Benha University
Faculty of Engineering–Benha

Department	**: Electrical Engineering**	**Date**	**: Monday 10-1-2022**
3rd year	**: Power and Control**	**Time**	**: 3.0 hrs.**
Exam	**: Re-Final / Regular**	**Code**	**: E1331**
Subject	**: Electrical Machines I**	**Examiner:**	**Dr. Abdelnasser Nafeh**

Answer the Following Questions

Question 1:[20 Marks] [CLO = a1, a8, b1, c1]

1.) A magnetic circuit, composed of two half-rings of different core materials, is joined at the ends to form a doughnut. The cross-sectional area of the core is 0.14 m^2, and the reluctances of the two halves are 650 A-t/Wb and 244 A-t/Wb, respectively. A coil of 268 turns and 5.2-Ω is wound around the doughnut and connected to 45-V battery. ***Determine (a)*** the core flux; ***(b)*** *repeat (a)*, assuming the half-rings are separated 0.12 cm at each end (assume no fringing), and the reluctance of the half-rings does not change; ***(c)*** the magnetic drop across each air gap in *(b)*.

2.) In a certain transformer, the hysteresis loss was found to be 160 watts when the maximum flux density was 1.1 Wb/m^2 and the frequency 60 Hz. **What** will be the loss when the maximum flux density is reduced to 0.9 Wb/m^2 and frequency to 50 Hz?

Question 2: [20 Marks] [CLO = a2, a6, b2, c2]

3.) The primary and secondary of a 25 kVA transformer has 500 and 40 turns, respectively. If the primary is connected to 3000 V, 50 Hz mains, **calculate (i)** primary and secondary currents at full load; **(ii)** The secondary emf and **(iii)** The maximum flux in the core. Neglect magnetic leakage, resistance of the winding and the primary no-load current in relation to the full load current.

4.) Two 100-kVA single-phase, 60-Hz Transformers A and B are to be operated in parallel. The respective no-load voltage ratios and respective impedances as obtained from the transformer nameplates are:

Transformer	Voltage ratio	% R	% X
A	2300--460	1.36	3.5
B	2300--450	1.4	3.32

Determine (a) the circulating current in the paralleled secondaries; **(b)** the circulating current as a percent of the rated transformer A; **(c)** the percent difference in secondary voltage that caused the circulating current.

Question 3: [20 Marks] [CLO = a1, a9, b1,b2, c3]

5.) A DC generator carries 600 conductors on its armature with lap connections. The generator has 8 poles with 0.06 Wb useful flux. **What** will be the induced emf at its terminals if it is rotated at 1000 rpm? Also **determine** the speed at which it should be driven to induce the same voltage with wave connections?

6.) A 200-V shunt motor takes 10-A when running on no-load. At higher loads the brush drop is 2-V and at light load it is negligible. The stray load loss at a line current of 100-V is 50 % of the no-load loss. **Calculate** the efficiency at a line current of 100-A if armature and field resistance are 0.2-Ω and 100-Ω respectively.

Question 4: Short Answer Type Questions [15 Marks] [CLO = a1, a8, b1, ,b2,c1,c2]

1.) Define and explain a magnetic circuit.
2.) Explain the term MMF.
3.) How does leakage flux occur in a transformer?
4.) Does the flux in a transformer core increase with load?
5.) How can iron loss be measured?
6.) What is the necessity of parallel operation of three-phase transformers?
7.) What do you expect if star-delta transformer is connected in parallel with a star-star transformer?
8.) Why the armature of a DC machine is made of laminated silicon steel?
9.) What is armature reaction?
10.) How can the direction of rotation of a DC shunt motor be reversed?

Question 5: Multiple Choice Questions [15 Marks] [CLO = a1, a2, b1,b4 c3,c4]

1.) Permanent magnets are normally made of (a) aluminum (b) wrought iron (c) cast iron (d) alnico alloys.
2.) Transient currents in electrical circuit are associated with (a) inductors (b) capacitors (c) resisters (d) both (a) and (b).
3.) A transformer transforms (a) frequency (b) voltage (c) current (d) voltage and current.
4.) The main purpose of using core in a transformer is to (a) decrease iron losses (b) prevent eddy current loss (c) eliminate magnetic hysteresis (d) decrease reluctance of the common magnetic circuit.
5.) Which of the following connections is best suited for 3-phase, 4-wire service?
(a) $\Delta - \Delta$ (b) Y – Y (c) $\Delta - Y$ (d) $Y - \Delta$.
6.) As compared to $\Delta - \Delta$ bank, the capacity of the $V - V$ bank of transformers is .... percent.
(a) 57.7 (b) 66.7 (c) 50 (d) 86.6.
7.) Instrument transformers are used on a.c. circuits for extending the range of (a) ammeters (b) voltmeters (c) watt meters (d) all of the above.
8.) Before removing the ammeter from a current transformer, its secondary must be short-circuited in order to avoid (a) excessive heating of the core (b) high secondary e.m.f. (c) increase in iron losses (d) all of the above.
9.) The critical resistance of the d.c. generator is the resistance of (a) armature (b) field (c) load (d) brushes.
10.) The d.c. series motor should never be switched on at no load because (a) the field current is zero (b) The machine does not pick up (c) The speed becomes dangerously high (d) It will take too long to accelerate.

