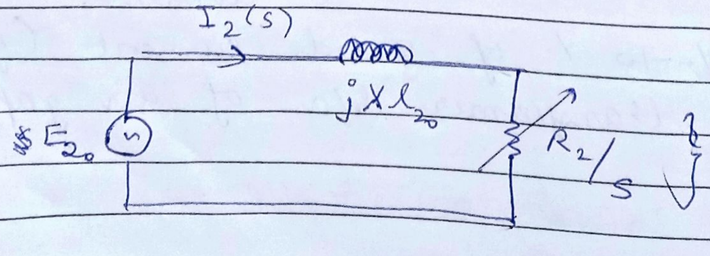
$X_{l_2} = s X_{l_{20}}$, where $X_{l_{20}}$ = leakage reactance of the rotor circuit at standstill condition.

$$I_2 = \frac{E_2}{R_2 + jX_{l_2}}$$

$$I_2(s) = \frac{s E_{20}}{R_2 + j s X_{l_{20}}}$$

Rotor current at any slip s

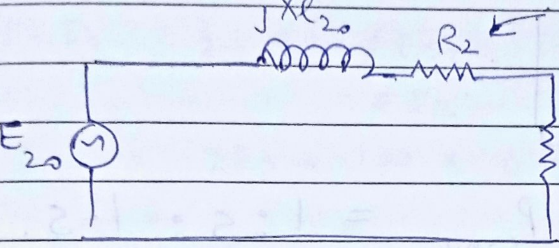
$$I_2(s) = \frac{E_{20}}{\frac{R_2}{s} + jX_{l_{20}}}$$



$\rightarrow$ accounts for P_{Ag}

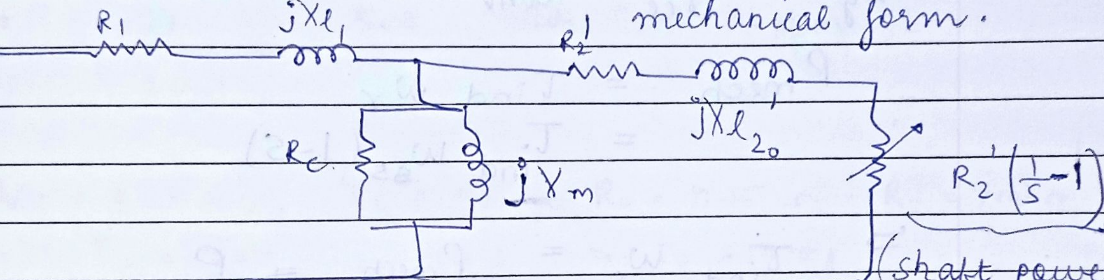
$$\frac{R_2}{s} = R_2 - R_2 + \frac{R_2}{s}$$

$$= R_2 + R_2\left(\frac{1}{s} - 1\right)$$



Rotor Cu loss

$R_2\left(\frac{1}{s}-1\right)$ = electrical power converted to mechanical form.

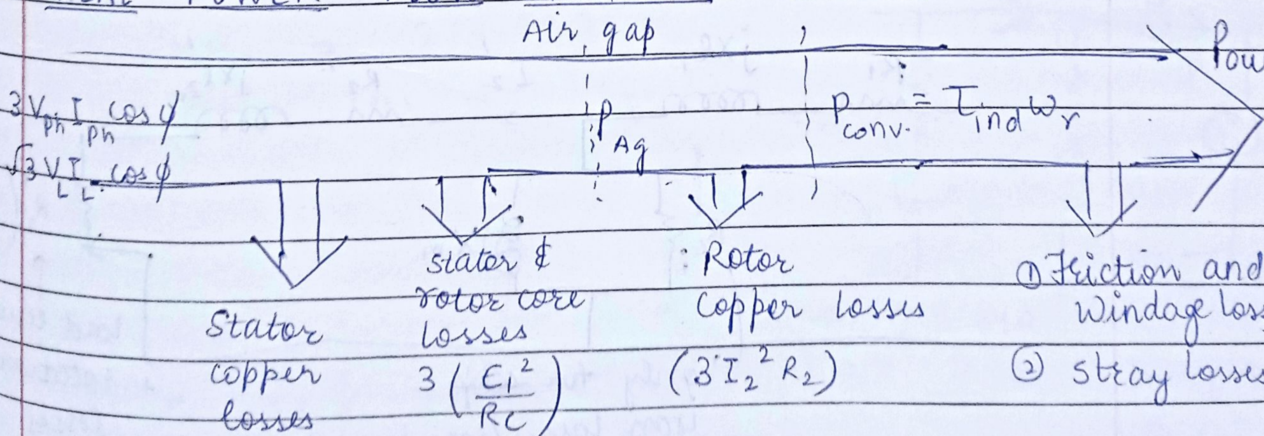


(shaft power + friction and windage losses.)

