CONFIDENTIAL

UNIVERSITY COLLEGE TATI

UNIVERSITY COLLEGE TATI (UC TATI)

FINAL EXAMINATION QUESTION BOOKLET

COURSE CODE	:	BMT 3013
COURSE	:	ELECTRICAL MACHINE
SEMESTER / SESSION	:	01 – 2022/2023
DURATION	:	3 HOURS

Instructions:

1. This booklet contains **4** questions. Answer **ALL.**
2. All answers should be written in the answer booklet.
3. Write legibly and draw sketches wherever required.
4. If in doubt, raise your hand and ask the invigilator.

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO

THIS BOOKLET CONTAINS 10 PRINTED PAGES INCLUDING COVER PAGE

QUESTION 1

a) Define electromechanical energy conversion. (3 marks)

b) A separately excited dc generator with generated voltage of 153V is driven at 1400RPM. The armature circuit resistance is 0.28Ω and the armature reaction effect is neglected.

   i) Calculate the no load terminal voltage, VT. (3 marks)

   ii) Calculate the voltage regulation for full load current of 60 A. (3 marks)

c) Define the rotating magnetic field R.M.F. of a 3-phase induction motor. (3 marks)

d) A 240V, 4 poles, 3-phase, star connected alternator is required to supply 15kW to a load at power factor of 0.75 lagging. The synchronous reactance of the generator is 3.0Ω and resistance of 7.0Ω. Calculate;

   i) The rotor speed, N_r. (3 marks)

   ii) The line value of e.m.f. generated, E_L (3 marks)

   iii) The resistance between the R and Y terminals, R_{RY}. (3 marks)

e) List **four (4)** favored characteristics of the single phase induction motor. (4 marks)

QUESTION 2

a) Describe the basic idea behind electromagnet. (3 marks)

b) State the type of pole construction on the following electrical machine stator.

i) DC machine. (1 mark)

ii) Asynchronous machine. (1 mark)

iii) Synchronous machine. (1 mark)

c) A shunt dc generator has a field resistance of 60Ω. When the generator delivers 6kW the voltage is 120V while the generated e.m.f. is 133V. Calculate;

i) The armature current, i_a. (3 marks)

ii) The field current, i_f. (3 marks)

d) Explain the rotation direction of a 3-phase induction motor with reference to the schematic diagram of Figure 1. Let phase R lead phase Y by 120°, and phase Y lead phase B by 120°. (5 marks)

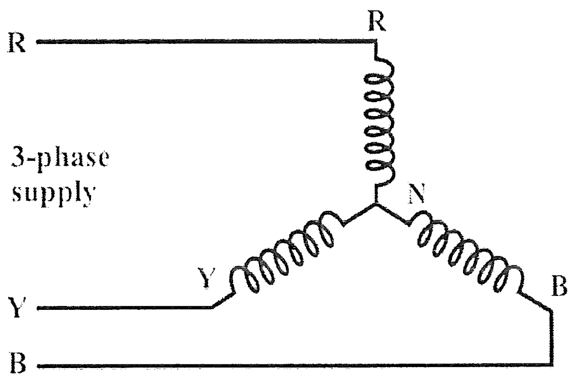


Figure 1

e) Describe the synchronous machine salient pole rotor construction. (6 marks)

f) List any **two (2)** domestic consumer products utilizing single phase induction motor. (2 marks)

QUESTION 3

a) Describe eddy current loss in electromagnetic core. (3 marks)

b) Explain any **one (1)** method of generating voltage in a rotating electrical machine. (3 marks)

c) A series dc motor is supplied 6.5kW when 12.5 A of current passes through the field and armature windings. The field and armature resistances are 3.3Ω and 2.0Ω respectively. Stray losses are assumed to be of 1.2kW. Calculate;

   i) The terminal voltage V_T. (3 marks)

   ii) The back e.m.f. E_b. (3 marks)

d) Explain why in a 3-phase induction motor the rotor speed must not be equal to the synchronous speed. (5 marks)

e) A 3-phase star connected alternator supplied a load of 1000kW at power factor of 0.8 lagging with a terminal voltage of 11kV. Its armature resistance is 0.4Ω per phase while synchronous reactance is 3Ω per phase.

   i) Calculate its phase voltage Vph. (3 marks)

   ii) Calculate its line current IL. (3 marks)

f) Explain why single phase induction motor stator is constructed with laminated stampings of silicon steel material. (2 marks)

QUESTION 4

a) Completes the Left Hand Screw Rule of Figure 2 by stating **i**, **ii** & **iii**. (3 marks)