Best wishes,

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(a) Given $A = 0.14\ m^2$

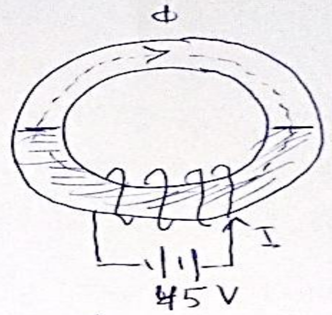
$\mathcal{R}_1 = 650\ At/wb$, $\mathcal{R}_2 = 244\ At/wb$

$N = 268\ t$, $R = 5.2\ \Omega$

$\mathcal{R}_T = \mathcal{R}_1 + \mathcal{R}_2 = 894\ At/wb$

$I = \frac{V}{R} = \frac{45}{5.2} = 8.65\ A$

$\therefore \Phi = \frac{NI}{\mathcal{R}_T} = 2.59\ wb.$



(b) $\mathcal{R}_T = \mathcal{R}_1 + \mathcal{R}_2 + \mathcal{R}_g + \mathcal{R}_g$

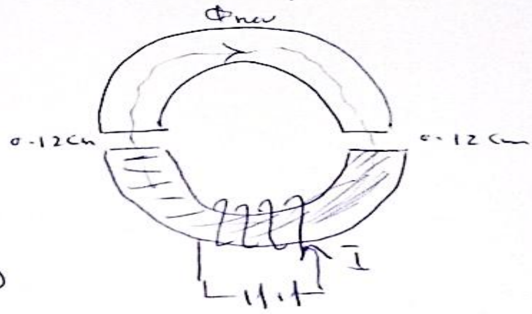
$\mathcal{R}_g = \frac{l_g}{\mu_0 A_g} = \frac{0.0012}{4\pi \times 10^{-7}(0.14)}$

$\therefore \mathcal{R}_g = 6820.93\ At/wb$

$\therefore \mathcal{R}_T = 894 + 2(6820.93)$

$\therefore \mathcal{R}_T = 14535.83\ At/wb$

$\therefore \Phi_{new} = \frac{NI}{\mathcal{R}_T} = \frac{268(8.65)}{14535.85} = 0.1595\ wb.$



(c) Find $\mathcal{F}_g$ when $\Phi = 0.1595\ wb.$ from (b)

$\because \mathcal{F}_g = \Phi_g \mathcal{R}_g = (0.1595)(6820.93) = 1088.3\ At$

or $\because B_g = \frac{\Phi_g}{A_g} = 1.397$ Tesla

$H_g = \frac{B_g}{\mu_0} = 906912.86\ At/m$

$\therefore \mathcal{F}_g = H_g l_g = 1088.3\ At$

2. In a certain transformer, the hysteresis loss was found to be 160 watts when the maximum flux density was 1·1 Wb/m^2 and the frequency 60 Hz. **What** will be the loss when the maximum flux density is reduced to 0·9 Wb/m^2 and frequency to 50 Hz?

Solution. According to Steinmetz hysteresis law,

$$\text{Hysteresis loss, } P_h \propto f(B_{max})^{1\cdot6}$$

$$\text{For the first case, } P_1 \propto 60 \times (1\cdot1)^{1\cdot6}$$

$$\text{For the second case, } P_2 \propto 50 \times (0\cdot9)^{1\cdot6}$$

$$\therefore \quad \frac{P_2}{P_1} = \frac{50 \times (0\cdot9)^{1\cdot6}}{60 \times (1\cdot1)^{1\cdot6}} = 0\cdot604$$

$$\therefore \quad P_2 = 0\cdot604\, P_1 = 0\cdot604 \times 160 = \mathbf{96\cdot64\ W}$$

Question 2: [20 Marks] [CLO = a2, a6, b2, c2]

3. The primary and secondary of a 25 kVA transformer has 500 and 40 turns, respectively. If the primary is connected to 3000 V, 50 Hz mains, **calculate (i)** primary and secondary currents at full load; **(ii)** The secondary emf and **(iii)** The maximum flux in the core. Neglect magnetic leakage, resistance of the winding and the primary no-load current in relation to the full load current.