$$R_2' = a^2 R_2$$

$$jXl_{20}' = a^2 \, jXl_{20}$$

- REAL POWER FLOW DIAGRAM OF IM



$$P_{Ag} = 3I_2^2 \frac{R_2}{s}$$

P_{rcl} (rotor Cu loss) $= 3I_2^2 R_2$

$$\boxed{\frac{P_{ag}}{P_{rcl}} = \frac{1}{s}}$$

$$P_{\substack{conv.\\(mech)}} = 3 I_2^2 R_2 \left(\frac{1}{s} - 1\right)$$

$$= P_{rcl}\left(\frac{1}{s} - 1\right)$$

$$\Rightarrow \boxed{\frac{P_{conv}}{P_{rcl}} = \frac{1}{s} - 1}$$

$$P_{Ag} : P_{rcl} : P_{conv} = 1 : s : 1-s.$$

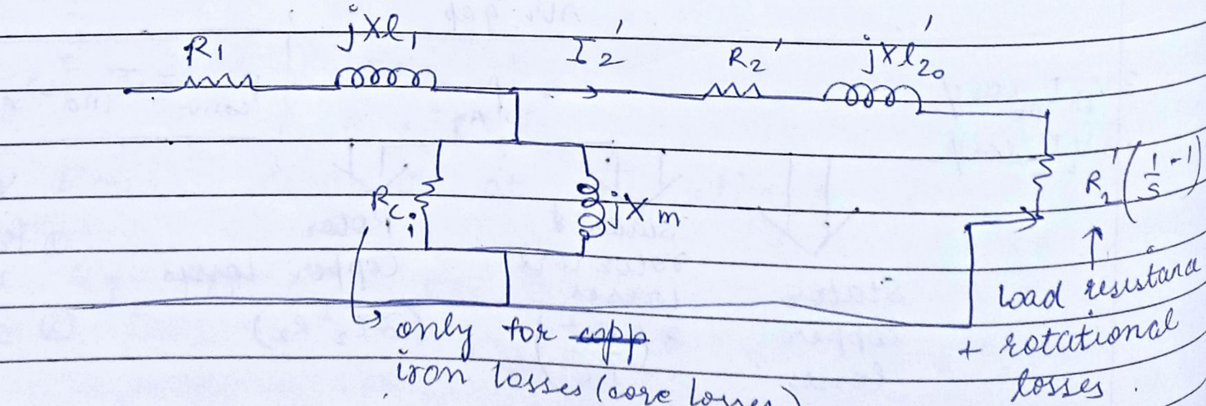
$$P_{mech} = T_{ind}\, \omega_r$$

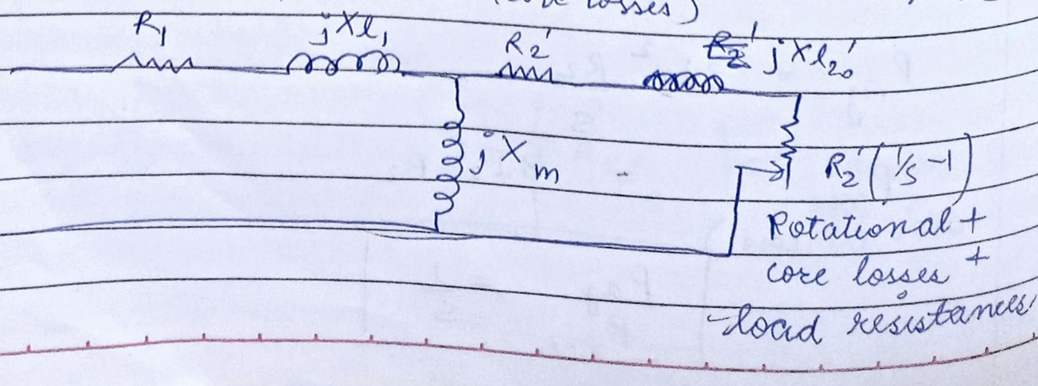
$$= T_{ind}\, \omega_s (1-s)$$

$$\Rightarrow T_{ind}\, \omega_s = \frac{P_{mech}}{1-s} = P_{Ag}$$

$$\Rightarrow P_{Ag} = T_{ind}\, \omega_s$$

Equivalent circuit diagram of IM referred to stator side

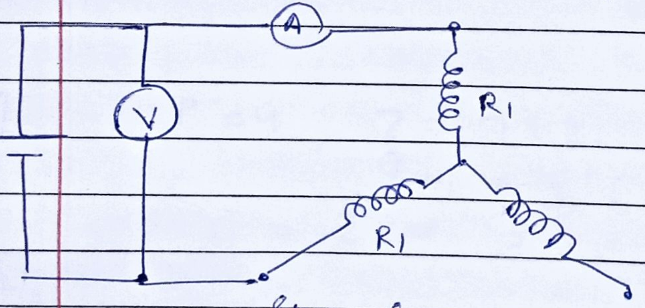




1) NO load test / Free run test
↳ To find shunt branch parameters

2) Block rotor test (similar to SC test of T/F)
↳ To find series branch parameters

DC resistance test to find the resistance of the stator winding (R_1)



Star Connected
Stator

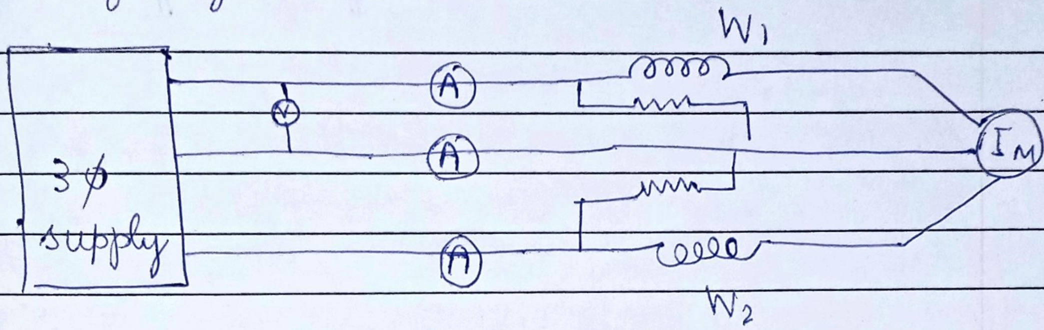
$$\frac{V_{dc}}{I_{dc}} = \cancel{2R_1(d} \; 2R_{1_{dc}}$$

$$R_{1_{dc}} = \frac{1}{2}\left(\frac{V_{dc}}{I_{dc}}\right)$$

$$R_{ac} = 1.5 R_{dc}$$

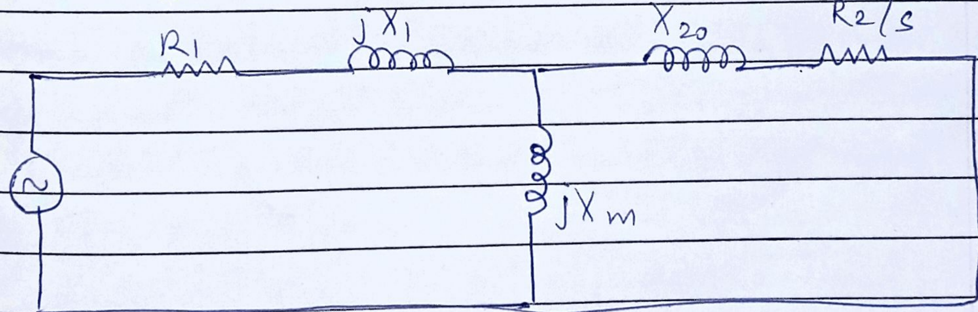
No load test

→ A rated voltage with no load connected at the shaft of the motor



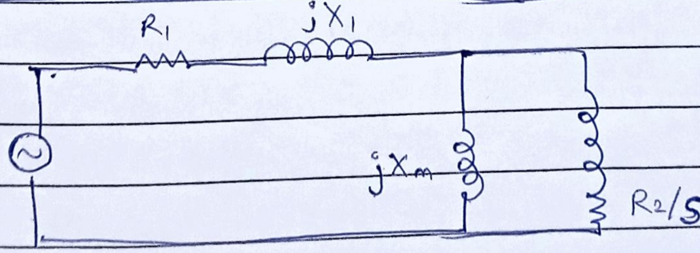
$$W_1 + W_2 = P_{nl}$$

$$I_l = \frac{I_a + I_b + I_c}{3}$$



$V_1 = \frac{V_L}{\sqrt{3}}$ (for star connection)

