Professional Engineers Ontario

Electromagnetic Energy Conversion Exam

98-Elec-A6

Spring 2002

Notes:

Attempt question 1 and FOUR (4) other questions (FIVE (5) questions in all). Unless you indicate otherwise, the first five questions will be the only ones marked. All questions are of equal value.

2. You may use one of the approved Casio or Sharp calculators.

3. This is a closed book exam. Formulae sheets are attached.

4. Marks will be lost if answers do not include appropriate units

5. All a.c. voltages and currents are rms values unless noted otherwise. For three-phase circuits, all voltages are line-to-line voltages unless noted otherwise.

6. You may use pencil.

7. Parts of questions may or may not be related - read carefully!

If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper a clear statement of any assumptions made.

Question 1

a. Show that, with the aid of a phasor diagram, the power output for a synchronous generator is given by:

$$P = \frac{3 V_t E_f}{X_s} \sin\delta$$

b. In the equivalent circuit of a transformer, the magnetizing branch is shown connected in parallel. Why is it not connected in series?

c. In a DC shunt motor, the field current is decreased by 10%. What, if any, is the effect on motor speed? Why?

d. A 3ϕ synchronous motor provides mechanical power to a full load. A decrease in the field current causes an increase in the line current. Is the line current leading or lagging the terminal voltage? Why?

e. Why can the fourth wire of a balanced 3ϕ, 4-wire, Y-connected load be smaller than the others?

f. When we get an electricity bill from our local utility, and the rate is 9.145¢/kWh, are we paying for power or for energy? Justify your answer.

g. At the start of the 20th century, most power systems were DC systems. However, with the introduction of the transformer, most systems became ac systems. Why weren't transformers used in the DC systems?

h. In the circuit of Figure 1 below, $\mathbf{Z}_1 = 1\angle 60°\ \Omega$ and $\mathbf{Z}_2 = 5\angle 36.9°\ \Omega$. The line-to-line voltage is 208 V. What is the magnitude of the line current?

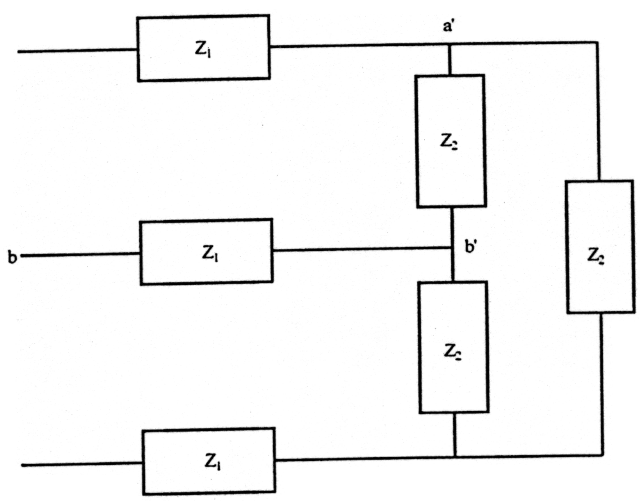

Figure 1

Question 2 - DC Machines

A 50 hp, 200 V, 1800 rpm shunt motor requires a starter box. The armature circuit resistance is 0.15 Ω.

a. Determine the starting current if no starting resistance is used in the armature circuit.

b. Design a starter box such that the armature current, I_a, is constrained within the range 200 to 400 A. Provide a sketch of your design, showing all resistor values.

c. Sketch curves showing the variation of I_a with time, and motor speed with time.

Question 3 - Induction Motors

A 4-pole, 208 V, 3ϕ, 60 Hz, 10 hp, Y-connected SCIM has the following characteristics:

$R_1 = 0.4\ \Omega$ $X_1 = 0.35\ \Omega$

$R_2' = 0.14\ \Omega$ $X_1' = 0.35\ \Omega$ $X_m = 16\ \Omega$

Rotor losses are 360 W. Draw an equivalent circuit showing the given parameters, and, at a motor speed of 1746 rpm, calculate, *on a per-phase basis*, the following:

a. the stator armature current;
b. the rotor current;
c. stator input power;
d. stator copper loss;
e. rotor power input;
f. rotor power developed;
g. total output power in watts and horsepower;
h. motor efficiency; and,
j. output torque.

