Benha University
Faculty of Engineering–Benha

Department : Electrical Engineering Programs	**Date : Sunday 13-6-2021**
5th Level : Electromechanical	**Time : 2.0 Hrs.**
Exam :Final / Regular	**Code : EME 502**
Subject : Electrical Machines	**Examiner: Dr. Abdelnasser Nafeh**

Total Degrees: 40 Marks

Answer the Following Questions

Question 1: [10 Marks]

1.) A rotor coil consisting of 30 series-connected turns, with a total resistance of 1.56 Ω, is situated within a uniform magnetic *field* of 1.34 T. Each coil side has a length of 54 cm, is displaced 22 cm from the center of the rotor shaft, and has a skew angle of 8.0°. ***Sketch the system and determine the coil current*** required to obtain a shaft torque of 84 N.m.

2.) A coil of insulated wire of 500 turns and of resistance 4 Ω is closely wound on an iron ring. The ring has a mean diameter of 0.25 m and a uniform cross-sectional area of 700 mm^2. **Calculate** the total flux in the ring when a DC supply of 6 V is applied to the ends of the winding. Assume a relative permeability of 550.

Question 2: [10 Marks]

3.) Data obtained from short-circuit and open-circuit tests of a 50-kVA, 2400—600-V, 60-Hz transformer are:

Open-circuit test (Low-side data)	Short-circuit test (High-side data)
V_{OC} = 600-V	V_{SC} = 76.4-V
I_{OC} = 3.34-A	I_{SC} = 20.8-A
P_{OC} = 484-W	P_{SC} = 754-W

Determine (a) the equivalent high-side parameters; ***(b)*** voltage-regulation; ***(c)*** efficiency at rated load and 92 % power-factor lagging.

4.) Two 60-kVA, 2300—230-V, 60-Hz transformers **A** and **B** are to be operated in parallel. The percent impedances based on individual transformer ratings are: $\mathbf{Z_A}$= (1.58 + j3.01) % and $\mathbf{Z_B}$ = (1.09 + j3.98) %. **Determine** the percent of total bank current drawn by each transformer.

Question 3: [10 Marks]

5.) A three-phase, 230-V, 60-Hz, 100-hp, six-pole induction motor operating at rated conditions has an efficiency of 91 percent and draws a line current of 248-A. The core loss, stator copper loss, and rotor conductor loss are 1697-W, 2803-W, and 1549- W, respectively. **Determine (a)** power input; **(b)** total losses; **(c)** air-gap power; **(d)** shaft speed; **(e)** power factor; **(f)** combined windage, friction, and stray load loss; **(g)** shaft torque.

Question 4: [10 Marks]