≈



$$P_{in} - 3I_L^2 R_1 = P_{core} + P_{F\&W} + P_{stray}$$

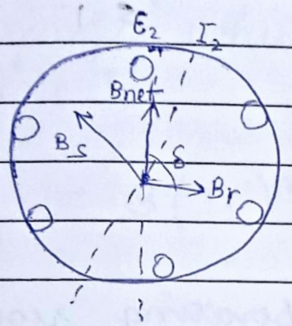
Block rotor test

→ At low voltage and rated current. ~~At~~

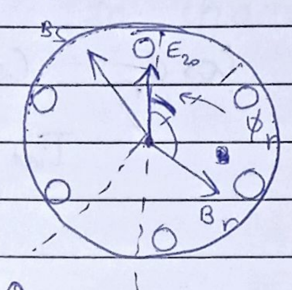
→ ~~reduced~~ At reduced frequency.

Torque Speed charateristic of IM

During no load condition



During loaded conditon



$\delta \uparrow$

$\delta' = 90 + \phi_r$

$T_{ind} - T_L = J\frac{d\omega_r}{dt}$

↓ inertia of machine

At no load condition, T_L will only account for friction, windage and stray losses

As $T_L \uparrow$, $\omega_r \downarrow \Rightarrow S \uparrow \Rightarrow$ induced emf increase

$\Rightarrow I_2 \uparrow, X_2 \uparrow$

During no load condition, the current will behave more like a resistive circuit as slip is very small. Hence, reactance is small.

$T_{ind} = K B_r \times B_{net}$

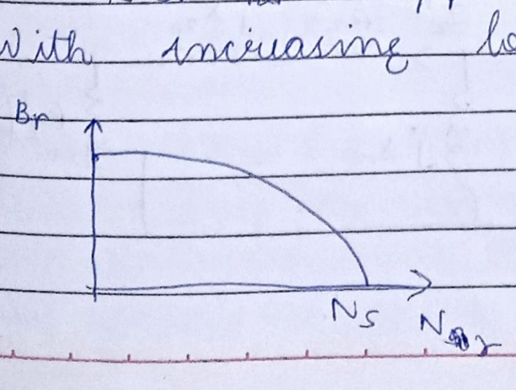
$= K B_r B_{net} \sin\delta$.

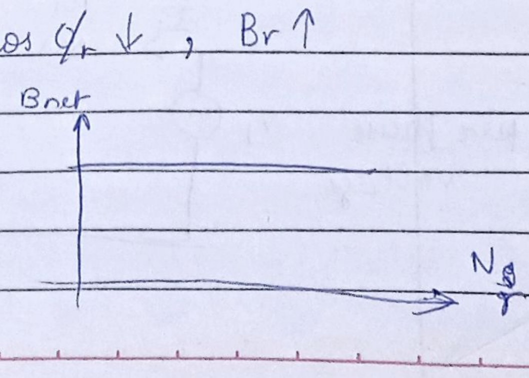
In ~~no~~ loaded case

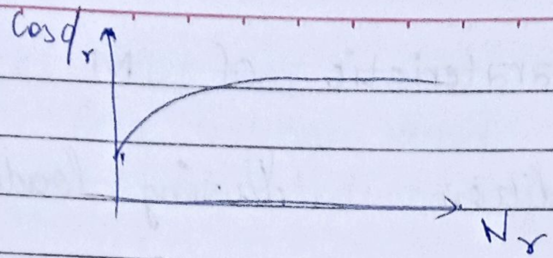
$T_{ind} = K B_r B_{net} \sin\delta'$

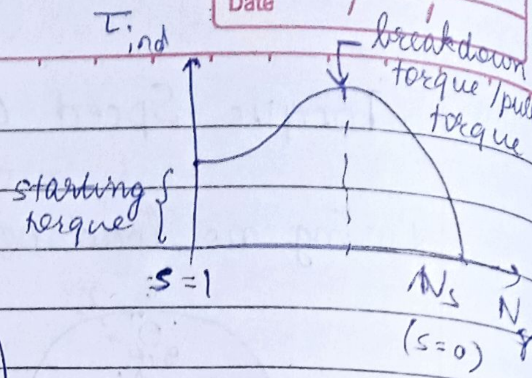
$= K B_r B_{net} \cos\phi_r$

With increasing load $\cos\phi_r \downarrow$, $B_r \uparrow$

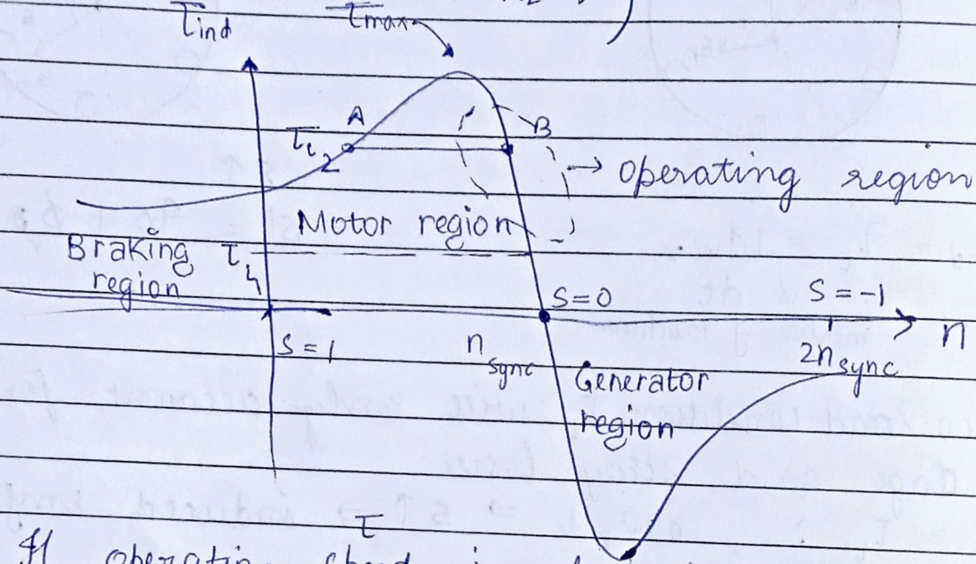








$$\cos\phi_r = \cos\left(\tan^{-1}\left(\frac{sX_{20}}{R_2}\right)\right)$$



If operating ~~speed~~ T is changed from T_{L_1} to T_{L_2}, then motor will acquired the speed corresponding to B.