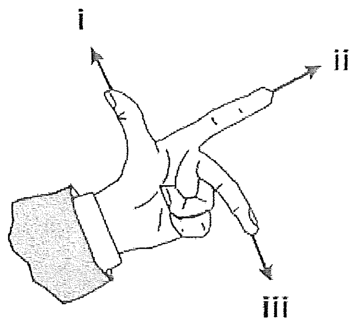


Figure 2

b) A voltage of 230V applied to the armature of a shunt dc motor resulted in a full load armature current of 205A. The armature resistance is 0.2Ω. Assume the stray losses are 1445W at full load speed of 1750rpm. Calculate;

i) The back e.m.f., E_b. (3 marks)

ii) The output power, P_{out}. (3 marks)

iii) The output torque, τ_O (3 marks)

c) The useful torque of a 3-phase, 50Hz, 8-pole, induction motor is 190Nm. The rotor frequency is 1.5Hz. Calculate the slip on full load. (3 marks)

d) Completes Figure 2 by stating the losses labeled **i** and **ii** in Figure 3 (2 marks)

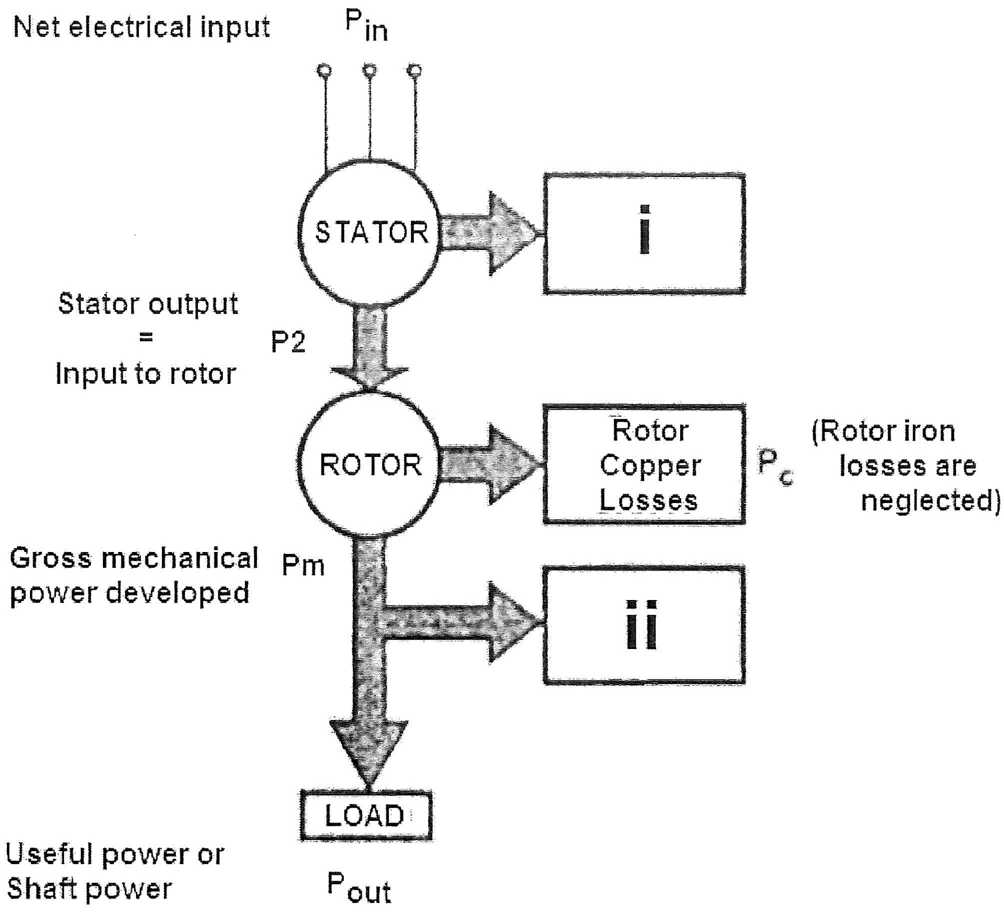


Figure 3

e) Describe the synchronous machine cylindrical pole construction. (6 marks)

f) List any **two (2)** types of single phase induction motor. (2 marks)

----------------End of Questions--------------

FORMULA TABLE

COULOMB'S LAW

$$F = K\frac{M_1 M_2}{d^2}$$

where;

F = magnetic force of attraction/repulsion (N), K = constant depending on nature of surrounding
M_1, M_2 = pole strength (Wb), d = distance between two poles (m)

