CBCS SCHEME

USN | | | | | | | | | | 21EE44

Fourth Semester B.E. Degree Examination, June/July 2023

Electric Motors

Time: 3 hrs. Max. Marks: 100

Note: ***Answer any FIVE full questions, choosing ONE full question from each module.***

Module-1

1 a. What is meant by Back emf? Explain the significance of Back emf. **(06 Marks)**

b. Sketch and explain the speed-current, speed-torque and torque-current characteristics of a shunt motor. **(06 Marks)**

c. A series motor having resistance of 1Ω between its terminals drives a fan, the torque of which is proportional to the square of the speed. At 230V, its speed is 300rpm and takes 15A. The speed of the fan is to be raised to 375rpm by supply voltage control estimate the supply voltage required. **(08 Marks)**

OR

2 a. Derive an expression for torque of a DC motor. **(06 Marks)**

b. Briefly explain the necessary of starter to start DC Motor and with a neat diagram explain the operation of 3 point starter. **(08 Marks)**

c. A 200 V shunt motor has $R_a = 0.1\Omega$ and $R_{sh} = 240\Omega$ and rotational loss 236w. On full load the line current is 9.8 with motor running at 1450 rpm.

Determine :

i) Mechanical power developed

ii) The power output

iii) The full load efficiency. **(06Marks)**

Module-2

3 a. With a neat circuit diagram explain the retardation test conducted on DC shunt motor and show how the stray losses are determined with and without flywheel. **(10 Marks)**

b. A test on two coupled similar tramway motors, with their field connected in series, gave following results when one machine acted as a motor and the other as a generator, calculate the efficiency of motor and generator.

Motor : Armature current : 56A
Armature voltage : 590V
Voltage drop across field wending : 40V

Generator : Armature current : 44A
Armature voltage : 400V
Field wending drop : 40V

Resistance of each armature : 0.3Ω. **(10 Marks)**

OR

4 a. Derive the torque equation for three phase IM and derive condition for maximum torque. **(08 Marks)**

b. Sketch and explain the typical torque – slip characteristics of a three phase IM. **(04 Marks)**

c. A 12-pole, 50Hz, 3ϕ IM has rotor resistance of 0.15Ω and standstill reactance of 0.25 per phase. On full load it is running at a speed of 480rpm. The rotor induced emf per phase at standstill is observed to be 32V. Calculate :

i) Starting torque ii) Full load torque

iii) Maximum torque iv) Speed at maximum torque. **(08 Marks)**

Module-3

5 a. Draw and explain the phasor diagram of 3-phase IM under loaded condition. (06 Marks)
b. Draw the power flow diagram of a 3-phase IM and explain. (06 Marks)
c. A 6 pole, 3-phase IM develops 30hp including mechanical losses of 2hp at a speed of 950rpm on 550V, 50Hz supply. Calculate for this load :
i) The slip ii) The rotor Cu loss iii) Total input if the stator losses are 2000 watts. (08 Marks)

OR

6 a. Explain the operation of deep bar rotor IM along with the equivalent circuit diagram and also draw its torque – slip characteristics. (08 Marks)
b. Draw the circle diagram for a 20HP, 50Hz, 3-phase, star connected IM with the following data :
No load test : 400V, 9A, 0.2pf lagging
Blocked rotor test : 200V, 50A, 0.4pf lagging
Determine the line current and efficiency for FL condition from circle diagram. (12 Marks)

Module-4

7 a. Explain the necessity of a starter to start 3-phase IM and with a neat sketch explain the operation of star-Delta Starter and rotor resistance starter. (10 Marks)
b. Enumerate the speed control methods of 3ϕ IM and explain any two methods in detail. (10 Marks)

OR

8 a. Explain double field revolving theory as applied to a single phase IM and prove that it cannot produce any starting torque. (08 Marks)
b. With neat sketch explain the construction and working of capacitor start single phase IM. (08 Marks)
c. Write a note on limitations and application of shaded pole IM. (04 Marks)