Solution:

(*i*) At full load, $I_1 = \frac{25 \times 10^3}{3000} = \mathbf{8\cdot33}$ (*Ans.*)

Now $\frac{I_1}{I_2} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$

secondary current, $I_2 = \frac{N_1}{N_2} \times I_1 = \frac{500}{40} \times 8\cdot33 = \mathbf{104\cdot15\ A}$ (*Ans.*)

(*ii*) Secondary emf, $E_2 = \frac{N_2}{N_1} \times E_1 = \frac{40}{500} \times 3000 = \mathbf{240\ V}$ (*Ans.*)

(*iii*) Using relation, $E_1 = 4\cdot44\, N_1 f \phi_m$

$3300 = 4\cdot44 \times 500 \times 50\, x\, \phi_m$

or $\phi_m = \frac{3000}{4\cdot44 \times 500 \times 50} = \mathbf{27\ mWb}$ (*Ans*)

4.)

Two 100-kVA single-phase, 60-Hz transformers *A* and *B* are to be operated in parallel. The respective no-load voltage ratios and respective impedances as obtained from the transformer nameplates are

Transformer	Voltage Ratio	%R	%X
A	2300—460	1.36	3.50
B	2300—450	1.40	3.32

Determine (a) the circulating current in the paralleled secondaries; (b) the circulating current as a percent of the rated current of transformer *A;* (c) the percent difference in secondary voltage that caused the circulating current.

Solution

(a) The rated low-side currents are

$$I_A = \frac{100 \times 1000}{460} = 217.39 \text{ A} \qquad I_B = \frac{100 \times 1000}{450} = 222.22 \text{ A}$$

The equivalent resistance and equivalent reactance of each transformer referred to the low side is

$$R_{PU} = \frac{I_{rated} \cdot R_{eq}}{V_{rated}} \qquad X_{PU} = \frac{I_{rated} \cdot X_{eq}}{V_{rated}}$$

$$0.0136 = \frac{217.39 \cdot R_{A,eq}}{460} \qquad 0.0350 = \frac{217.39 \cdot X_{A,eq}}{460}$$

$$R_{A,eq} = 0.0288\ \Omega \qquad X_{A,eq} = 0.0741\ \Omega$$

$$0.0140 = \frac{222.22 \cdot R_{B,eq}}{450} \qquad 0.0332 = \frac{222.22 \cdot X_{B,eq}}{450}$$

$$R_{B,eq} = 0.0284\ \Omega \qquad X_{B,eq} = 0.0672\ \Omega$$

The impedance of the closed loop formed by the two secondaries is

$$\mathbf{Z}_{loop} = \mathbf{Z}_A + \mathbf{Z}_B = 0.0288 + j0.0741 + 0.0284 + j0.0672 = 0.0572 + j0.1413$$

$$\mathbf{Z}_{loop} = 0.1524\angle 67.97^\circ\ \Omega$$

From Eq. (3–4),

$$\mathbf{I}_{circulating} = \frac{460\angle 0^\circ - 450\angle 0^\circ}{0.1524\angle 67.97^\circ} = 65.62\angle -67.97^\circ \text{ A} \quad \Rightarrow \quad \underline{65.6\angle -68.0^\circ \text{A}}$$

(b)

$$\frac{65.62}{217.39} \cdot 100 = \underline{30.2\%}$$

(c)

$$\frac{460 - 450}{450} \cdot 100 = \underline{2.2\%}$$

Note that a 2.2 percent difference in secondary voltages caused a circulating current equal to 30.2 percent of transformer *A* rated current. Although the circulating current is not apparent at the load terminals, loading the transformer bank until rated load is supplied will seriously overload transformer *A*, and the resultant overheating will damage the winding insulation. It is extremely important that the turns ratio of paralleled transformers be as close to identical as possible if circulating currents and their adverse effects are to be avoided.

Question 3: [20 Marks] [CLO = a1, a9, b1,b2, c3]

5.

A DC generator carries 600 conductors on its armature with lap connections. The generator has 8 poles with 0.06 Wb useful flux. What will be the induced emf at its terminals if it is rotated at 1000 rpm? Also determine the speed at which it should be driven to induce the same voltage with wave connections?

Solution:

Here, $P = 8$; $Z = 600$; $\phi = 0.06$ Wb; $N = 1000$ rpm.

$$A = P = 8 \text{ (when lap wound)}$$

$$\text{Induced emf, } E_g = \frac{\phi ZNP}{60A} = \frac{0.06 \times 600 \times 1000 \times 8}{60 \times 8} = \mathbf{600\ V}\ (Ans.)$$

when wave wound, let the speed be N′ rpm but $E_g = 600$ V

$$\text{Now, } N' = \frac{E_g \times 60A}{\phi ZP} = \frac{600 \times 60 \times 2}{0.06 \times 600 \times 8} = \mathbf{250\ rpm}\ (Ans.)$$

6.

