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Internal Assesment Test - II

Sub:	ELECTRIC MOTORS						Code:	17EE44
Date:	15/ 04/2019	Duration:	90 mins	Max Marks:	50	Sem: IV	Branch:	EEE

Note: **Answer any FIVE questions.** Sketch figures as necessary. Each Question is for 10 marks.(5x10=50M)

		Marks	OBE CO	OBE RBT
1 (a)	Explain clearly the various power stages in a 3-phase Induction motor.	[02]	CO4	L2
(b)	Show that, Rotor input: Rotor Gross Power: Rotor Copper Loss = 1:(1-S) : S in a 3-phase Induction Motor, where S is the slip of the motor.	[04]	CO1	L3
(c)	Describe the construction and working of Deep Bar Rotor induction motor.	[04]	CO1	L3
2 (a)	Explain Hopkinson's test on two similar DC shunt motors.	[05]	CO6	L2
(b)	Derive the expression to calculate the different losses and efficiency of both the machines in Hopkinson's test.	[05]	CO4	L2
3 (a)	Draw the circle diagram for a 3.73kW,200V,50Hz,4-pole,3-ph, star connected induction motor from the following test data: No load: Line voltage 200V, line current 5A, total input power 350W. Blocked rotor: line voltage 100V, line current 26A, total input 1700W. Estimate from the diagram for full load condition (assuming rotor cu-loss at standstill is half of the total cu-loss) i) line current, ii) input p.f., iii) efficiency	[06]	CO3	L2
(b)	Find also maximum output power, maximum torque and starting torque from the above circle diagram.	[04]	CO5	L5
4 (a)	Draw the torque-slip characteristics of an induction motor at motoring, generating, braking region of operation.	[03]	CO4	L4
(b)	Derive an expression to get maximum value of running torque.	[04]	CO2	L1
(c)	Write working principle of 3-phase induction generator.	[03]	CO4	L2
5 (a)	Explain how to calculate constant loss, rotational loss, magnetic loss and moment of inertia of a DC motor using retardation test.	[07]	CO1	L3
(b)	A retardation test is carried out on a 1000 rpm DC machine. The time taken for the speed to fall from 1030 rpm to 970 rpm is 36 sec with no excitation, 15 sec with full excitation, 9 sec with full excitation and armature supplying an extra load of 10A at 219V. Calculate moment of inertia of the armature, iron losses, mechanical losses at the mean speed of 1000 rpm.	[03]	CO5	L3
6 (a)	Define the term slip of the Induction motor and explain the effect of slip on the rotor parameters.	[04]	CO2	L4
(b)	Write short note on: i) cogging ii) crawling	[06]	CO4	L2

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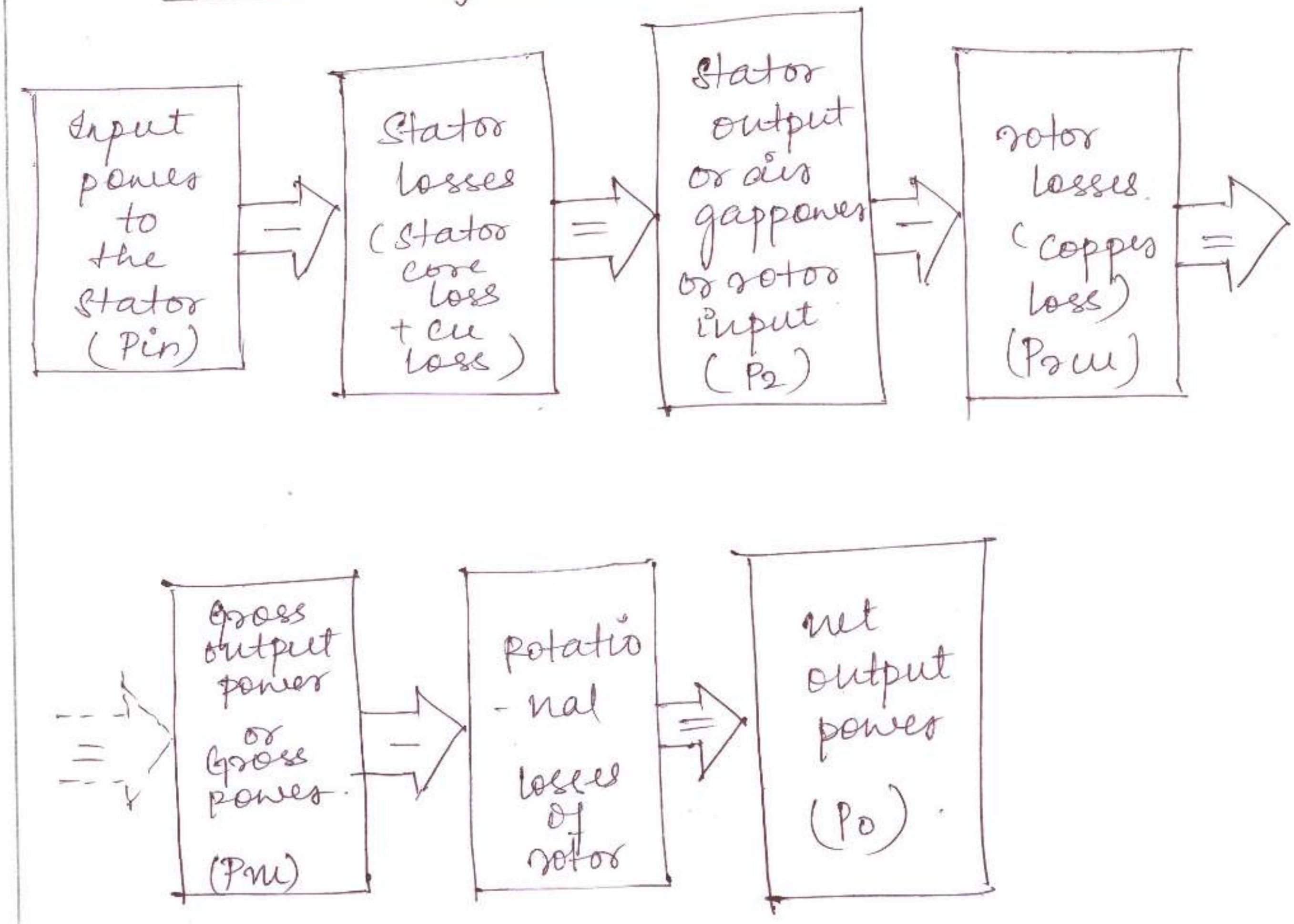
Internal Assessment Test-II

