Electromagnetic Energy Conversion Exam

98-Elec-A6

Fall 2003

Notes:

1. Attempt question 1 and FOUR (4) other questions (FIVE (5) questions in all). All questions are of equal value. Please indicate on the front of the first answer booklet which questions were attempted, and in which order.

2. Be neat! Work that is messy and/or difficult to read or follow may not be marked.

3. You may use pencil.

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

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

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

7. 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.

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

If doubt exists as to the interpretation of any question, please submit with your answer paper a clear statement of any assumptions made. Also, please note any assumptions used in calculations.

Question 1 - General Knowledge

a. Sketch the hysteresis loop of a magnetic core, and discuss the behaviour of the loop as the magnetizing current goes through the first 1.5 cycles of a.c. current, assuming the magnetic core is initially demagnetized.

b. Sketch a conductor carrying DC current, situated in, and normal to, the magnetic field of a permanent magnet. Show the direction of current, component magnetic fields, resultant field, and direction of mechanical forces exerted on the conductor.

c. Why is the iron core of a transformer laminated?

d. Sketch the torque-speed curve of a typical induction motor, with torque as the y-axis, and the slip *and* motor speed as the x-axis.

e. What is the purpose of an amortisseur winding on a synchronous motor?

f. Many DC shunt motors will automatically be switched off if the field is lost. Why is that?

g. Define voltage regulation as it pertains to a synchronous generator.

h. What two methods can be used to reverse the direction of rotation of a DC shunt motor?

i. Give two reasons why a three-phase power system is preferable to three single-phase systems for delivering the same amount of power.

j. When a synchronous generator is connected to the grid, its terminal voltage and supply frequency are fixed. What, then, will be the effect of decreasing the field current?

Question 2 - Three-phase power

Two balanced three-phase loads are connected in parallel and are fed by a three-phase line having a series impedance of $(0.4 + j2.7)\ \Omega$ per phase. One of the loads absorbs 560 kVA at 0.707 power factor lagging, while the other 132 kW at unity power factor. The line-to-line voltage at the loads is 3800 V. Draw a one-line diagram for this system, and determine:

a. the line-to-line voltage at the source end of the line;
b. the real and reactive power losses in the line;
c. the real and reactive power supplied at the sending end of the line; and,
d. the total load power factor.

Question 3 - Transformers

A 100 kVA, 60 Hz, 7200/480 V, single-phase transformer has the following parameters:

$R_{HV} = 3.06\ \Omega$	$X_{HV} = 6.05\ \Omega$	$X_{m,HV} = 17{,}809\ \Omega$
$R_{LV} = 0.014\ \Omega$	$X_{LV} = 0.027\ \Omega$	$R_{c,HV} = 71{,}400\ \Omega$

The transformer load draws rated current at 480 V and 0.75 power factor lagging. Sketch the *approximate* equivalent circuit (indicating whether you are showing the HV side of the LV side), and determine:

a. the transformer equivalent impedance, referred to the HV side;
b. the load current referred to the HV side;
c. the source voltage; and,
d. the excitation current (referred to the HV side).

Question 4 - Induction Motors

A three-phase, 230 V, 30 hp, 60 Hz, six-pole induction motor is operating with a shaft load that requires 21.3 kW to cross the air gap to the rotor. Rotor copper loss is 1.05 kW, and mechanical and stray load losses are 300 W. Determine:

a. shaft speed;
b. mechanical power developed;
c. developed torque;
d. shaft torque; and,
e. percent of rated hp the machine is required to deliver to the load.

Question 5 - Synchronous Machines

A three-phase, 60 Hz, 460 V system supplies the following loads:

1. a six-pole, 60 Hz, 400 hp, three-phase, Y-connected induction motor, operating at three-quarters rated load with an efficiency of 95.8% and power factor of 0.891 lagging ; and,

2. a 50 kW, Δ-connected, three-phase resistance heater; and,

3. a 300 hp, 60 Hz, four-pole, Y-connected, cylindrical-rotor synchronous motor, operating at one-half rated load, with a power angle of -16.4°, an efficiency of 96%, and a synchronous reactance of 0.667 Ω/phase (copper resistance is negligible).

Determine:

a. the system active power;
b. the power factor of the synchronous motor;
c. the system power factor;
d. the percent change in synchronous motor field current required to adjust the system power factor to unity; and,
e. the power angle of synchronous motor for the conditions of part (d).