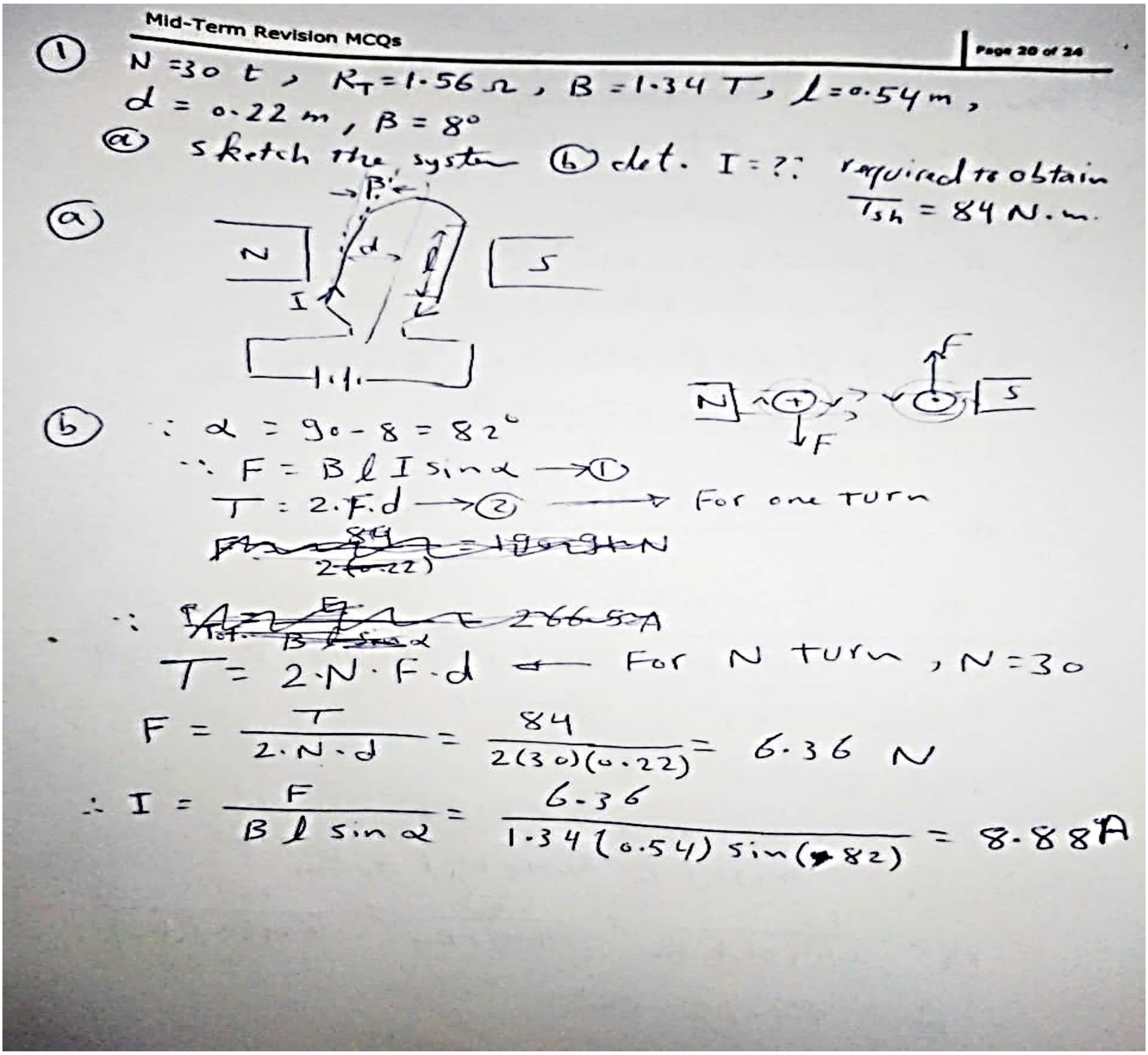
6.) A 240-V, 20-hp, 850 r/min shunt motor draws 72-A when operating at rated conditions. The respective resistances of armature and shunt field are 0.242 Ω and 95.2 Ω. **Determine** the percent reduction in field flux required to obtain a speed of 1650 r/min, while drawing an armature current of 50.4 A.

7.) A 250-volt DC shunt motor has armature resistance of 0.25 ohm, on load it takes an armature current of 50 A and runs at 750 rpm. If the flux of motor is reduced by 10 % without changing the load torque, **find** the new speed of the motor.

Best wishes,

Question 1**: [10 Marks]**

1.) A rotor coil consisting of 30 series-connected turns, with a total resistance of 1.56 Ω, is situated within a uniform magnetic *field* of 1.34 T. Each coil side has a length of 54 cm, is displaced 22 cm from the center of the rotor shaft, and has a skew angle of 8.0°. ***Sketch the system and determine the coil current*** required to obtain a shaft torque of 84 N.m.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① $N = 30\ t$, $R_T = 1.56\ \Omega$, $B = 1.34\ T$, $l = 0.54\ m$, $d = 0.22\ m$, $\beta = 8°$

ⓐ sketch the system ⓑ det. I = ?? required to obtain $T_{sh} = 84$ N.m.

ⓐ

ⓑ $\because \alpha = 90 - 8 = 82°$

$\therefore F = B l I \sin\alpha \rightarrow ①$

$T = 2.F.d \rightarrow ②$ ⟶ For one turn

$T = 2 \cdot N \cdot F \cdot d$ ← For N turn, N = 30

$$F = \frac{T}{2 \cdot N \cdot d} = \frac{84}{2(30)(0.22)} = 6.36\ N$$

$$\therefore I = \frac{F}{B l \sin\alpha} = \frac{6.36}{1.34(0.54)\sin(82)} = 8.88\ A$$

2.) A coil of insulated wire of 500 turns and of resistance 4 **Ω** is closely wound on an iron ring. The ring has a mean diameter of 0.25 m and a uniform cross-sectional area of 700 mm^2. **Calculate** the total flux in the ring when a DC supply of 6 V is applied to the ends of the winding. Assume a relative permeability of 550.