① ⓐ Power diagram



Input is given to the stator, the currents & magnetic fields are produced.

P_{in} - stator Losses = P_2.

P_2 is the input to the rotor.

$P_2 - P_{2cu} = P_m$ → Gross power

↳ Copper losses of rotor

P_m - mechanical losses gives the net output powe

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$$\eta_{gross} = \frac{P_m}{P_{in}}$$

$$\eta_{net} = \frac{P_o}{P_{in}}$$

1 (b) $P_2 : P_m : P_{rcu} = 1 : (1-s) : s$.

Now

Gross efficiency, $\eta_{gross} = \frac{P_m}{P_{in}}$

net efficiency $\eta_{net} = \frac{P_o}{P_{in}}$.

$P_2 = T\omega_s$ — (1); $\omega_s \rightarrow$ synchronous. $n_s \rightarrow$ synchronous speed.

$P_m = T\omega_r$ — (2)

↳ rotor.

We know $P_2 - P_{rcu} = P_m$ — (3)

(3) ÷ (2) ⇒

$$\frac{P_M}{P_2} = \frac{P_2 - P_{rcu}}{P_2} = \frac{\cancel{T}\omega_r}{\cancel{T}\omega_s} = \frac{\omega_r}{\omega_s}$$

$$1 - \frac{P_{rcu}}{P_2} = \frac{\omega_r}{\omega_s} \Rightarrow$$

$$\frac{P_{rcu}}{P_2} = 1 - \frac{\omega_r}{\omega_s} = \frac{\omega_s - \omega_r}{\omega_s} = \frac{2\pi n_s - 2\pi n_r}{2\pi n_s}$$

$$\frac{P_{rcu}}{P_2} = \frac{n_s - n_r}{n_s} = s$$ ↳ slip.