ELECTROMAGNETISM

$$e = Blv$$

where;

e = induced voltage, B = magnetic flux,
l = length of conductor, V = velocity

$$f = Bli$$

where;

f = force/thrust/motion, B = magnetic flux,
l = length of conductor, i = current in conductor

DC MACHINES

$$E_g = K\phi N \quad , \quad E_{\text{one conductor}} = \phi P\frac{N}{60}\times\frac{Z}{A} \quad , \quad E_{wavewound} = \frac{\phi PNZ}{120} \quad , \quad E_{lapwound} = \frac{\phi NZ}{60}$$

where;

Eg = generated voltage, K=fixed constant, Φ = magnetic flux, N = speed in rpm , P = number of poles, Z = total number of conductor,A = number of parallel paths

Separately Excited DC Generator	Shunt DC Generator
$V_T = E_g - I_a R_a$	$V_T = E_g - I_a R_a = I_f R_f$
$I_a = I_L = I_f$	$I_a = I_L + I_f$

$$P_L = V_T I_L$$

where;

PL = power delivered to/consumed by load, VT = terminal voltage, Eg = generated EMF, Ra = armature winding resistance
Rf = field winding resistance, Ia = armature current, IL = load current, If = field current

Voltage Regulation

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

where;

VNL = no load terminal voltage, VFL = full load terminal voltage

<table>
<tr><td>Shunt DC Motor</td><td>Series DC Motor</td></tr>
<tr><td colspan="2">(back e.m.f.) $E_b = K_e\phi\omega = k_1 k_2 i_a \omega$</td></tr>
<tr><td>$V_T = i_f R_f = E_b + i_a R_a + V_{brush}$
$i_L = i_a + i_f$</td><td>$V_T = E_b + i_a(R_a + R_f) + V_{brush}$
$i_L = i_a = i_f$</td></tr>
<tr><td>$P_{in} = V_T i_L, P_m = E_b i_a, P_{cf} = i_f^2 R_f, P_{ca} = i_a^2 R_a$</td><td>$P_{in} = V_T i_L, P_m = E_b i_a, P_{cf} = i_a^2 R_f, P_{ca} = i_a^2 R_a$</td></tr>
<tr><td>$P_{out} = P_m - P_\mu$
$= (P_{in} - P_{cf} - P_{ca}) - P_\mu$
$= P_{in} - (P_{cf} + P_{ca} + P_\mu)$
$= P_{in} - \sum P_{loss}$
$P_{in} = P_{out} + total\ losses$</td><td>for output/load torque, $\tau_o = \left(\frac{60P_{out}}{2\pi N}\right)$
for mechanical torque, $\tau_m = \left(\frac{60P_m}{2\pi N}\right)$
$efficiency,\ \eta = \frac{P_{out}}{P_{in}}$</td></tr>
<tr><td colspan="2">3-PHASE INDUCTION MACHINE</td></tr>
<tr><td colspan="2">$$N_s = \frac{120f}{P}$$
where;
N_s = rotating magnetic field speed @ synchronous speed, f = power supply frequency, P = number of poles</td></tr>
<tr><td colspan="2">$$\tau_{ind} = kB_R \times B_s$$
where;
τ_{ind} = induced torque, k = constant, B_R = magnetic flux densities of rotor, Bs = magnetic flux densities stator</td></tr>
<tr><td colspan="2">$$s = \frac{N_s - N_r}{N_s} \times 100\% \quad N_r = (1-s) \times N_s$$
;
where;
s = slip of motor, Ns = synchronous speed, Nr = rotor speed</td></tr>
<tr><td colspan="2">$$\frac{E_{1ph}}{E_{2ph}} = \frac{\text{stator winding turns}}{\text{rotor winding turns}}$$
where;
E1ph = stator winding e.m.f.per phase, E2ph = rotor winding e.m.f. per phase</td></tr>
<tr><td colspan="2">$$E_r = s \times E_{BR}$$
where;
Er = rotor induced e.m.f., s = slip of motor, E_{BR}=blocked rotor induced e.m.f. per phase</td></tr>
</table>

$$f_r = s \times f$$

where;

f_r = rotor induced e.m.f. frequency, s = slip of motor, f=line voltage frequency

$$P_{rcu} = 3I_{2r}^2 R_2 \ldots (analysed\ s\ eparately)$$

where;

I_{2r} = rotor current per phase at a particular load, R_2 = rotor resistance per phase

$$P_{in} = \sqrt{3} V_L I_L \cos\phi$$

where;