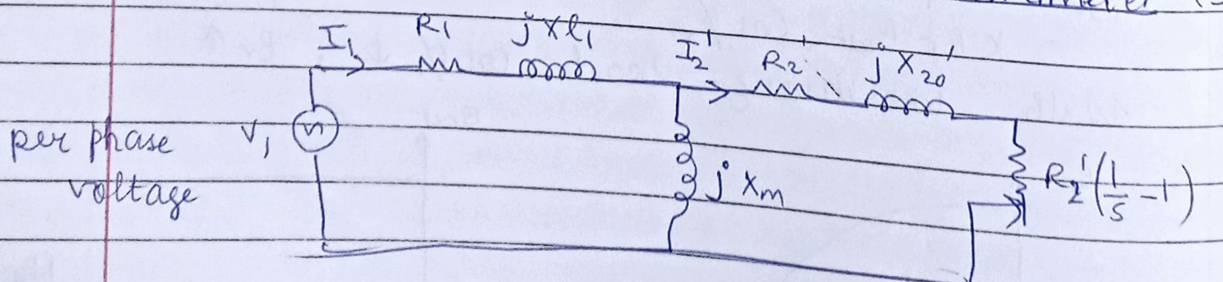
In case of A, as T_L incresses, ω increases

In B, as $T_L \uparrow$, $\omega \downarrow$

satisfies $T_{ind} - T_L = J\frac{d\omega}{dt}$ b/as ω should decrease ~~are~~ as $T_L \uparrow$

Thus, B is the stable point.

Torque Expression From machine Parameter (SSF)



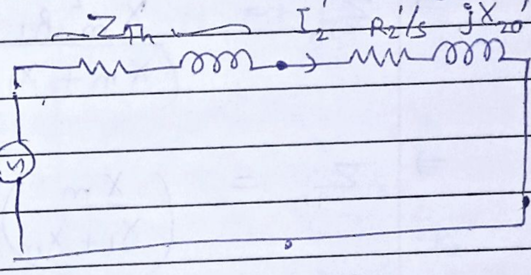
I_2' is changing $\Rightarrow$ I_1 will also change.

* With change in load torque, I_2' current is changing which eactially leads to chang in current I_1

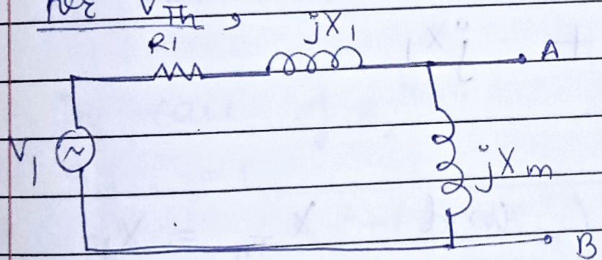
$$P_{Ag} = 3(I_2')^2 \frac{R_2'}{S} = \tau_{ind}\, \omega_s$$

$$\Rightarrow \tau_{ind} = \frac{3(I_2')^2 R_2'}{S W_s} \quad \text{---} \ (1)$$

We will draw the thevenin's equivalent of the circuit.

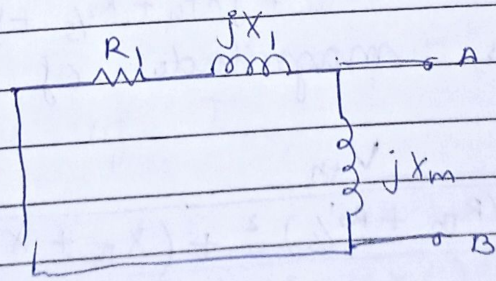


For V_{Th},



$$V_{Th} = V_{AB} = \frac{jX_m}{R_1 + jX_1} V_1$$

For Z_{Th},



$$\frac{1}{Z_{Th}} = \frac{1}{jX_m} + \frac{1}{R_1 + jX_1}$$

$$\Rightarrow Z_{Th} = \frac{jX_m (R_1 + jX_1)}{R_1 + j(X_1 + X_m)}$$

$$I_2' = \frac{V_{Th}}{Z_{Th} + \frac{R_2'}{s} + jX_{20}'}$$

Generally, $X_1 << X_m$ and $R_1 << (X_m + X_1)$

$$\Rightarrow Z_{Th} = \frac{jX_m(R_1 + jX_1)}{R_1 + j(X_1 + X_m)} \times \frac{R_1 - j(X_1 + X_m)}{R_1 - j(X_1 + X_m)}$$

$$Z_{Th} = \frac{j\, X_m(X_1 + X_m)(R_1 + jX_1) + jR_1X_m(R_1 + jX_1)}{R_1^2 + (X_1 + X_m)^2}$$

$$\Rightarrow Z_{Th} = \frac{\cancel{X_mX_1R_1} + jX_mX_1^2 + X_m^2R_1 + jX_m^2X_1 + jR_1^2X_m - \cancel{X_mX_1}}{(X_1 + X_m)^2}$$

$$\Rightarrow Z_{Th} = \frac{X_m^2 R_1}{(X_m + X_1)^2} + \frac{j\, X_1X_m(X_1 + X_m)}{(X_1 + X_m)^2}$$