A 200-V shunt motor takes 10-A when running on no-load. At higher loads the brush drop is 2-V and at light load it is negligible. The stray load loss at a line current of 100-V is 50 % of the no-load loss. **Calculate** the efficiency at a line current of 100-A if armature and field resistance are 0.2-Ω and 100-Ω respectively.

Solution:

Here, $V = 200$ V; $I_{L0} = 10$ A; $V_{bf} = 2$V; $V_{b0} = 0$ V

Stray load loss = 50% of no-load loss; $R_a = 0.2\ \Omega$; $R_{sh} = 100\ \Omega$

$$\text{Input at no-load} = V \times I_{L0} = 200 \times 10 = 2000 \text{ W}$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{100} = 2\text{A}$$

$$\text{Shunt field Cu loss} = I_{sh}^2 R_{sh} = (2)^2 \times 100 = 400 \text{ W}$$

$$\text{Stray loss} = \frac{50}{100} \times 2000 = 1000 \text{ W}$$

At load, armature current, $I_a = I_L - I_{sh} = 100 - 2 = 98$ A

$$\text{Armature copper loss} = I_a^2\ R_a = (98)^2 \times 0.2 = 1920.8 \text{ W}$$

$$\text{Loss at brushes} = V_{bf} \times I_a = 2 \times 98 = 196 \text{ W}$$

$$\text{Total losses} = \text{Stray loss} + \text{Armature Cu loss} + \text{Shunt field Cu loss} + \text{Brush contact loss}$$

$$= 1000 + 1920.8 + 400 + 196 = 3516.8 \text{ W}$$

$$\text{Input to motor} = V \times I_L = 200 \times 100 = 20000 \text{ W}$$

$$\text{Motor efficiency, } \eta = \frac{\text{output}}{\text{input}} = \frac{\text{Input} - \text{Losses}}{\text{Input}} \times 100$$

$$= \frac{20000 - 3516.8}{20000} \times 100 = \mathbf{82.416\%}\ (Ans.)$$

<u>Question 4: Short Answer Type Questions [15 Marks] [CLO = a1, a8, b1, ,b2,c1,c2]</u>

1. **Define and explain a magnetic circuit.**

Ans. A complete closed path followed by a group of magnetic lines force is called a magnetic circuit. In a magnetic circuit, the magnetic flux leaves from north pole, passes through the circuit and returns to the north pole.

2. **Explain the term MMF.**

Ans. The force which drives the magnetic flux through a magnetic circuit is called the magneto motive force. It is produced by passing electric current through wire of number of turns. It is measured in ampere-turns (AT). MMF in a magnetic circuit can be compared to EMF in an electric circuit. Both are pressure. MMF is magnetic pressure and EMF is electric pressure.

3. **How does leakage flux occur in a transformer?**

Ans. When current flows through primary winding of a transformer, it produces magnetic flux. Most of the flux is set-up in the magnetic core, since it offers very low reluctance, and links with the secondary. But at the same time minute flux is set-up in air around the coil which does not link with the secondary. This magnetic flux is called primary leakage flux. Similarly, there will be secondary leakage flux.

4. **Does the flux in a transformer core increase with load?**

Ans. No, flux in the core of a transformer remains the same from no-load to full-load.

5. **How can iron loss be measured?**

Ans. Iron losses can be measured by performing no-load test on a transformer.

6. **What is the necessity of parallel operation of three-phase transformers?**

Ans. ***(i)*** It is desirable to place another transformer is parallel when the electrical load on the existing transformer increases beyond its rated capacity.

(ii) Parallel operation of transformers is necessary when the amount of power to be transformed is much more than that which can be handled by single unit (transformer).

(iii) It is desirable to do parallel operation of transformers if we want to keep the spare transformer of smaller size.

7. **What do you expect if star-delta transformer is connected in parallel with a star-star transformer?**

Ans. The phasor displacement cannot be compensated and the transformers will come under direct short -circuit condition.

8. **Why the armature of a DC machine is made of laminated silicon steel?**

Ans. To reduce hysteresis and eddy current loss.

9. **What is armature reaction?**

Ans. The effect of magnetic field set up by the armature current carrying conductors on the distribution of flux set-up by the main poles of a DC machine is called armature reaction.

10. **How can the direction of rotation of a DC shunt motor be reversed?**

Ans. Direction of rotation of a DC shunt motor can be reversed by reversing the current flow through either the armature winding or the field winding.

<u>Question 5: Multiple Choice Questions [15 Marks] [CLO = a1, a2, b1,b4 c3,c4]</u>

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(b) Δ − Δ (b) Y – Y ***<u>(c) Δ − Y</u>*** (d) Y − Δ.

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<u>(b)</u> ***<u>57.7</u>*** (b) 66.7 (c) 50 (d) 86.6.

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1-c	2-d	3-d	4-d	5-c	6-a	7-d	8-d	9-b	10-c

Best wishes,