③ mean length of the iron ring

$$l_m = 2\pi r = \pi D = \pi(0.25) = 0.25\pi \ m$$

Area of cross section,

$$A = 700 \ mm^2 = 700 \times 10^{-6} \ m^2$$

$$I = \frac{V}{R} = \frac{6}{5} = 1.5 \ A$$

$$\because \ mmf = \Phi \mathcal{R} = H \cdot l = NI \ , \quad \mathcal{R} = \frac{l}{\mu A} = \frac{l}{\mu_0 \mu_r A}$$

$$\therefore \ \Phi = \frac{NI}{\mathcal{R}} = \frac{NI \mu_0 \mu_r A}{l}$$

$$\therefore \ \Phi = \frac{500 \times 1.5 \times 4\pi \times 10^{-7} \times 550 \times 700 \times 10^{-6}}{0.25\pi}$$

$$\therefore \ \Phi = 0.462 \ mWb$$

<u>Question 2</u>: [10 Marks]

3.) Data obtained from short-circuit and open-circuit tests of a 50-kVA, 2400—600-V, 60-Hz transformer are:

Open-circuit test (Low-side data)	Short-circuit test (High-side data)
V_{OC} = 600-V	V_{SC} = 76.4-V
I_{OC} = 3.34-A	I_{SC} = 20.8-A
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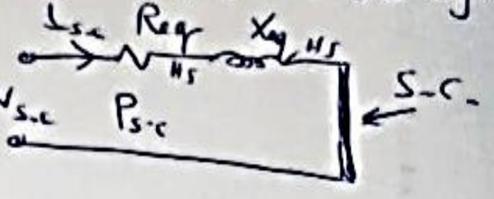
Determine (a) the equivalent high-side parameters; ***(b)*** voltage-regulation; ***(c)*** efficiency at rated load and 92 % power-factor lagging.

⑤ Det. ⓐ $R_{eq,HS}$, $X_{eq,HS}$ ⓑ $V_{reg.}$ ⓒ η at rated load, P.F. = 0.92 Lag.

ⓐ From S.C. Test:



$$Z_{eq,HS} = \frac{V_{s.c}}{I_{s.c}} = 3.673\ \Omega$$

$$P_{s.c.} = I_{s.c}^2 R_{eq,HS} \quad \therefore R_{eq,HS} = 1.743\ \Omega$$

$$\because X_{eq,HS} = \sqrt{Z_{eq,HS}^2 - R_{eq,HS}^2} = 3.233\ \Omega$$

From O.C. Test:

$$I_{fe} = \frac{P_{o.c.}}{V_{o.c.}} = 0.8067\ A$$

$$R_{fe_{LS}} = \frac{V_{o.c.}}{I_{fe}} = 743.8\ \Omega$$

$$I_M = \sqrt{I_{oc}^2 - I_{fe}^2} = 3.24 A$$

$$\therefore X_{M,LS} = \frac{V_{o.c.}}{I_M} = 185.19\ \Omega$$

$$\because a = \frac{2400}{600} = 4$$

$$\therefore R_{fe,HS} = a^2 R_{fe_{LS}} = 11901\ \Omega$$

$$X_{M,HS} = a^2 X_{M_{LS}} = 2962.96\ \Omega$$

ⓑ $\because Z_{base_{HS}} = \frac{V_{HS}^2}{S_{Rated}} = 115.2\ \Omega$ at $\cos\theta = 0.92 \Rightarrow \theta = 23.07°$

$$\therefore R_{pu} = \frac{R_{eq,HS}}{Z_{base}} = 0.01513 \quad \& \quad X_{pu} = \frac{X_{eq,HS}}{Z_{base,HS}} = 0.02806$$

$$\therefore V_{reg.pu} = \sqrt{(R_{pu} + \cos\theta)^2 + (X_{pu} + \sin\theta)^2} - 1 = 0.0251 = 2.51\ \%$$