$$\boxed{P_{rcu} = sP_2} \quad \text{--- (4)}$$

using (4) in (3),

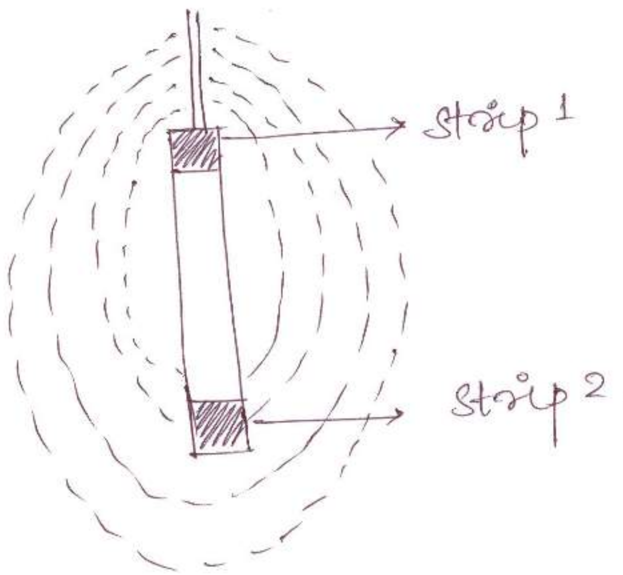
$$P_2 - sP_2 = P_m$$

$$\boxed{P_M = (1-s)\,P_2}$$

$\therefore$ $P_2 : P_m : P_{rcu} :: 1 : (1-s) : s$

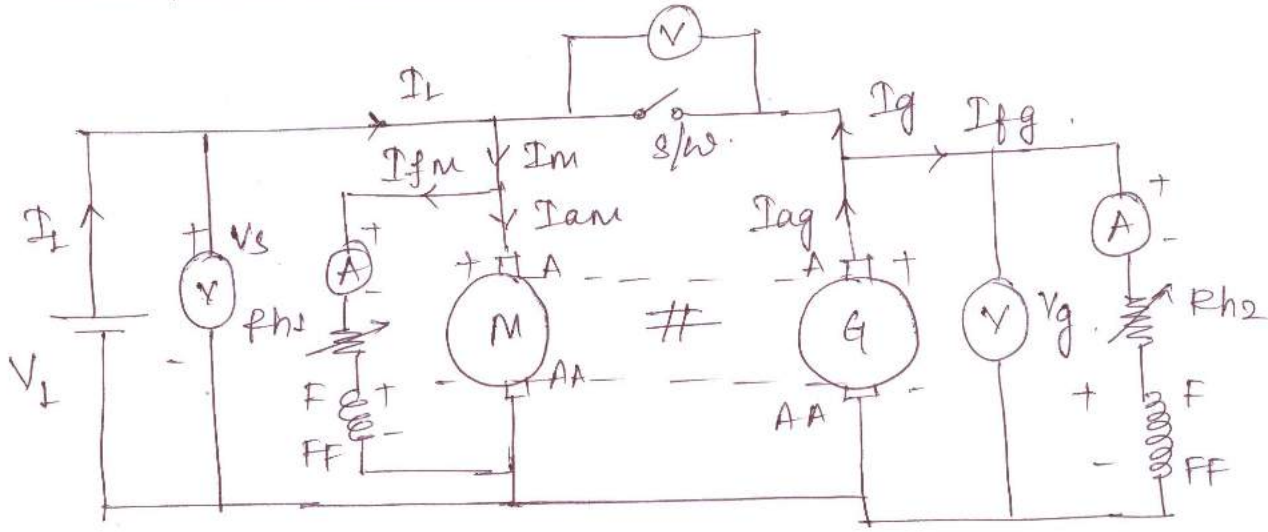
$$\boxed{P_2 : P_m : P_{rcu} = 1 : (1-s) : s}$$

(c) <u>Deep Bar Rotor Induction motor.</u>



<u>Construction</u>

② ⓐ Hopkinson's test



In this, the motor and the generator are mechanically as well as electrically coupled.

As the supply is provided the armature of motor starts rotating. This gives mechanical input to the armature of the generator. When the voltage is increased to the rated voltage, then the generator starts producing electrically energy due to the mechanical input from the motor. This electrical energy supplies the motor. But the supply cannot be switch off, as there are

~~motor~~ losses present. These losses are compensat
by the supply. Hence the supply needs to be
present.
Before closing the switch, we need to check whet
the generator is producing electricity or not. ~~as bs~~
when voltage is zero in that voltmeter, close the
switch.

(2) (b). Total losses = W_T.

$W_T = V_t \times I_t$.

$W_T = W_V + W_C \rightarrow$ Constant loss of both the machi-nes.

W_V ↓ Variable loss of both machines

~~Sometimes when~~ The brush contact losses also needs to be added if given.

$W_V = W_{vm} + W_{vg}$.

$W_{curm} = (I_{am}^2 R_{am})$ = Copper loss of the motor

$W_{curg} = (I_{ag}^2 R_{ag})$ = Copper loss of the genera

$W_{cufm} = V_L \times I_{fm}$ = Losses due to field of motor.

$W_{cufg} = V_L \times I_{fg}$ = Losses due to field of generator.

$W_{BM} = (V_B \times I_{am}) \rightarrow$ for motor

$V_{BG} = (V_B \times I_{ag}) \rightarrow$ for generator.

Not considering brush contact losses,

$W_V = W_{cuag} + W_{cuam} + W_{cufm} + W_{cufg}$.

$W_C = W_T - W_V$

$W_C = W_T - [W_{cuag} + W_{cuam} + W_{cufm} + W_{cufg}]$

$$\underset{\text{for a single machine}}{\underline{W_C'}} = \frac{W_C}{2}.$$

Now, efficiency of motor = $\frac{\text{o/p power of motor}}{\text{i/p power of motor}} \times 100$

$$= \frac{\text{i/p power of motor} - \text{losses}}{\text{i/p power of motor}} \times 100$$

$$= \frac{V_L I_M - \{W_C' + W_{VM}\}}{V_L I_M} \times 100$$

$$\eta_M(\%) = \frac{V_L I_M - \{W_C' + W_{cuam} + W_{cufm}\}}{V_L I_M} \times 100.$$