Module-5

9 a. List the methods of starting synchronous motor explain any one method with neat sketch. (08 Marks)
b. Describe a phenomenon of hunting in synchronous machine and methods to overcome this. (06 Marks)
c. What is synchronous condenser? What is its application? (06 Marks)

OR

10 a. Briefly explain the V and inverted V curves of a synchronous motors and the methods of obtaining them. (08 Marks)
b. Explain the construction and working of Chiversal motor and stipper motor. (12 Marks)

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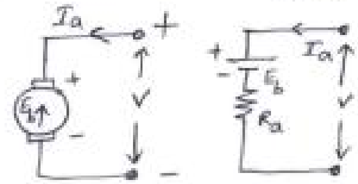
Scheme and Solutions

1 a

<u>Back emf</u>: In a Motor, After motoring action, there exists a generating action by which emf will be induced in Rotating armature conductors according to <u>Faraday's law of electromagnetic Induction</u>. The induced emf in armature always acts in the opposite direction of the supply voltage according to <u>Lenz's Law</u>, hence called as Back emf and denoted as E_b , $E_b = \frac{\phi Z N P}{60 A}$ ——— (3M) 6M



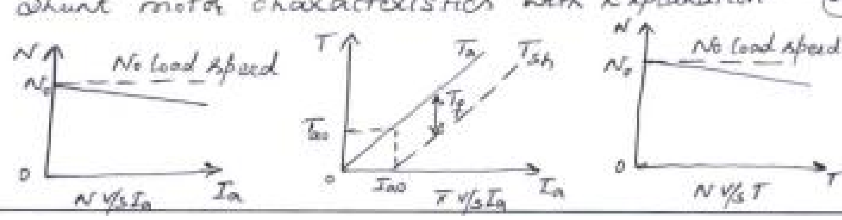
——— (1M)

<u>Significance of Back emf</u> :-

1) It makes the DC motor a self regulatory ie it makes the motor to draw armature current which is just sufficient to supply load demand.

2) $I_a = \frac{V - E_b}{R_a}$, Under no load $E_b \approx V$ ——— (2M)

Shunt motor characteristics with Explanation — (6M) 6M



c

$R_a + R_{se} = 1\Omega$

$V_1 = 230V$

$N_1 = 300 rpm$

$I_1 = I_{a1} = 15A$

$N_2 = 375 rpm$

$T \propto \phi I_a \propto I_a^2$

$\frac{T_1}{T_2} = \left(\frac{I_{a1}}{I_{a2}}\right)^2$ Also $T \propto N^2$

$\frac{T_1}{T_2} = \left(\frac{N_1}{N_2}\right)^2$ — (2M)

$\therefore \left(\frac{I_{a1}}{I_{a2}}\right)^2 = \left(\frac{N_1}{N_2}\right)^2$

$\left(\frac{15}{I_{a2}}\right)^2 = \left(\frac{300}{375}\right)^2 \Rightarrow I_{a2} = 18.75A$ — (2M)

8M

Speed equation $N \propto \frac{E_b}{\phi} \propto \frac{E_b}{I_a}$

$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{I_{a2}}{I_{a1}}$

$E_{b1} = V_1 - I_{a1}(R_a + R_{se}) = 215V$ — (2M)

$E_{b2} = V_2 - I_{a2}(R_a + R_{se}) = V_2 - 18.75$

$\therefore \frac{300}{375} = \frac{215}{V_2 - 18.75} \times \frac{18.75}{15} \Rightarrow V_2 = 354.68V$ — (2M)

2a

Torque Expression of a DC Motor:

Torque is twisting or turning effect about an axis.