ⓒ $\because \eta_{rated} = \frac{P.F.}{P.F. + P_{core_{pu}} + R_{pu}}$ & $\because P_{core_{p.u.}} = \frac{P_{core}}{S_{rated}} = \frac{P_{o.c.}}{50000} = \frac{484}{50000} = 0.00968$

$$\therefore \eta_{rated} = \frac{0.92}{0.92 + 0.00968 + 0.01513} = 0.9737 = 97.37\ \%$$

4.) Two 60-kVA, 2300—230-V, 60-Hz transformers **A** and **B** are to be operated in parallel. The percent impedances based on individual transformer ratings are: $\mathbf{Z_A}$= (1.58 + j3.01) % and $\mathbf{Z_B}$ = (1.09 + j3.98) %.

Determine the percent of total bank current drawn by each transformer.

Solution

Since the transformers have the same apparent power ratings and the same voltage ratings, they will also have the same base impedance, and the problem may be solved using per-unit values.

$$\mathbf{Z}_{A,PU} = 0.0158 + j0.0301 = 0.033995\angle 62.3043^\circ$$

$$\mathbf{Z}_{B,PU} = 0.0109 + j0.0398 = 0.041266\angle 74.6840^\circ$$

$$\mathbf{Y}_{A,PU} = \frac{1}{0.033995\angle 62.3043^\circ} = 29.416\angle -62.3043^\circ = 13.672 - j26.046$$

$$\mathbf{Y}_{B,PU} = \frac{1}{0.041266\angle 74.6840^\circ} = 24.233\angle -74.6840^\circ = 6.401 - j23.373$$

$$\mathbf{Y}_{P,PU} = \mathbf{Y}_{A,PU} + \mathbf{Y}_{B,PU}$$

$$\mathbf{Y}_{P,PU} = (13.672 - j26.046) + (6.401 - j23.373) = 53.340\angle -67.89^\circ$$

$$I_A = \frac{Y_{A,PU}}{Y_{P,PU}} \times 100 = \frac{29.416}{53.340} \times 100 = \underline{55.15\%}$$

$$I_B = 100 - 55.15 = \underline{44.85\%}$$

***Question 3*: [10 Marks]**

5.) A three-phase, 230-V, 60-Hz, 100-hp, six-pole induction motor operating at rated conditions has an efficiency of 91 percent and draws a line current of 248-A. The core loss, stator copper loss, and rotor conductor loss are 1697-W, 2803-W, and 1549- W, respectively. **Determine (a)** power input; **(b)** total losses; **(c)** air-gap power; **(d)** shaft speed; **(e)** power factor; **(f)** combined windage, friction, and stray load loss; **(g)** shaft torque.

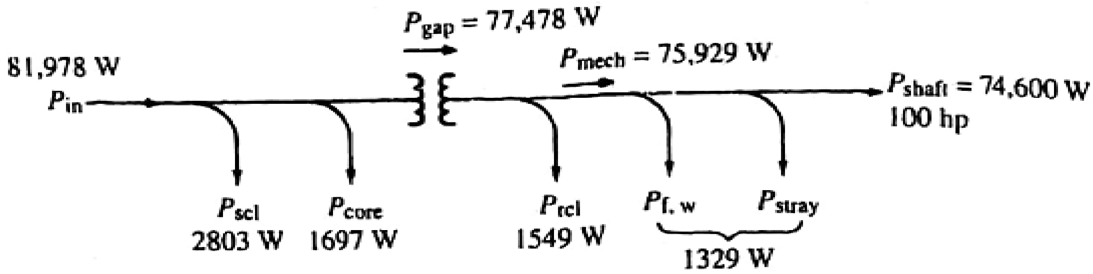


FIGURE 4.14
Power-flow diagram for Example 4.6.