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efficiency of Generator

$$\eta_g (\%) = \frac{\text{o/p power of Gen.}}{\text{i/p power of Gen}} \times 100$$

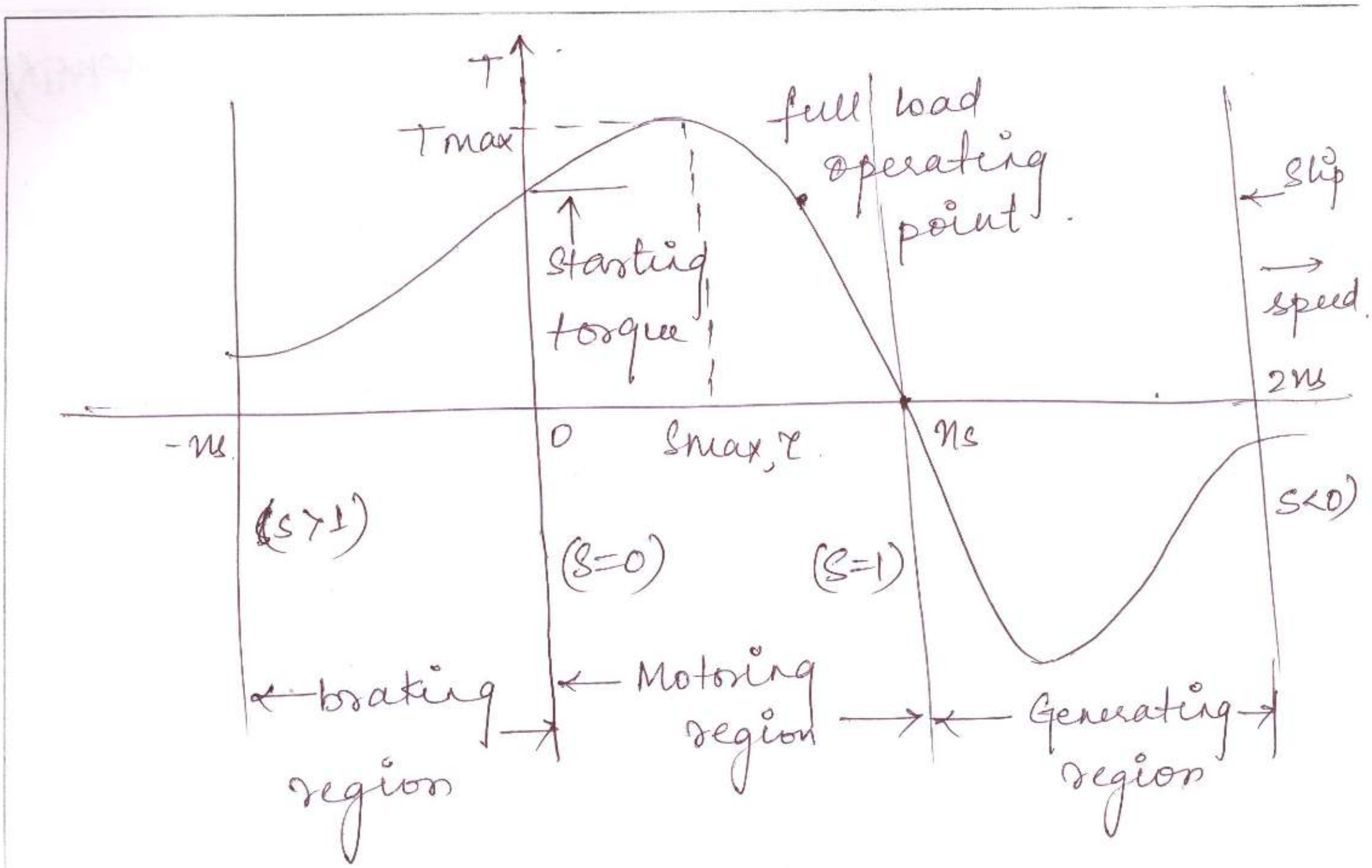
$$= \frac{\text{o/p power}}{\text{o/p power} + \text{losses}} \times 100$$

$$\eta_g (\%) = \frac{V_L I_g}{V_L I_g + \{ W_c' + W_{cuag} + W_{cufg})} \times 100$$

(4) Torque Slip Characteristics

The Torque Slip characteristic gives us the idea of the variation of torque wrt slip.

The slip is defined as the change in spe[ed] from N_s to N_r by N_r. The variation of speed affects the speed which in turn affects the torque.



The Torque slip characteristic can be divided into 3 parts :-

1. Low slip region
2. Medium slip region
3. High slip region.

<u>Motoring Region</u> :

In this region, supply is given to the stator & energy is produced. The torque varies from upto ~~to~~ full load torque ie max. torque. The slip varies from 0 to 1.

The speed varies from 0 to synchronous speed (ie) standstill to full load.
Here, the IM acts as a motor that takes electrical energy & produces mechanical energy.