Work done = F x distance travelled

$= F \times 2\pi R$

Power $= \frac{\text{Workdone}}{\text{Time}} = \frac{F \times 2\pi R}{60/N} = (F \times R) \times \frac{2\pi N}{60}$ — (2M)

$P = T \times \omega$ where $\omega = \frac{2\pi N}{60}$

$P = E_b I_a = \frac{\phi 2 N P}{60 A} I_a$ —— (2M)

6M

Substituting

$$\boxed{T_a = 0.159 Z \phi I_a \left(\frac{P}{A}\right) Nm}$$ —— (2M)

b Necessity of starter:

1) To reduce inrush or starting current drawn by motor during starting
2) Provide safety against over load and open circuit or No voltage

} — (2M)

8M

3 point starter —— diagram — (3M)

Explanation — (3M)

c $V = 200V$

$R_a = 0.1\Omega$

$R_{sh} = 240\Omega$

Rotational loss $= 236$ W

$I_L = 9.8A$

$N = 1450$ rpm

$I_L = I_a + I_{sh}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{240} = 0.83A$

$I_a = I_L - I_{sh} = 9.8 - 0.83 = 8.97A$

$E_b = V - I_a R_a = 199.10$ V

} — (2M)

(i) Mech. power developed $= E_b I_a$

$= 199.10 \times 8.97 = 1785.32$ W

(ii) Power output

= Power developed − Rotational losses

$= 1785.32 - 236 = 1549.32$ W

} — (2M)

(iii) $\eta = \frac{\text{Power o/p}}{\text{Power i/p}} = \frac{1549.32}{200 \times 9.8} \times 100$

$= 79.04$ %

} — (2M)

(6M)

3 a **Retardation Test :**

Circuit diagram — (2M)

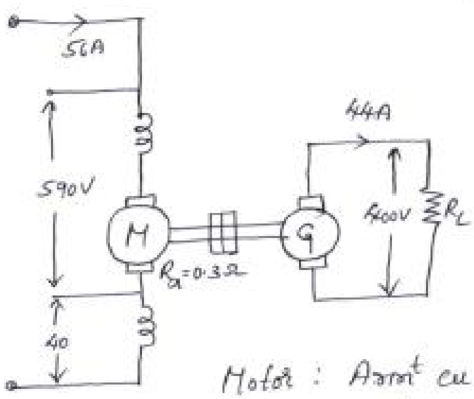
Explanation of procedure — (2M)

Determination of dN/dt — (2M)

Determination of Stray losses with and without flywheel — (4M)

10M

b **Field Test :**



Total i/p = 630 × 56
= 35280 W

Total o/p = 400 × 44
= 17600 W

Total losses of 2 M/c's
= 35380 − 17600
= 17680 W — (2M)

Motor : Armt cu loss = $56^2 \times 0.3 = 940.8$ W

Field cu loss = $\left(\frac{40}{56}\right) \times 56^2 = 2240$ W

Generator : Armt cu loss = $44^2 \times 0.3 = 580.8$ W

Field cu loss = $\left(\frac{40}{56}\right) \times 56^2 = 2240$ W — (2M)

Stray losses of 2 Machines = Total losses − Total copper losses

= 17680 − (940.8 + 2240 + 580.8 + 2240)

= 11678.4 W

Stray loss/machine = 5839.2 W — (2M)

Efficiency of motor:

$$\eta_m = \frac{P_{in} - Losses}{P_{in}} \times 100$$

$P_{in} = 590 \times 56 = 33040 W$

$Losses = 5839.2 + 940.8 + 2240 = 9020 W$

$$\eta_m = \frac{33040 - 9020}{33040} \times 100 = 72.69\%$$ — (2M)

10M

Efficiency of Generator:

$$\eta_g = \frac{P_{out}}{P_{out} + Losses} \times 100$$

$P_{out} = 400 \times 44 = 17600 W$

$Losses = 5839.2 + 580.8 + 2240 = 8660 W$

$$\eta_g = \frac{17600}{17600 + 8660} \times 100 = 67\%$$ — (2M)

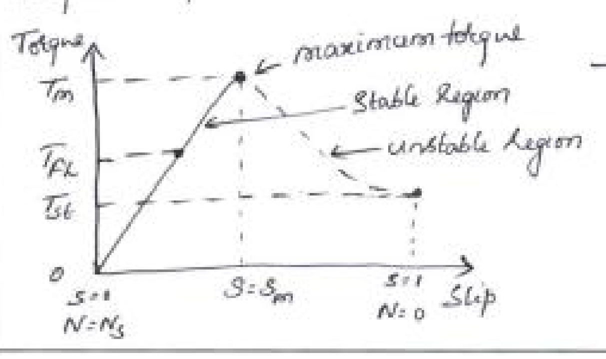
4 a Derive Torque equation of 3φ IM — (6M)

$$T = \frac{3}{2\pi n_s} \frac{sE_2^2 R_2}{R_2^2 + s^2 X_2^2}$$

Condition for maximum torque $S_m = \frac{R_2}{X_2}$ — (2M)