$$\Rightarrow Z_{Th} = \left(\frac{X_m}{X_1 + X_m}\right)^2 R_1 + jX_1$$

Thus,

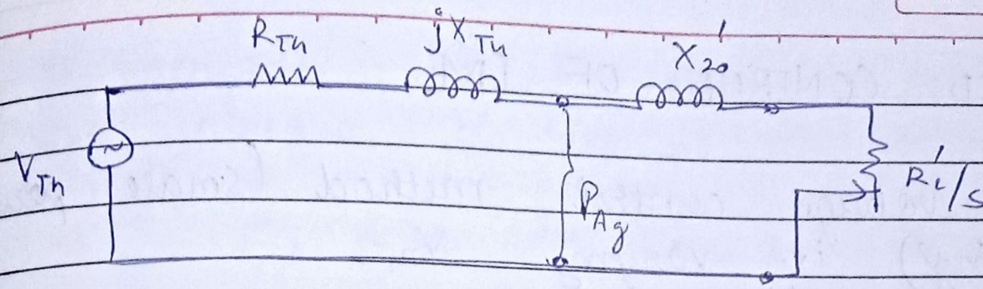
$$R_{Th} = \left(\frac{X_m}{X_1 + X_m}\right)^2 R_1 \text{ and } X_{Th} = X_1$$

$$\Rightarrow I_2' = \frac{V_{Th}}{R_{Th} + jX_{Th} + R_2'/s + jX_{20}'}$$

Thus, magnitude of I_2 will be

$$\frac{V_{th}}{\sqrt{(R_{Th} + R_2'/s)^2 + (X_{Th} + X_{20}')^2}}$$

$$\tau_{ind} \approx \frac{3V_{th}^2\, R_2/s}{\omega_s\left[(R_{Th} + R_2'/s)^2 + (X_{Th} + X_{20}')^2\right]} \quad \leftarrow (1)$$



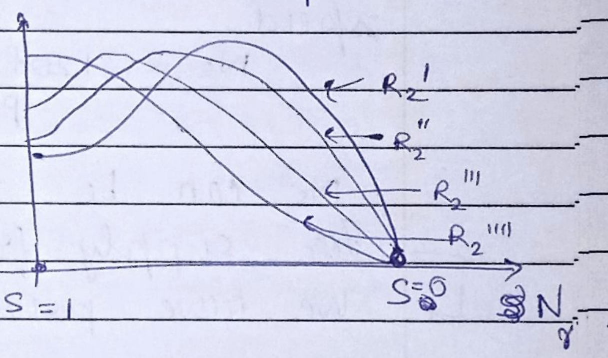
Maximum power will be delivered when

condition for T_{max} $\Leftarrow$ $\left|\dfrac{R_2'}{S}\right| = \left|R_{Th} + jX_{Th} + jX_{20}'\right|$

$\Rightarrow$ S_{max} (corresponding to T_{max}) $= \dfrac{R_2'}{\sqrt{R_{Th}^2 + (X_{Th} + X_{20}')^2}}$

If ~~slip~~ torque > ~~S_{max}~~ T_{max}, then, motor will stop.

$R_2'''' > R_2''' > R_2'' > R_2'$



In case of R_2'''',
$S_{max} = 1$

$\Rightarrow R_2' = \sqrt{R_{Th}^2 + (X_{Th} + X_{20}')^2}$

$\hookrightarrow$ In this case, starting torque and maximum torque are equal.

This value of Smax when put in eq^n (11) gives the value of T_{max}.

$$T_{max} = \frac{3V_{Th}^2}{2\omega_s\left[R_{Th} + \sqrt{R_{Th}^2 + (X_{Th} + X_{20}')^2}\right]}$$

Varying R_2' (i.e. Smax condition) is only possible in case of ~~squirrel cage~~ wound rotor type I/M and not in squirrel cage I/M

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SPEED CONTROL OF IM.

(I) Line voltage control method (small power rating) i.e varying V_{Th}.
This is ~~form~~ for small ~~smal~~ power rated ~~dice~~ devices.

(II) Rotor resistance control method.
(possible in wound rotor type and slip ring type induction motor)

(III) By controlling the synchronous speed b/as rotor speed is slightly less than the synchronous speed.

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

N_s can be varied by varying f and p.
For supply frequency control methods :
We have power electronic circuits (Inverters)

$$V \approx E = 4.44 f \phi_p N_{ph} K_w$$

$$\Rightarrow \phi = K\left(\frac{V}{f}\right)$$

~~In~~ If we reduce f, then we have to reduce V, to operate the induction motor at its knee point.

If $\omega_s \downarrow$, ~~$\Rightarrow$ then~~ then V_{Th} is also reduced T_{ind} also reduces

To increase N_s, we increase f, but do not increase V b/as it will affect insulation

$\Rightarrow \phi_p \downarrow$

$\because \quad T_{ind} \propto \phi_p \Rightarrow T_{ind} \downarrow$. (For $f > f_{rated}$)

(see graph from Chapman)

→ Above the base speed, maximum T is reduced but power is constant (flux weaking region)

Below the bases speed, we go with armature voltage method.

- STARTING METHOD

(I) DOL (Direct on line) Method

→ for less (1K – 2KW) rating.

$I_{L_{max}} = 10A, \quad V_{L_{max}} = 415V$.

(II) Using Autotransformers.

(III) Using star-delta starters.

Starters are connected in such a way that first the phase windings are connected in star and later on, it converts it into delta

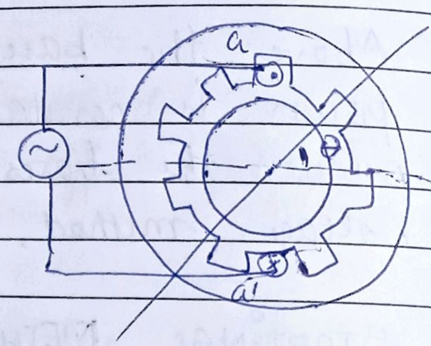
Thus, in starting $V_{ph} < V_L$

SINGLE PHASE I/M

Used in small power applications.

- Construction

→ Rotors are squirrel cage type.