Generating region:

Here the ~~motor~~ IM is made to run at negative slip and the speed is more than syn. speed so prime mover is ~~requ~~ required. Here the IM converts the mechanical energy given as input to the electrical energy. Here, the IM acts as a generator.

Braking region

Here supply terminals are exchanged and the rotor rotates in the opposite direction. The speed is $-N_s$ slip is greater than one. This is required when the machine needs to be stopped in a brief amount of time. This produces braking action ~~of~~ on the machine and the heat is dissipicated at the rotor.

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4(b) Max. running torque

$$T = K\left[\frac{(R_2'/s)}{(R_2'/s)^2 + (X_2')^2}\right]$$

Condition for max running torque is,

$$\frac{d}{ds}(T) = 0$$

$$\frac{d}{ds}(T) = \frac{d}{ds}\left[\frac{K\,\frac{R_2'}{s}}{\left(\frac{R_2'}{s}\right)^2 + \left(X_2'\right)^2}\right]$$

$$0 = K\left[\frac{\left(\frac{R_2'^2}{s^2} + X_2'^2\right)\left(\frac{-R_2'}{s^2}\right) - \left(\frac{R_2'}{s}\right)\left(\frac{2R_2'}{s}\right)\left(\frac{-R_2'}{s^2}\right)}{\left(\left(\frac{R_2'}{s}\right)^2 + (X_2')^2\right)^2}\right]$$

$$-\frac{R_2'^3}{s^4} - \frac{X_2'^2 R_2'}{s^2} + \frac{2R_2'^3}{s^4} = 0$$

$$\frac{R_2'^3}{s^4} - \frac{X_2'^2 R_2'}{s^2} = 0$$

$$R_2'^3 - s^2 X_2'^2 R_2' = 0$$

$$R_2'^{\cancel{3}} = s^2 X_2'^2 \cancel{R_2'}$$

$$\boxed{s^2 = \frac{R_2'^2}{X_2'^2}}$$

$$\boxed{s = \frac{R_2'}{X_2'}}$$

when s = 1 we get $s \rightarrow s_{max}$.

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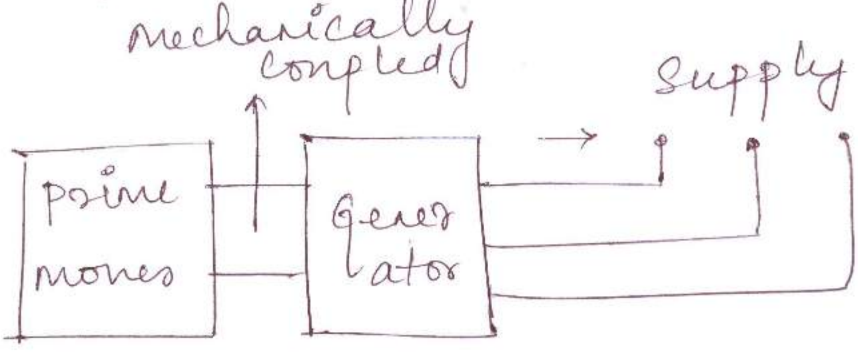
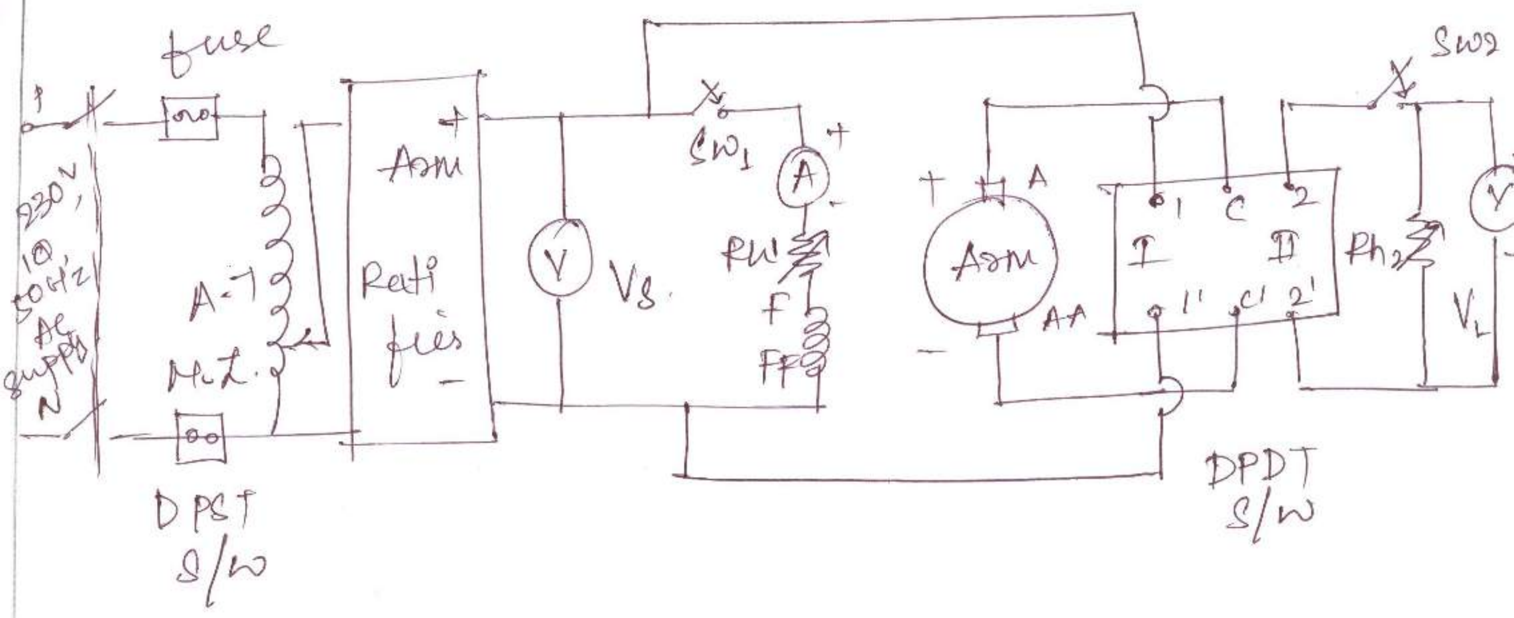
(4) (c) Principle of 3 phase I Generator