(a) $$\eta = \frac{P_{shaft}}{P_{in}} \Rightarrow 0.910 = \frac{100 \times 746}{P_{in}}$$

$$P_{in} = \underline{81{,}978\text{ W}}$$

(b) $$P_{loss} = P_{in} - P_{shaft} = 81{,}978 - 100 \times 746 = \underline{7378\text{ W}}$$

(c) From Figure 4.14,

$$P_{gap} = P_{in} - P_{core} - P_{scl} = 81{,}978 - 1697 - 2803 = \underline{77{,}478\text{ W}}$$

(d) $P_{gap} = \frac{P_{rcl}}{s} \Rightarrow 77{,}478 = \frac{1549}{s}$

$$s = 0.0200$$

$$n_s = \frac{120f}{P} = \frac{120 \times 60}{6} = 1200 \text{ r/min}$$

$$n_r = n_s(1 - s) = 1200(1 - 0.0200) = \underline{1176 \text{ r/min}}$$

(e) $S = \sqrt{3}\, V_{line} I_{line} = \sqrt{3} \times 230 \times 248 = 98{,}796 \text{ VA}$

$$F_P = \frac{P_{in}}{S_{in}} = \frac{81{,}978}{98{,}796} = \underline{0.83}$$

(f) $P_{loss} = P_{core} + P_{scl} + P_{rcl} + P_{w,f} + P_{stray}$

$$7378 = 1697 + 2803 + 1549 + P_{w,f} + P_{stray}$$

$$P_{w,f} + P_{stray} = \underline{1329 \text{ W}}$$

(g) From Eq. (4–39)

$$T_{shaft} = \frac{5252 \times P_{shaft}}{n_r} = \frac{5252 \times 100}{1176} = \underline{446.6 \text{ lb-ft}}$$

<u>Question 4</u>: [10 Marks]

6.) A 240-V, 20-hp, 850 r/min shunt motor draws 72-A when operating at rated conditions. The respective resistances of armature and shunt field are 0.242 Ω and 95.2 Ω. **Determine** the percent reduction in field flux required to obtain a speed of 1650 r/min, while drawing an armature current of 50.4 A.

Solution

$$I_{f1} = \frac{240}{95.2} = 2.52 \text{ A}$$

$$I_{a1} = I_T - I_{f1} = 72 - 2.52 = 69.48 \text{ A}$$

$$E_{a1} = V_T - I_{a1}R_a = 240 - 69.48 \times 0.242 = 223.19 \text{ V}$$

$$E_{a2} = V_T - I_{a2}R_a = 240 - 50.4 \times 0.242 = 227.80 \text{ V}$$

$$n_2 = n_1 \cdot \frac{[E_a/\Phi_p]_2}{[E_a/\Phi_p]_1} \Rightarrow \Phi_{p2} = \frac{n_1}{n_2} \times \frac{E_{a2}}{E_{a1}} \times \Phi_{p1}$$

$$\Phi_{p2} = \frac{850}{1650} \times \frac{227.80}{223.19} \times \Phi_{p1} = 0.5258\Phi_{p1}$$

$$\frac{0.5258\Phi_{p1} - \Phi_{p1}}{\Phi_{p1}} \times 100 = \underline{-47.4\%}$$

7.) A 250-volt DC shunt motor has armature resistance of 0.25 ohm, on load it takes an armature current of 50 A and runs at 750 rpm. If the flux of motor is reduced by 10 % without changing the load torque, **find** the new speed of the motor.

Solution. $\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\Phi_1}{\Phi_2}$

Now, $T_a \propto \Phi I_a$. Hence $T_{a1} \propto \Phi_1 I_{a1}$ and $T_{a2} \propto \Phi_2 I_{a2}$.

Since $T_{a1} = T_{a2}$ ∴ $\Phi_1 I_{a1} = \Phi_2 I_{a2}$

Now, $\Phi_2 = 0.9\,\Phi_1$ ∴ $50\,\Phi_1 = 0.9\,\Phi, I_{a2} = 55.6$ A

∴ $E_{b1} = 250 - (50 \times 0.25) = 237.5$ V ; $E_{b2} = 250 - (55.6 \times 0.25) = 231.1$ V

∴ $\frac{N_2}{750} = \frac{231.1}{237.5} \times \frac{\Phi_1}{0.9\Phi_1}$; $N_2 =$ **811 r.p.m.**

Best wishes,