Question 4 - Synchronous Machines

The nameplate of a three-phase, Y-connected synchronous motor has the following information:

HP	20,000	RPM	1800	pf	1.0
Volts	6600	Amps	1350	Frequency	60
Excitation voltage	120	Amps	5.5		

The per-unit synchronous reactance is X_s is 0.95 Ω, and the per-unit resistance is $R_a = 0.012\ \Omega$.

a. Determine the number of poles of the synchronous motor.

b. Determine X_s and R_a in ohms, using the rated voltage as base, and a base current of 1500 A.

c. For rated (full-load) condition,

   i. Determine the output torque in N-m.

   ii. Determine the efficiency.

   iii. Determine the rotational loss.

   iv. Determine the power loss in the field circuit.

   v. Determine the per-unit E_f and I_a, and sketch a neatly-labelled phasor diagram.

Question 5 - Transformers

a. Determine the secondary voltage (referred to the secondary) for the two transformer circuits below if the percentage voltage regulation is 3% and rated load is connected to the secondary.

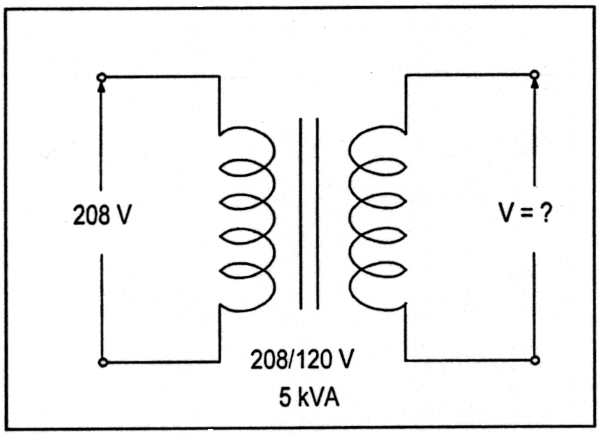

Figure 2

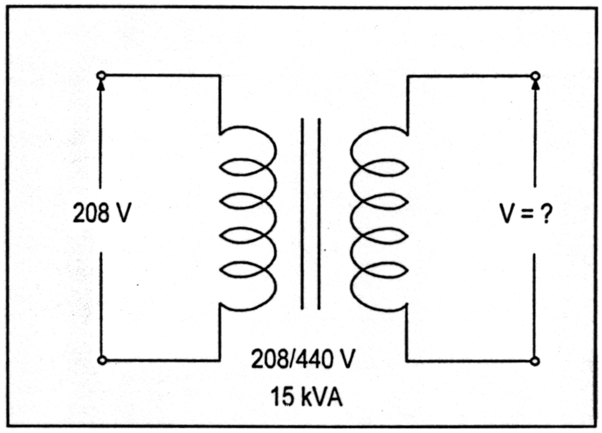

Figure 3

b. A 10 kVA, 4000/125 V, 60 Hz, single-phase transformer provides the following test results:

	Voltage	Current	Power input
Open-circuit test	125 V	0.25 A	25 W
Short-circuit test	100 V	2.5 A	125 W

i. Indicate on which side the measurements were taken, and the reasons for your choice;

ii. Determine the approximate parameters of the transformer referred to the high-voltage winding; and,

iii. With a load of 7 kVA at 0.707 pf lagging attached to the low-voltage winding, and rated voltage across the winding, determine the efficiency.

Question 6 - Magnetic Circuits

The table below is for the magnetic circuit shown below. The core is made of cast steel and its magnetization curve is provided on the next page. Determine (a) the required coil mmf to provide the specified flux; and, (b) the length of the air gap.

Path	Cross-sectional area (m^2)	Length (m)	Flux (Webers)
cfa	0.05	0.8	
abc	0.03	0.4	4.2×10^{-2}
ad	0.272	0.15	
de	0.272	?	2.8×10^{-2}
ec	0.272	0.15	