When the IM is supplied with very high speed and -ve slip using a prime mover, ~~g~~ currents are produced. The stator produc flux which produces current in rotor. But here, ~~and~~ ~~cor~~ the rotor flux cut the stator coils and hence an active current is produced in stator. This active current supplies the electrical energy to the electrical grid.



(5) (a) Retardation Test

This ~~is~~ test is performed to find the losses of the machine.



Case 1 : S_1 - OFF , S_2 - OF

DPDT S/W - pos. II

~~N_{max}~~ ~~N_{min}~~ ~~t_1(sec)~~

Here only, rotational losses are present as the field & armature are off.

t_1(sec) 1700 → 1300 rpm -

$W_R = 0.011\ IN\left(\frac{dN}{dt_1}\right)$ —— ① $= 0.011\ IN\frac{(1700-1300)}{t_1}$

$= 0.011\ IN\left(\frac{400}{t_1}\right)$

↳ rotational loss = mechanical loss.

Case 2 : S_1 = ON , S_2 - OFF

DPDT - pos. II

Here core loss is found.

$$W_C = W_R + W_M = 0.011\ IN\left(\frac{dN}{dt_2}\right) \quad -(2)$$

$\hookrightarrow$ core loss $= 0.011\ IN\ \frac{400}{t_2}$.

Case 3 : $S_1 = ON$, $S_2 = ON$

DPDT- post II.

Here load loss + core loss is present.

$$W = W_C + W_L = 0.011\ IN\left(\frac{dN}{dt_3}\right) \quad -(3)$$

$$= 0.011\ IN\ \frac{400}{t_3}.$$

$$\frac{(3)}{(2)} \Rightarrow \frac{W_C + W_L}{W_C} = \frac{t_2}{t_3}$$

$$1 + \frac{W_L}{W_C} = \frac{t_2}{t_3}$$

$$\frac{W_L}{W_C} = \frac{t_2 - t_3}{t_3}$$

$$W_C = W_L\left(\frac{t_3}{t_2 - t_3}\right)$$

$$W_L = \text{Load power} = \left(\frac{V_{max} + V_{min}}{2}\right) \times \left(\frac{I_{max} + I_{min}}{2}\right)$$

$$W_L = V_{avg} \times I_{avg}$$

$\frac{②}{①} \rightarrow \quad \frac{W_R + W_M}{W_R} = \frac{t_1}{t_2}$

$$1 + \frac{W_M}{W_R} = \frac{t_1}{t_2}$$

$$\frac{W_M}{W_R} = \frac{t_1 - t_2}{t_2}$$

$$W_M = W_R\left(\frac{t_1 - t_2}{t_2}\right).$$

↳ magnetic loss.

Using these we can find out by considering any of the eqn ①, ②, ③.

⑤ⓑ $N = 1000$ rpm.

$dN = 1030 - 970 = 60$

$t_1 = 36$ sec

$t_2 = 15$ sec

$t_3 = 9$ s.