8M

b Torque - Slip characteristic



— (2M)

Explanation — (4M)

6M

c

$P = 12$

$f = 50\ Hz$

$R_2 = 0.15\ \Omega/ph$

$X_2 = 0.25\ \Omega/ph$

$E_{2ph} = 32V$

$N_s = \frac{120f}{P} = 500\ rpm$

(i) Starting torque T_{st}

$$T = \frac{3}{2\pi n_s} \frac{sE_2^2R_2}{R_2^2+s^2X_2^2}$$

At start $s = 1$, $n_s = \frac{N_s}{60} = 8.33\ rps$

$$T_{st} = \frac{3}{2\pi \times 8.33} \frac{1\times 32^2 \times 0.15}{0.15^2 + 0.25^2}$$

$= 103.57\ Nm$ —— (2M)

(ii) Full load torque ie $S_f = \frac{N_s - N}{N_s} = \frac{500-480}{500} = 0.04$

$$T_f = \frac{3}{2\pi n_s} \frac{SE_2^2R_2}{R_2^2+S^2X_2^2} = 15.576\ Nm$$ —— (2M)

(iii) Maximum torque ie $S_m = \frac{R_2}{X_2} = \frac{0.15}{0.25} = 0.6$

$$T_m = \frac{kE_2^2}{2X_2} = \frac{3}{2\pi n_s} \frac{32^2}{2\times 0.25} = 117.34\ Nm$$ —— (3M)

(iv) Slip at T_m is $S_m = \frac{R_2}{X_2} = \frac{0.15}{0.25} = 0.6$

$\therefore N = N_s(1 - S_m) = 500(1-0.6) = 200\ rpm$ —— (2M)

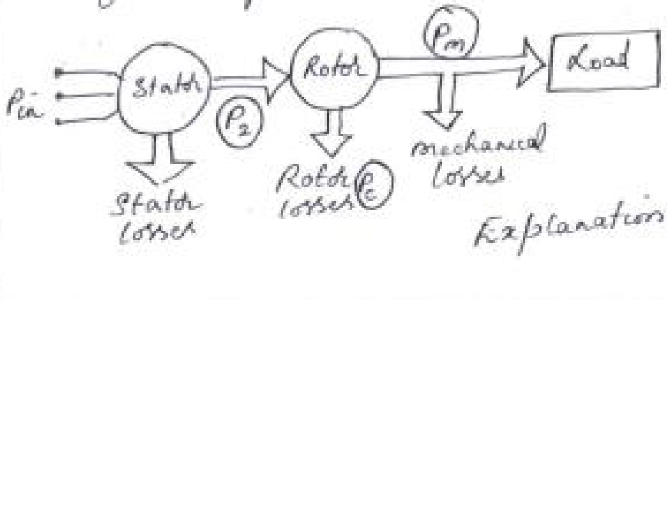
8M

5 a Phasor diagram of 3ϕ IM —— (3M)

Explanation with equations —— (3M)

6M

b Power flow diagram of 3ϕ IM



—— (3m)

Explanation —— (3M)

6M

5c

$P = 6$, $f = 50\,Hz$, $N = 950$ rpm, $N_S = \frac{120f}{P} = 1000$ rpm

(i) Slip $= \frac{N_S - N}{N_S} = \frac{1000 - 950}{1000} = \underline{0.05 \text{ or } 5\%}$ } — (2M)

(ii) Rotor copper loss

$P_2 : P_c : P_m = 1 : S : 1-S$

$P_m = 30\,hp = 30 \times 735.5 = 22065\,W$ } — (3M)