$i_a = i_m \cos \omega t$

$H_a = H_m \cos \omega t \cos \theta$

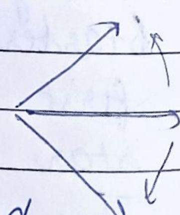
$H_a = \underbrace{\frac{1}{2} H_m \cos(\omega t - \theta)}_{\text{Forward field}} + \underbrace{\frac{1}{2} H_m \cos(\omega t + \theta)}_{\text{Backward field}}$

$H_f = \frac{1}{2} H_m \cos(\omega t - \theta)$, $H_b = \frac{1}{2} H_m \cos(\omega t + \theta)$

H_f would be having peak in space when $\theta = \omega t$

H_b would be having peak in space when $\theta = -\omega t$

One field is splitted into two rotating field where one is rotating into clockwise direction and the other in anti-clockwise direction

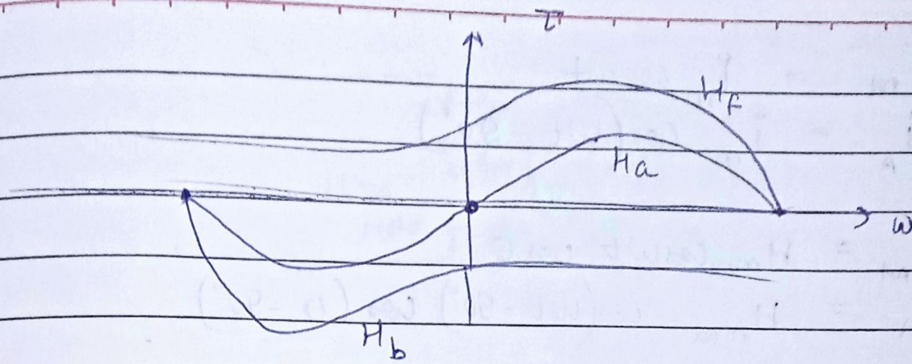


This is known as double-field revolving theory

The field always pulsates in the x-direction.

$\tau_{ind} = K B_{net} \times B_R = 0$

There is not torque at the time of start



* Single phase IM without any modification as such are not self starting.

Slip of rotor w.r.t. forward field

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

$$S_b = \frac{N_s - (-N_r)}{N_s} = \frac{N_s + N_r}{N_s}$$

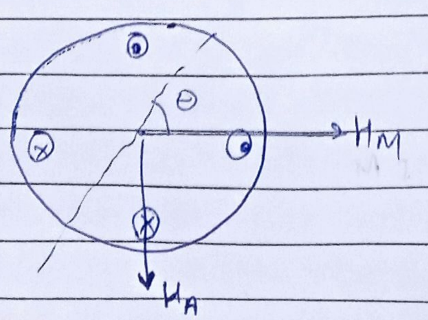
$$\Rightarrow S_b = \frac{N_s + N_r + N_s - N_s}{N_s} = \frac{2N_s - (N_s - N_r)}{N_s}$$

$$\Rightarrow \boxed{S_b = 2 - s}$$

→ 2 main thing to make the motor self-starting):

a) Atleast two ~~wi~~ windings which are separated in space (by different space angles)

b) Two ~~wi~~ windings should be energised by two supply which is separated in time domain (phase angle difference)



H_M = Main ~~fel~~ field winding

H_A = field produced by auxilliary winding

$$i_M = i_m \cos\omega t$$
$$i_A = i_m \cos(\omega t - 90^\circ)$$

$$H_M = H_{max}\cos\omega t \cos\theta.$$
$$H_A = H_{max} \cos(\omega t - 90^\circ) \cos(\theta - 90^\circ)$$

$$H_A + H_M = H_{max}[\cos\omega t \cos\theta + \cos(\omega t - 90^\circ) \cos(\theta - 90^\circ)]$$

$$\Rightarrow H_A + H_M = H_{max}(\cos\omega t \cos\theta + \sin\omega t \sin\theta]$$
$$= H_{max} \cos(\omega t - \theta)$$

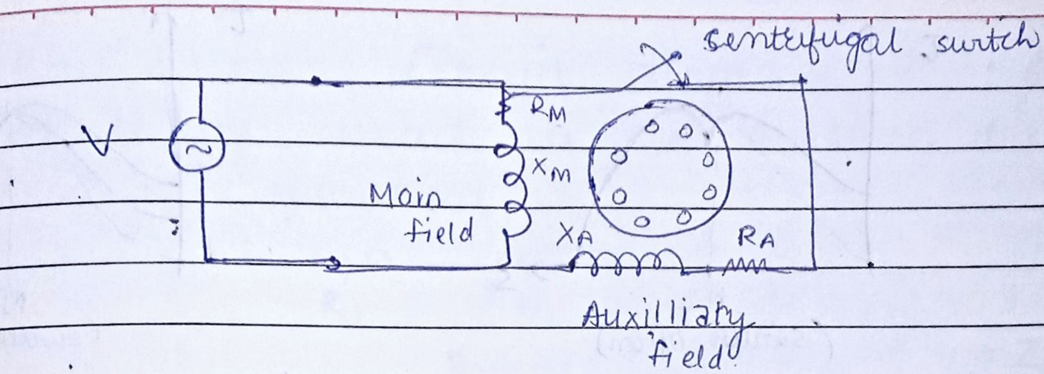
$$\Rightarrow H_{net} = H_{max} \cos(\omega t - 30^\circ)$$

If $\theta = 30^\circ$, then peak will be at $\omega t = 30^\circ$
If $\theta = 0^\circ$, then peak will be at $\omega t = 0^\circ$.
$\Rightarrow$ we have a rotating magnetic field with speed ω.

- ~~DIFFENT~~ Different types of Single phase I/M

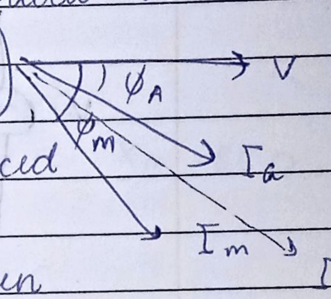
1. Resistive Split phase IM
2. Capacitive split phase IM
   - Capacitor start IM
   - Capacitor start - Capacitor run motor
3. Shade pole type IM.

1. Resistive split phase IM.



Once shaft acquires the speed, at predefined speed the switch gets open.

* Auxially winding has high R/X_A ratio as compared to main winding $\left(\frac{R_A}{X_A} > \frac{R_M}{X_M}\right)$

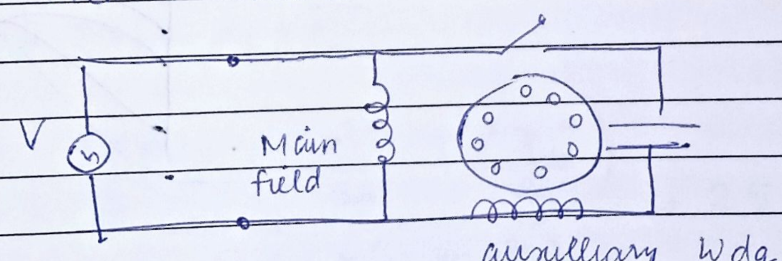


$\phi_M > \phi_A$

∴ I_a and I_m are not displaced by 90°.