$W_L = 10A \times 219V = 2190\,W.$

$$W_C = W_L\left(\frac{t_3}{t_2 - t_3}\right) = 2190 \times \left(\frac{9}{15 - 9}\right)$$

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$$\boxed{W_C = 3285W}$$

↳ iron losses.

$$W_C = W_R + W_M$$

$$W_M = W_R\left(\frac{t_1 - t_2}{t_2}\right) = W_R\left(\frac{36-15}{15}\right)$$

$$W_M = 1.4\,W_R$$

$$W_C = W_R + W_M = W_R + 1.4\,W_R = 2.4\,W_R$$

$$W_R = \frac{W_C}{2.4} = \frac{3285}{2.4} = 1368.75W$$

$$\boxed{W_R = 1368.75W}$$

↳ mechanical losses.

$$W_R = 0.011\ IN\ \frac{dN}{dt_1}$$

$$1368.75 = 0.011 \times I \times 1000 \times \frac{(60)}{36}$$

$$I = \frac{1368.75 \times 36}{0.011 \times 1000 \times 60}$$

$$\boxed{I = 74.659\ \text{kgm}^2}$$

3 (a) $\cos\phi_0 = \dfrac{W_0}{\sqrt{3}\, I_0 V_0} = \dfrac{\cancel{30.78} \; 350 \times \cancel{10}^3}{\sqrt{3} \times 200 \times 5}$

$= 0.2$

$\phi_0 = 78.34^\circ$

$I_0 = 5/4 = 1.25 \text{ cm}$

$\cos\phi_{brN} = \dfrac{1700}{\sqrt{3} \times 100 \times 26} = 0.377$

$\phi_{brN} = 67.82^\circ$

$I_{brN} = 26 \times \left(\dfrac{200}{100} \right) = 52 A$

$W_{brN} = 1700 \times \left(\dfrac{200}{100} \right)^2 = 6800 W$

Let 1A 4cm - scale

$I_{brN} = \dfrac{52}{4} = 13 \text{ cm}$

Current Scale → 4 cm = 1A

Power Scale

$P_M = \dfrac{\cancel{30.78}\; 6800 \text{ kW}}{} = 5 \text{ cm}$

power scale $\Rightarrow \dfrac{\cancel{30.78}\; 6800 \times \cancel{10^3}}{5} = \cancel{7616 W}\; 1360 W$

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At full load :, $\dfrac{3.73 \times 10^3}{1360}$

$= 2.74$ cm.

OR = line current = 4 cm × Current Scale
(i) line current
= 16 A

$\phi = 31°$

$\cos\phi = \cos 31° = 0.857$

(iii) $\eta = \dfrac{RT}{RY} = \dfrac{2.8}{3.4} = 0.8235$

$\eta\% = 82.35\%$.

8 (3)
(b) max o/p power = 4.3 cm × 1360 = 5848W

max. torque = 5.3 cm × 1360 = 7208 syn watt

Starting torque = rotor copper loss
= 2.5 × 1360 = 3400W

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

$$\tau = \frac{P_2}{\omega_s} = \frac{P_2}{2\pi n_s} = \frac{P_2}{2\pi \times 1500} \text{ N m}$$

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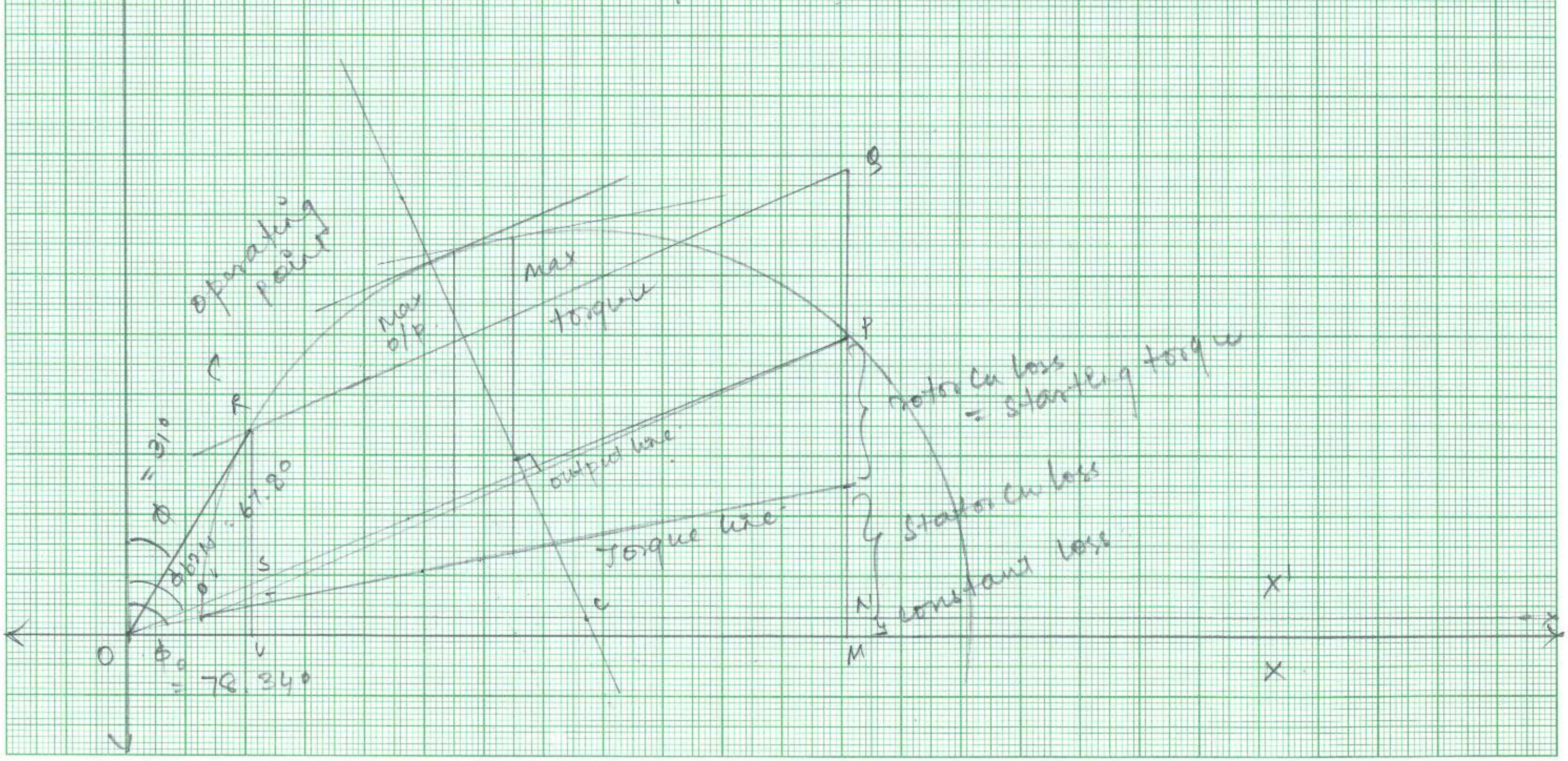
Current Scale : 1 cm = 4 A
Power scale 1 cm = 1360 W.