Pin = input power, VL = line voltage, IL = line current, cos ϕ = power factor

$$P_{in(rotor)} = P_{in(stator)} - (P_c + P_{scu})$$

where;

Pc = stator core loss, Pscu=stator copper winding loss

$$P_{rcu} = 3I_{2r}^2 R_2 \text{ ; } I_{2r} = \frac{sE_2}{\sqrt{R_2^2 + sX_2^2}}$$

where;

Prcu = rotor copper winding loss, I_2r = rotor current per phase at running condition, R2 = rotor winding resistance per phase

$$P_m = P_{in(rotor)} - P_{rcu} \text{ ; } P_{out} = P_m - P_\mu$$

where;

Pm = mechanical power, Prcu = rotor copper loss, Pμ = stray loss

$$Eph^2 = (Vph \cos\theta + IaRa)^2 + (Vph \sin\theta + IaXs)^2$$

Power, $P = \omega\tau$;

with $\omega = \dfrac{2\pi N_r}{60} (rad/s)$ $\quad \tau_m = \dfrac{60P_m}{2\pi N_r}$; $\quad \tau_o = \dfrac{60P_{out}}{2\pi N_r}$

hence, $\tau = \dfrac{60P}{2\pi N_r}$;

$$\eta = \frac{\text{net output at shaft}}{\text{net electrical input to rotor}} = \frac{P_{out}}{P_{in}} \text{ ; } \eta_{rotor} = \frac{P_m}{P_{in(rotor)}}$$

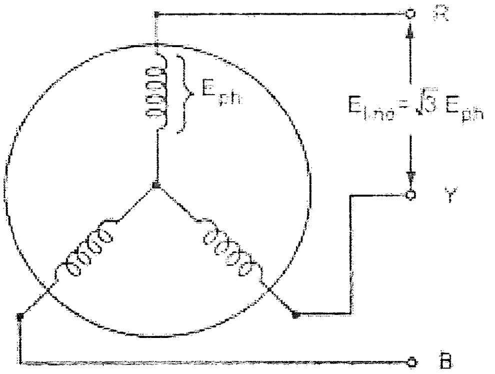
<table>
<tr><th colspan="2">SYNCHRONOUS MACHINE</th></tr>
<tr><td colspan="2">

$$f = \frac{PN}{120}$$

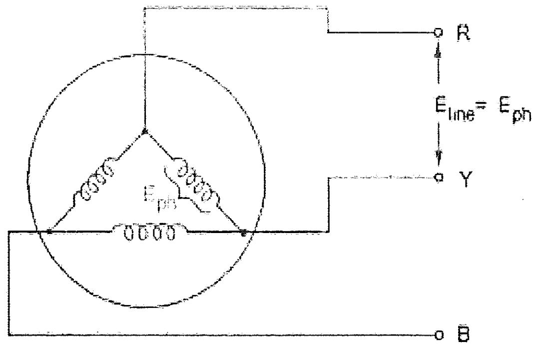
where;

f = frequency of the induced e.m.f., P = no of poles, N = rotor speed in rpm

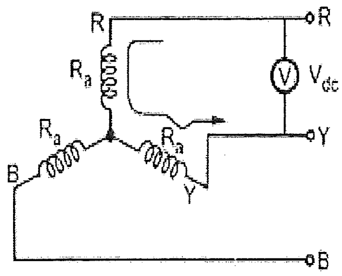
</td></tr>
<tr><td>



</td><td>



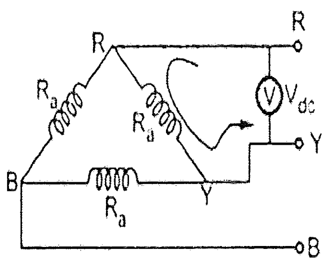
</td></tr>
<tr><td>



</td><td>

R_{RY} = $R_a + R_a$ = $2R_a$
R_a = $R_{RY}/2$ (Ω/ph)
where;
R_{RY} = resistance between RY terminals
R_a = armature resistanse per phase

</td></tr>
<tr><td>



</td><td>

$R_{RY} = 2/3\ R_a$
$R_a = 3/2\ R_{RY}$

</td></tr>
<tr><td>Alternator Voltage</td><td>

$$(E_{ph})^2 = (V_{ph}\cos\theta + I_a R_a)^2 + (V_{ph}\sin\theta \pm I_a X_s)^2$$

</td></tr>
<tr><td>Voltage Regulation</td><td>

$$VR = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100\%$$

</td></tr>
<tr><td>kVA Rating</td><td>

$$kVA = \sqrt{3} V_L I_L \times 10^{-3}$$

</td></tr>
</table>