$\frac{P_c}{P_m} = \frac{S}{1-S} \Rightarrow P_c = \underline{1161.32\,W}$

(iii) Total input

$\frac{P_2}{P_c} = \frac{1}{S} \Rightarrow P_2 = \frac{P_c}{S} = 23226.4\,W$ = Rotor i/p

P_{in} = Total input = Rotor input + Stator losses

$= 23226.4 + 2000 = \underline{25226.4\,W}$ } — (3M)

8M

6a

Deep bar Rotor IM

operation — Fig + Explanation — (4M)

T-S characteristic — Fig + Explanation — (4M)

8M

b

$\cos\phi_0 = 0.2$ $\phi_0 = 78.46^\circ$

$\cos\phi_{SC} = 0.4$ $\phi_{SC} = 66.42^\circ$

$I_{SN} = I_{SC}\left(\frac{V_L}{V_{SC}}\right) = 50\left(\frac{400}{200}\right) = 100A$

$W_{SN} = W_{SC}\left(\frac{I_{SN}}{I_{SC}}\right)^2$

$W_{SC} = \sqrt{3}\,V_{SC} I_{SC} \cos\phi_{SC} = 6928.2\,W$

$W_{SN} = 27712.81\,W$

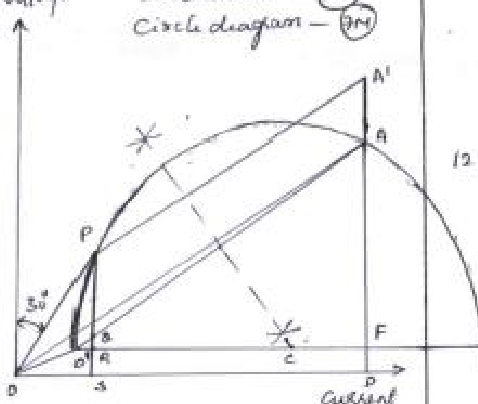
Power scale $= 3379.61$ W/cm

Full load line current $= \underline{30A}$

$Pf = \underline{0.866 \text{ lag}}$, $\eta = \underline{80.75\%}$

Calculation — (5M)

Circle diagram — (7M)



12M

7 a	Necessity of starter in 3ϕ IM — (2M) Star - Delta Starter — Fig + Explanation — (4M) Rotor - Resistance Starter — Fig + Explanation — (4M)	10M
b	Speed control method of 3ϕ IM 1) Supply frequency control 2) Supply voltage control 3) Controlling number of poles 4) Adding resistance in Stator 5) Adding Resistance in Rotor 6) Cascade control (1–6) — (2M) Any two method — Fig + Explanation (4M) each	10M
8 a	Double Revolving theory Fig + Explanation — (6M) Explanation of why Starting torque zero — (2M)	8M
b	Capacitor Start IM Figure — (4M) Explanation — (4M)	8M
c	Shaded Pole IM Limitations : 1) T_{st} is Poor 2) Low Pf 3) High I^2R losses, hence low η 4) Speed Reversal is difficult (1–4) — (2M) Applications : Small fans, Toy motors, advertising displays, film projectors, Record players, gramophones hair dryers, photo copying machines — (2M)	4M

9 a	Methods of Starting Synchronous Motor 1) Using pony motors 2) Using Damper winding 3) As a Slip Ring IM 4) Using small DC machines coupled to it. } — (2M) ~~Slip Ring IM method~~ Any method Figure — (3M) ✓ Explanation — (3M) ✓	8M
b	Hunting explanation — (3M) Method to overcome Hunting (Damper winding) — (3M)	6M
C	Synchronous Condenser: Synchronous motor <u>over excited</u> operating on <u>no load condition</u> called as synchronous condenser or synchronous capacitor. This is the property due to which synchronous motor is used as power improvement device. — (2M) Applications: 1) Industries using many IM 2) Heating and lighting load supplied through transformer } — (2M)	4M
10 a	V and Inverted V curves Explanation — (4M) Experimental setup to obtain V and Inverted V curves — (4M)	8M
10 b	Universal motor — Fig + Explanation — (6M) ~~2 Phase AC servo motor~~ Stepper motor — Fig + Explanation — (6M)	12M

— END —