$\cancel{(R_2')^2} \; S_2$

$$(R_2')^2 - S^2(X_2')^2 = 0$$

$$(R_2')^2 = S^2(X_2')^2$$

$$S^2 = \frac{(R_2')^2}{(X_2')^2}$$

$$S = \frac{R_2'}{X_2'} \Rightarrow S_{max}$$

c) <u>Working principle of 3ϕ induction generator</u>

* Induction generator is not a self excited machine, it is driven by prime mover.
* It runs at speed greater than synchronous speed i.e asynchronous speed.
* Therefore both slip and torque are negative.
* Rotor current flows in direction opposite to rotor magnetic field.
* It takes reactive power from AC supply and gives active power back to supply.
* Stator winding is connected to 3ϕ AC supply.
* The reactive power needs to be externally supplied, because of this the generate starts consuming electrical power instead of supplying it.

The Deep Bar Rotor is made up multiple bars and divided into strips namely

(I) Bottom Strip

(II) Upper Strip

The leakage inductance is more in the Bottom strip than the upper Strip. Because the flux leakage of bottom strip is more than that of upper strip. At the starting of motor the frequency of stator is equal to the frequency of rotor, thus the leakage inductance is more in the bottom strip thus resulting in low current. Whereas the leakage inductance is low for the upper strip thus it has high current. Due to this rotating magnetic field generates its own flux thus produces current which opposes the supply current.

These strips are made up of different elements. Thus stator produces R.M.F when it is connected to the supply mains, these R.M.F cuts the rotor conductor, producing e.m.f in the rotor, then there is rotor flux generates, hence both flux interact with each other. At one side they supports each other and other side they cancel each other. Thus this now they rotates the rotor.

$$\frac{\cancel{W_R + W_M}}{\cancel{W_R + W_M + W_L}}$$

$$\frac{W_R + W_M + W_L}{W_R + W_M} = \frac{t_2}{t_3}$$

$$\frac{W_C + W_L}{W_C} = \frac{t_2}{t_3}$$

$$1 + \frac{W_L}{W_C} = \frac{t_2}{t_3}$$

$$\frac{W_L}{W_C} = \frac{t_2 - t_3}{t_2}$$

$$W_C = \left(\frac{t_2}{t_2 - t_3}\right) W_L$$

6. (i) crawling

When fifth harmonic field rotates in opposite of the rotor rotation, then torque is produces which opposes the fundamental torque. While seventh harmonic field rotates in direction of the rotor rotation, thus, the torque is produces which aids the fundamental torque. The resultant torque is addition of fundamental torque, fifth and seventh harmonic torque.

the fifth harmonic is zero at $-\frac{n_s}{5}$ and seventh harmonic is zero at $\frac{n_s}{7}$.

There are two dip; one is at 1.2 slip and other is at slip 6/7. the dip near $\frac{6}{7}$ is more important, it shows torques decreas, increase in the speed

cogging.

It is the special behavious of squirrel cage IM. The motor starts having equal no. of stator slots to the equal no. of rotor slots or integral multiple of rotor slott. The variation is reluction in space pronounced the effect strong force than the accelerating torque. Thus motor ~~stops~~ fails to start. In the design