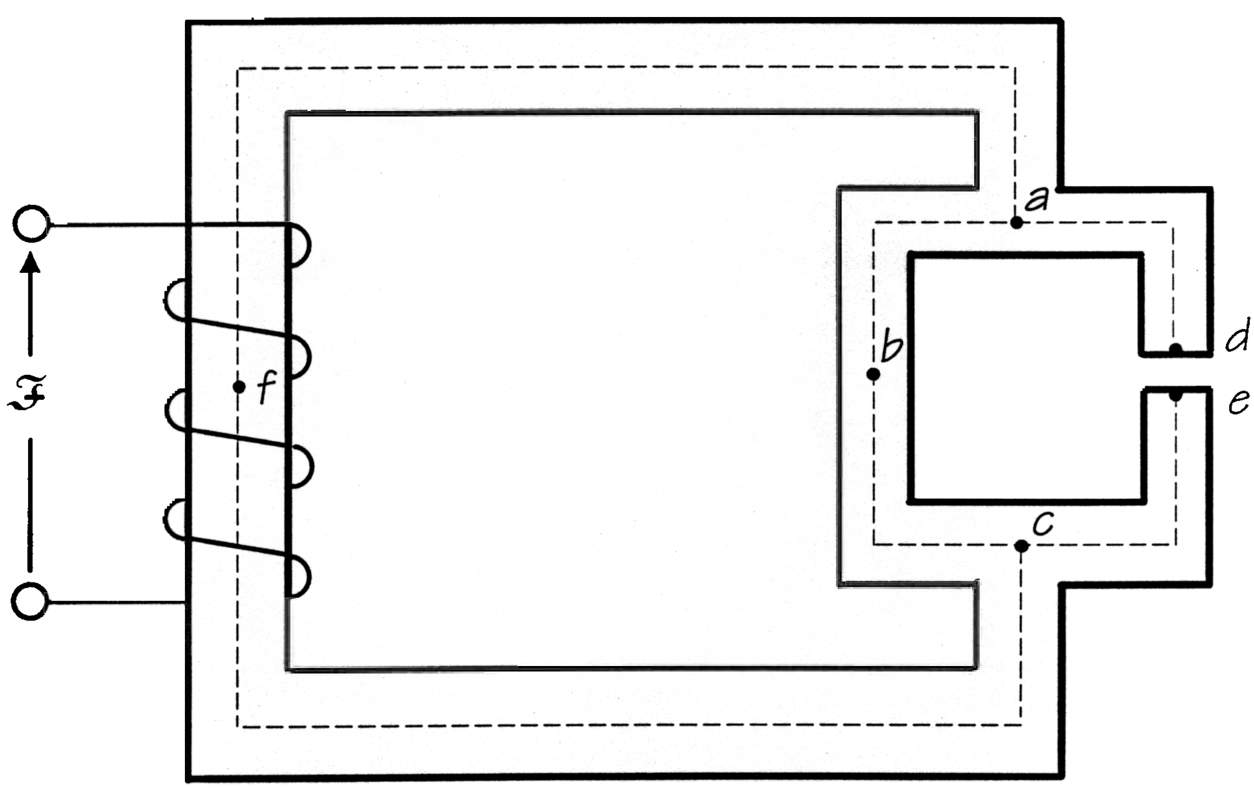

Figure 4

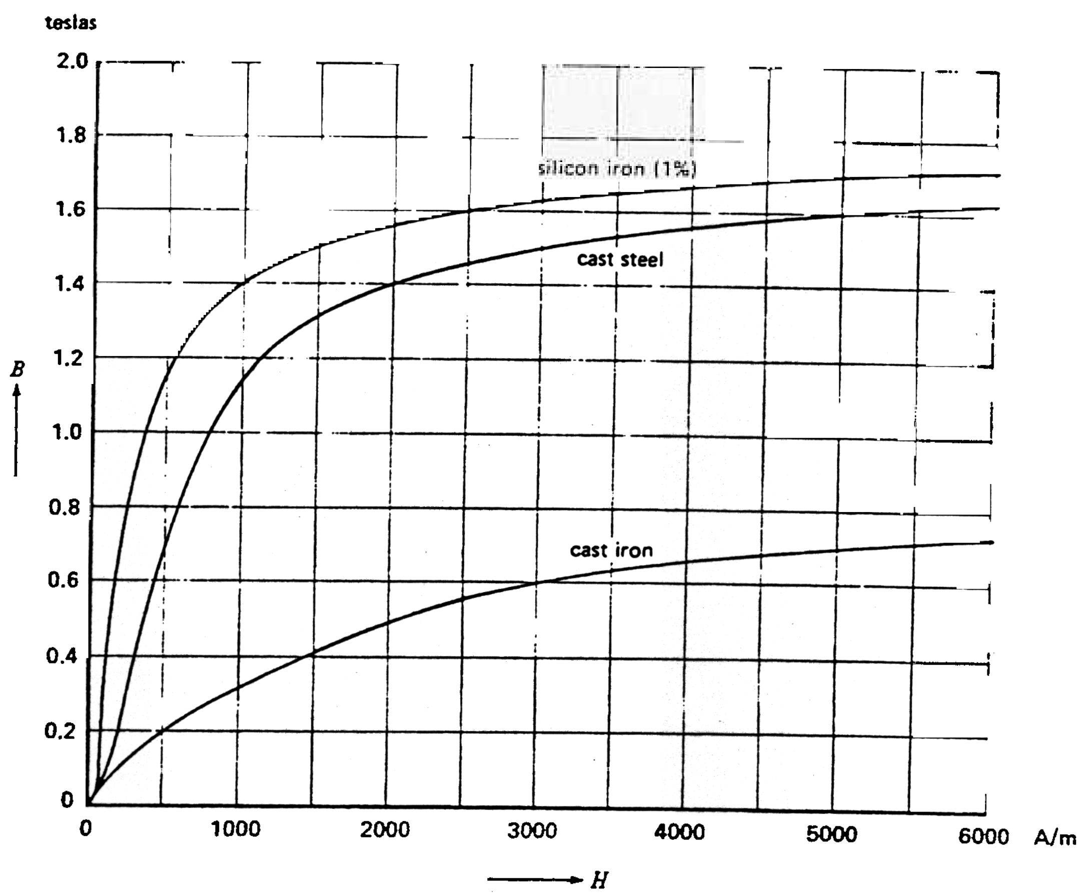
teslas
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
B
silicon iron (1%)
cast steel
cast iron
0
1000
2000
3000
4000
5000
6000
A/m
H