Question 6 - DC Motors

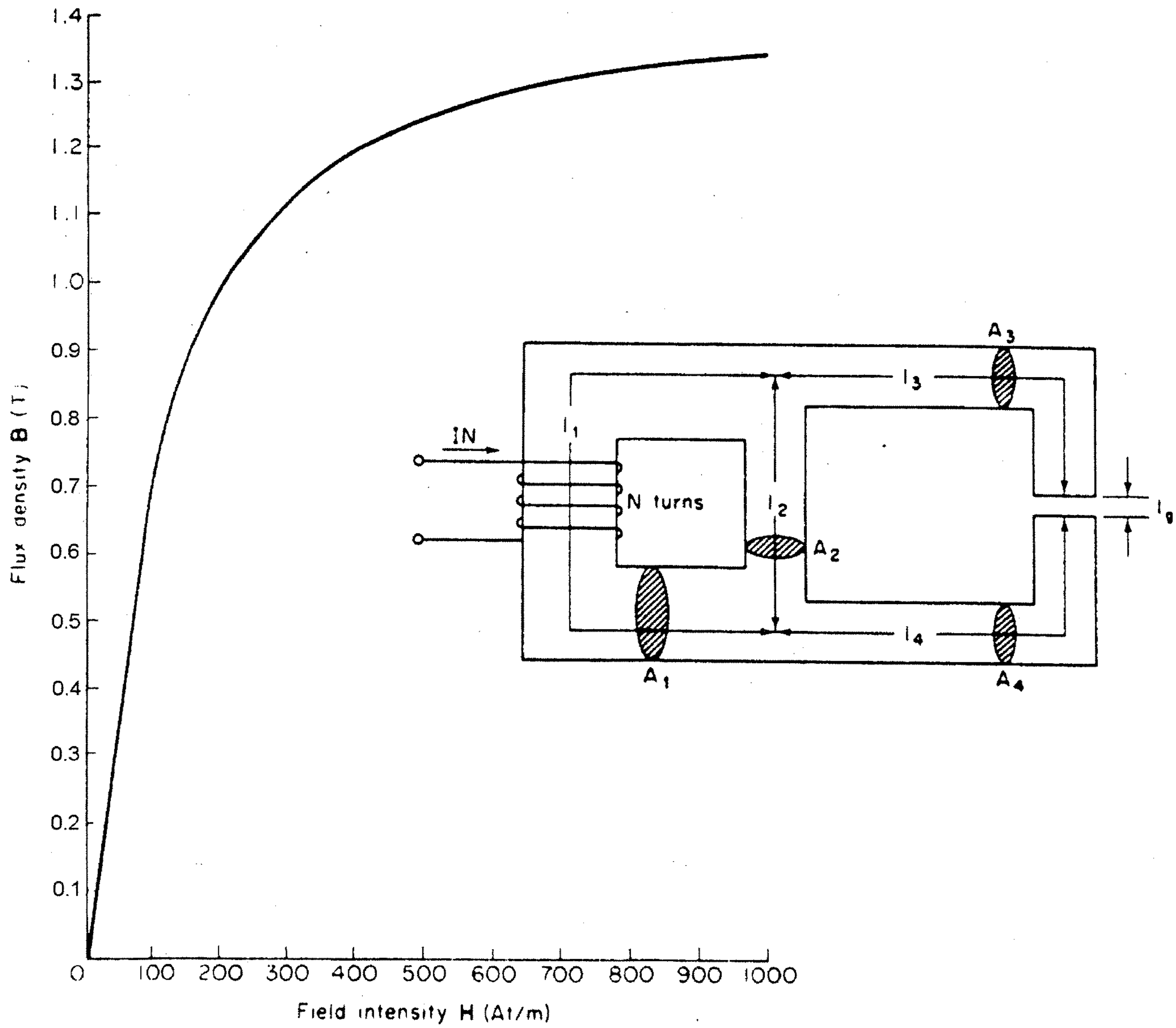
A 50 hp, 240 V, 650 rpm DC shunt motor operating at rated load draws a line current of 173 A. The motor has an armature resistance of 0.0705 Ω and a shunt field resistance of 81.63 Ω.

a. Sketch the equivalent circuit for this motor.
b. Determine the efficiency if rotational losses are 732 W.
c. If a reduction in load causes the armature current to drop to 70% of its rated value, determine the new line current and new motor speed. What is the motor output power (assuming rotational losses are constant)?

Question 7 - Magnetic Circuits

Find the current, I_N, required to establish a flux of 2 mWb in the air gap of the magnetic structure shown in the figure below. The structure is made of silicon sheet steel, and its magnetization curve is as shown. Assume that the coil has 500 turns, and the structure has the following dimensions:

$l_1 = 40$ cm	$A_1 = 40$ cm^2	$l_3 = l_4 = 26$ cm	$A_3 = A_4 = 25$ cm^2
$l_2 = 24$ cm	$A_2 = 12$ cm^2	$l_g = 25 \times 10^{-3}$ cm	$A_g = 26$ cm^2



Potentially useful formulae

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

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

$$\mathbf{S} = \mathbf{V}\,\mathbf{I}^*$$

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

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

$$P_T = \sqrt{3}\,V_L I_L\cos\theta = 3P_P \qquad P_P = V_P I_P\cos\theta$$

$$Q_T = \sqrt{3}\,V_L I_L\sin\theta = 3Q_P \qquad Q_P = V_P I_P\sin\theta$$

$$S_T = \sqrt{3}\,V_L I_L \qquad S_P = V_P I_P$$

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

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

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

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

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

$$P_e = K_e f^2 B^2_{\max} V_{vol} \qquad P_h = K_h f B^x_{\max} V_{vol}$$

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

$$P_{dev} = E_a I_a = T_{dev} \omega_m$$

$$P_{out} = P_{dev} - P_{rot} = T_{out} \omega_m$$

$$P_{rot} = \text{No load } P_{dev}$$

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

$$s = \frac{n_s - n_m}{n_s}$$

$$P_{input} = 3 V_1 I_1 \cos\theta$$

$$P_{gap} = P_{input} - 3 I_1^2 R_1 = 3 I_2'^2 \frac{R_2'}{s} = T_{dev} \omega_s$$

$$3 I_2'^2 R_2' = s P_{gap}$$

$$P_{dev} = P_{gap} - 3 I_2'^2 R_2' = (1 - s) P_{gap}$$

$$P_{out} = P_{dev} - P_{rot} = T_{out} \omega_m$$

$$\mathbf{E_f} = \mathbf{V_t} + \mathbf{I_a}(R_a + jX_s)$$

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