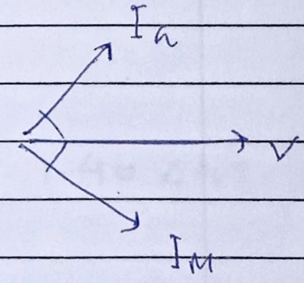
Maximum τ will be present when phase difference is 90°.

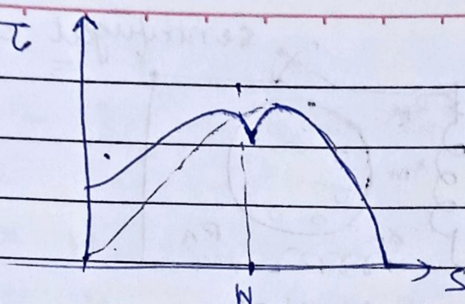
② Capacitor start motor.



$\tau = K I_a I_M \sin 90°$

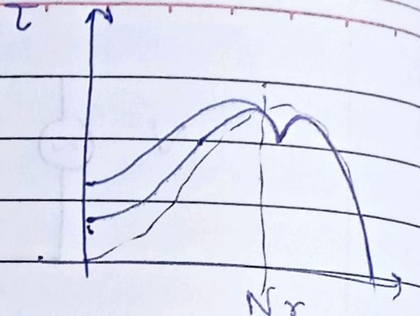
→ High starting torque





(switch open)

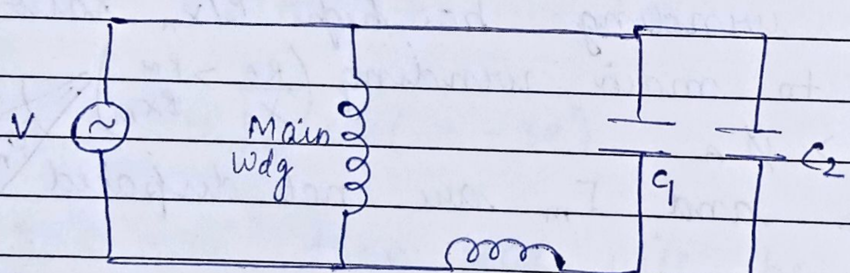
(Resistive split 1φ IM)



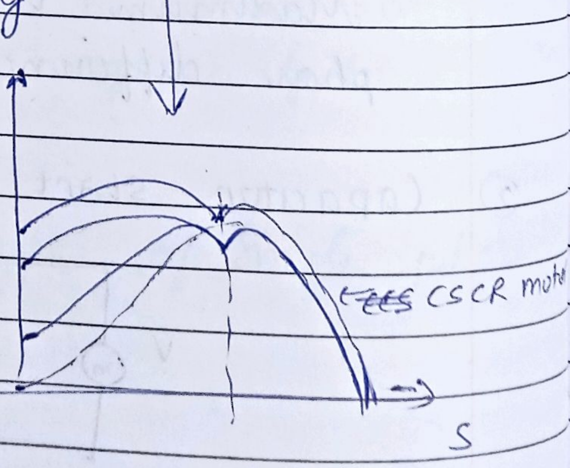
(switch open)

(Capacitive split 1φ IM)

③ Capacitive start and capacitor run motor.

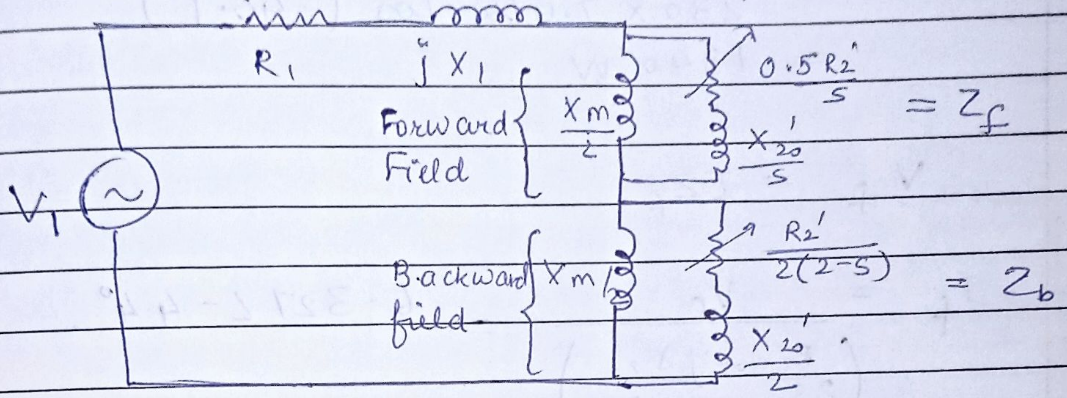


④ Shaded-pole type



Equivalent Circuit diagram of 1 ϕ IM

Auxilliary circuit is not available during running operation.



Q 230 V, 50 hz, 4-pole, 1 ϕ, $R_1 = 2.2\Omega$.
$X_1 = 3\Omega$, $R'_2 = 3.8\Omega$, $X'_2 = 2.1\Omega$, $X_m = 86\Omega$

$N_s = 1500$ $(=120f/p)$, $N_r = 1410$

$$S = \frac{N_s - N_r}{N_s} = \frac{1500 - 1410}{1500} = 0.06.$$

$$I = \frac{V}{R_1 + jX_1 + Z_f + Z_b}$$

$$Z_f = \frac{\frac{jX_m}{2} \times \left(\frac{R_2'}{2s} + j\frac{X_{20}'}{2}\right)}{\frac{R_2'}{2s} + j\left(\frac{X_{20}'}{2} + \frac{X_m}{2}\right)} = 25.22\angle 37.61^\circ$$

$$Z_b = \frac{\frac{jX_m}{2} \times \left(\frac{R_2'}{2(2-s)} + j\frac{X_{20}'}{2}\right)}{\frac{R_2'}{2(2-s)} + j\left(\frac{X_{20}'}{2} + \frac{X_m}{2}\right)} = 1.40\angle 48.3^\circ$$

$$\Rightarrow I = \frac{230\angle 0^\circ}{2.2 + j3 + 25.22\angle 37.61 + 1.40\angle 48.3}$$