Figure 5

Question 7 - Three-phase circuits

a. In a factory, the following are the three-phase loads:

Induction motors:	1000 hp 0.7 average power factor 0.85 average efficiency
Lighting and heating loads:	100 kW

A three-phase synchronous motor is to be installed to provide 300 hp for a new process. The synchronous motor operates at 92% efficiency. Determine the required kVA rating of the synchronous motor if the overall factory power factor is to be raised to 0.95. Determine the power factor of the synchronous machine.

b. If the factory supply voltage is 600 V (line-to-line), determine the three line currents. Draw a phasor diagram showing these currents, as well as the three line-to-line and three line-to-neutral voltages.

END OF THE EXAM

Potentially useful formulae

$$VI\cos\theta = \frac{V_R^{\,2}}{R} = I^2R = Re[\mathbf{VI}^*]$$

$$VI\sin\theta = \frac{V_X^{\,2}}{X} = I^2X = Im[\mathbf{VI}^*]$$

$$\mathbf{S} = \mathbf{VI}^*$$

$$|\mathbf{S}| = \sqrt{P^2 + Q^2} = VI = I^2Z = \frac{V^2}{Z}$$

$$p.f. = \cos\theta = \frac{R}{Z} = \frac{P}{S}$$

$$P_T = \sqrt{3}V_LI_L\cos\theta = 3P_P \qquad P_P = V_PI_P\cos\theta$$

$$Q_T = \sqrt{3}V_LI_L\sin\theta = 3Q_P \qquad Q_P = V_PI_P\sin\theta$$

$$S_T = \sqrt{3}V_LI_L \qquad S_P = V_PI_P$$

$$B = \frac{\phi}{A} = \mu H = \mu\frac{\mathscr{F}}{l} = \mu\frac{Ni}{l} \qquad \left[\frac{Wb}{m^2} = T\right]$$

$$H = \frac{NI}{l} = \frac{B}{\mu} = \frac{\phi/A}{\mu} \qquad \left[\frac{A-t}{m}\right]$$

$$\mathscr{F} = Ni = \phi\frac{l}{\mu A} \qquad [A-t]$$

$$\Re = \frac{l}{\mu A} \qquad \left[\frac{A-t}{Wb}\right]$$

$$\mathscr{F} = \Re\phi$$

$$\mu_0 = 4\pi \times 10^{-7}\,\frac{Wb}{A-t-m} \qquad \mu = \mu_0\mu_r$$

$$P_e = K_t f^2 B^2_{\max} V_{vol}$$

$$P_h = K_h f B^x_{\max} V_{vol}$$

$$L = \frac{N^2}{\Re}$$

$$I \quad I \quad I$$

$$V \qquad I\, R$$

$$E \quad K\, \phi\, \omega$$

$$T \quad K\, \phi\, I$$

$$P_{input} \quad V\, I$$

$$P \quad E\, I \quad T$$

$$P \quad P \quad P \quad T$$

$$P \quad \text{No load } P_{dev}$$

$$120 \frac{f}{p}$$

$$\frac{s \quad m}{}$$

$$P_{input} \quad V\, I$$

$$P \quad P_{input} \quad I_1\, R \quad 3I \quad \frac{R_2}{} \quad T_{dev}\, \omega$$

$$I \quad R_2' \quad P$$

$$P_{dev} \quad P \quad 3I \quad R_2' \quad 1 \quad P$$

$$P \quad P_{dev} \quad P_{rot} \quad T$$

$$\mathbf{E} \quad \mathbf{V} \quad (R_a \quad X_s$$

$$P \quad \frac{3 V_t E_f}{X_s}$$