National Exams May 2004

98-Elec-A6

Electromagnetic Energy Conversion

3 hours duration

Notes:

1. FIVE (5) questions constitute a complete exam paper. Unless you indicate otherwise, the first five questions as they appear in the answer book will be the only ones marked. All questions are of equal value.

2. Any Sharp or Casio approved calculator is permitted.

3. This is a CLOSED BOOK EXAM. Formulae sheets are attached. However, ONE aid sheet 8.5" x 11" hand written on both sides containing notes and formulae. Note, that example problems and solutions to problems are not allowed!

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

5. All ac 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 - Transformers

A 100 kVA, 60 Hz, 7200/480 V, single-phase transformer has the following parameters (all expressed in ohms):

$R_{HV} = 3.06$ $\quad X_{HV} = 6.05$ $\quad X_{m,HV} = 17{,}809$

$R_{LV} = 0.014$ $\quad X_{LV} = 0.027$ $\quad R_{c,HV} = 71{,}400$

The transformer supplies a load that draws rated current at 0.75 power factor lagging at 480 V at the load. Sketch the *approximate* equivalent circuit for this transformer, and determine:

a. the input voltage;
b. the efficiency; and,
c. the percent voltage regulation.

Question 2 - DC Machines

A 300 hp, 500 V, 1750 rpm DC shunt motor, operating at rated conditions, has an efficiency of 92.0 percent. The armature resistance is 0.042 Ω and the field resistance is 86.2 Ω. Draw an equivalent circuit for the motor, and determine:

a. what percentage of the total losses are due to rotation losses;
b. the external resistance needed in series with the armature circuit to limit the starting current to 225 percent of rated armature current on start-up; and,
c. the new speed if the flux is reduced by 10 percent and the shaft load is adjusted to maintain rated armature current.

Question 3 - Synchronous motor

A 2500 hp, 6600 V, 60 Hz, 3600 rpm, three-phase, Y-connected, round rotor synchronous motor, operating at rated load and 0.84 power factor leading, has an efficiency of 96.5 percent, neglecting field losses and armature resistance losses. The synchronous reactance per phase is 15.8 Ω. Sketch a phasor diagram for this motor for the given operating condition, and determine:

a. rotational losses;
b. the armature current;
c. the excitation voltage; and,
d. maximum output torque available from this motor.

Question 4 - Synchronous generator

A 250 kVA, 480 V, three-phase, four-pole, 60 Hz, synchronous generator with a synchronous reactance of 0.99 Ω per phase is operating at rated conditions and a power factor of 0.832 lagging. The magnetization curve for the generator is shown in Figure 1 (on the next page).

a. Sketch a phasor diagram for this generator.

b. Name the 2 curves shown on the graph, and indicate briefly how they are found. Why is it that one is a straight line, but the other exhibits a curve?

c. Determine:
   i. the excitation voltage (magnitude and angle);
   ii. the open-circuit phase voltage;
   iii. the voltage regulation; and,
   iv. the no-load voltage if the field current is reduced to 60% of its value at rated load.