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$I_{in} = 7.616 \angle -40.1^\circ A$

$P_{in} = VI\cos\phi$
$= 230 \times 7.616 \cos(-40.1^\circ)$
$= 1340 \, W$

$V_f = IZ_f$

$I_f = \dfrac{V_f}{\left(\dfrac{R_2'}{2S} + j\dfrac{X_{20}'}{2}\right)} = 6.327 \angle -4.4^\circ$

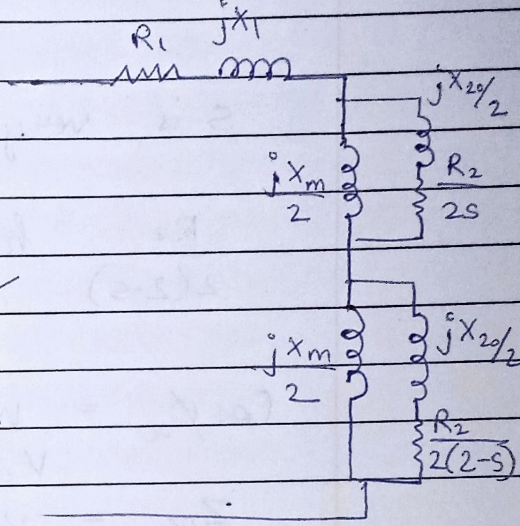
$P_{Agf} = I_f^2 \dfrac{R_2}{2S}$

$P_{conv_f} = I_f^2 \dfrac{R_2}{2S} - \underbrace{\dfrac{I_f^2 R_2}{2}}_{P_{rcl}} = 1192 \, W$

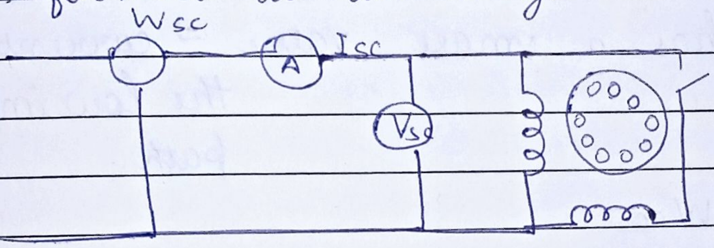
Tests to find the parameter of equivalent circuit of 1ϕ Induction motor

a) Block rotor test
b) No load test. (force run test).

a) Block rotor test

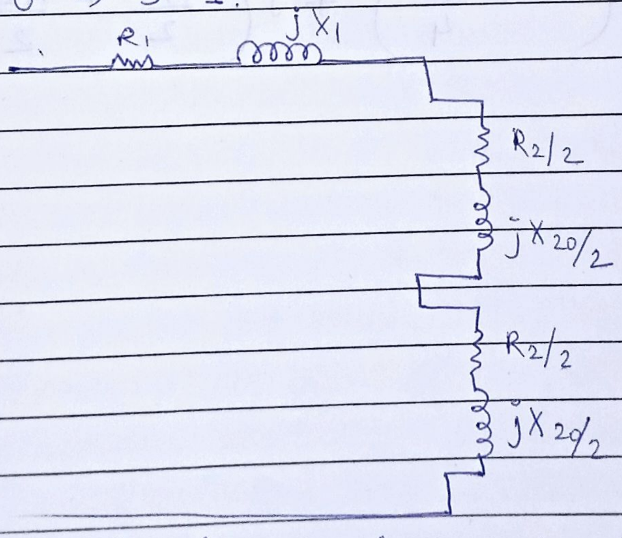


→ Rotor would be blocked
→ Performed at low voltage.



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

$\because N_r = 0 \Rightarrow S = 1.$



$$\frac{V_{sc}}{I_s} = Z_{sc}$$

$$I_{sc}^2\left(R_1 + \frac{R_2}{2} + \frac{R_2}{2}\right) = W_{sc}$$

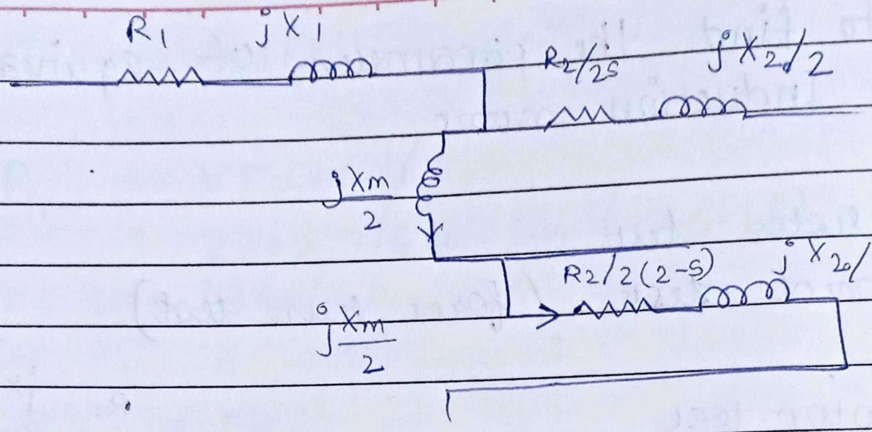
$$(R_1 + R_2) = \frac{W_{sc}}{I_{sc}^2}$$

$$X_1 + X_2 = \sqrt{Z_{sc}^2 - (R_1 + R_2)^2}$$

R_1 can be found from dc test.

b) No load test

→ Performed at rated supply and motor would be allowed to run freely.



s is very small $\Rightarrow \frac{R_2}{2s}$ has a high value and

$\frac{R_2}{2(2-s)}$ has a small value. $\Rightarrow$ current takes the low impedance path.

$$\cos\phi_{oc} = \frac{W_{oc}}{V_{oc} I_{oc}}$$

$$Z_{oc} = \frac{V_{oc}}{I_{oc}}, \quad Z_{oc} \sin\phi_{oc} = \frac{X_m}{2} + \frac{X_2}{2} + X_1$$

$$Z_{oc} = \left(R_1 + \frac{R_2}{4}\right) + j\left(\frac{X_m}{2} + \frac{X_2}{2} + X_1\right)$$