Question 5 - Induction motors

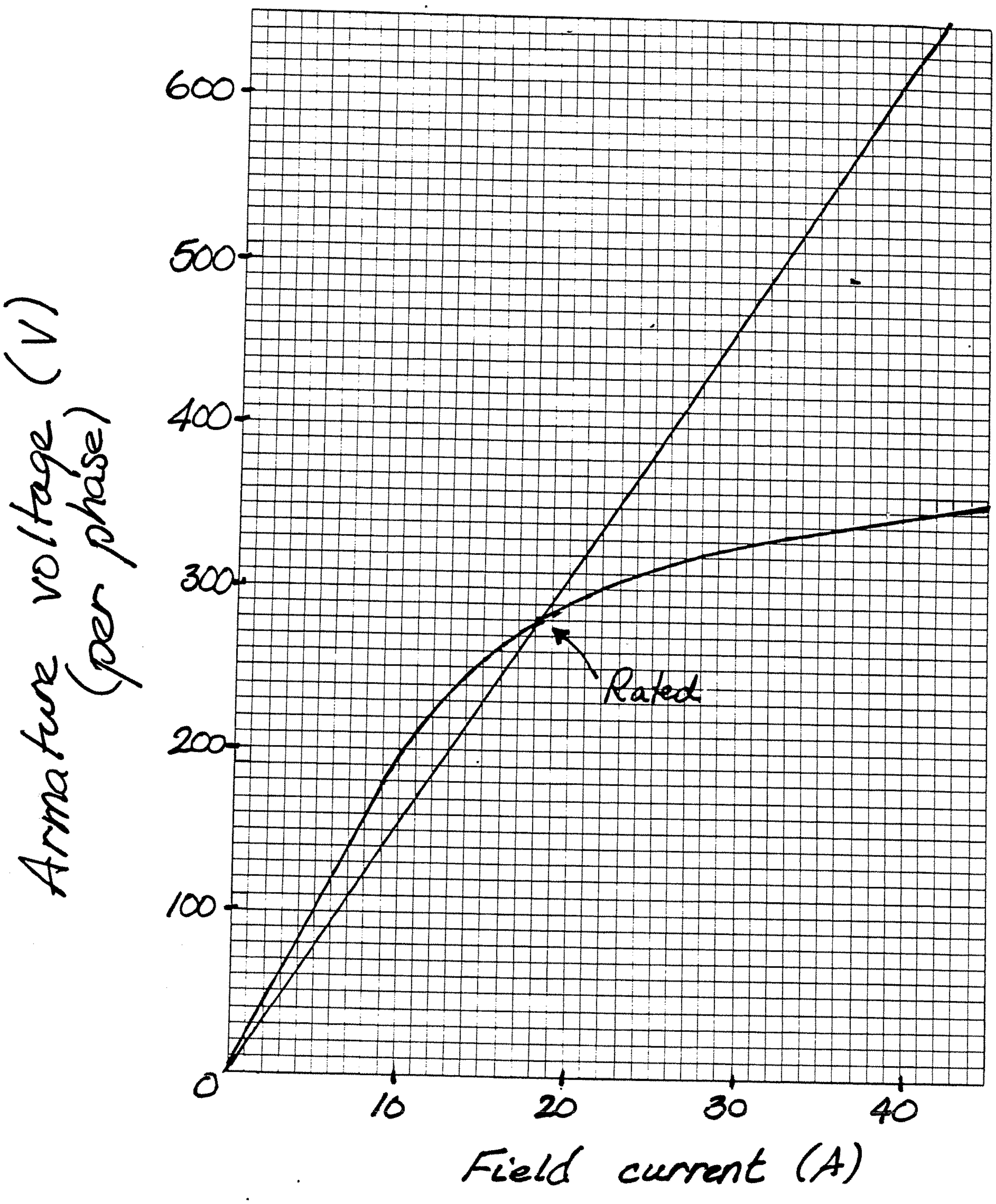
A 60 Hz, 15 hp, 460 V, three-phase, six-pole, Y-connected induction motor is driving a centrifugal pump at 1185 rpm. Rotational losses due to friction and windage and core losses are 978 W, and the motor parameters, referred to the stator, are as follows:

$R_1 = 0.200\ \Omega$ $R_2' = 0.250\ \Omega$ $X_m = 42.0\ \Omega$

$X_1 = 1.20\ \Omega$ $X_2' = 1.29\ \Omega$

Draw an equivalent circuit for this motor, and determine:

a. the slip;
b. the line current;
c. the total input power, reactive power and apparent power of the motor;
d. air-gap power;
e. rotor and stator copper losses;
f. developed power; and,
g. output power (in Watts and in hp).



600
500
400
300
200
100
0
10
20
30
40
Armature voltage (V) (per phase)
Field current (A)
Rated

Figure 1

Question 6 - Magnetic circuits

A magnetic core with its dimensions is shown in Figure 2. The thickness of the magnetic material is 10 cm. What must be the current in a 100-turn coil to establish a flux of 6.5 mWb in leg c? The magnetization curve for the material is provided in Figure 3. Note that $l_a = l_b = 115$ cm, $l_c = 45$ cm.

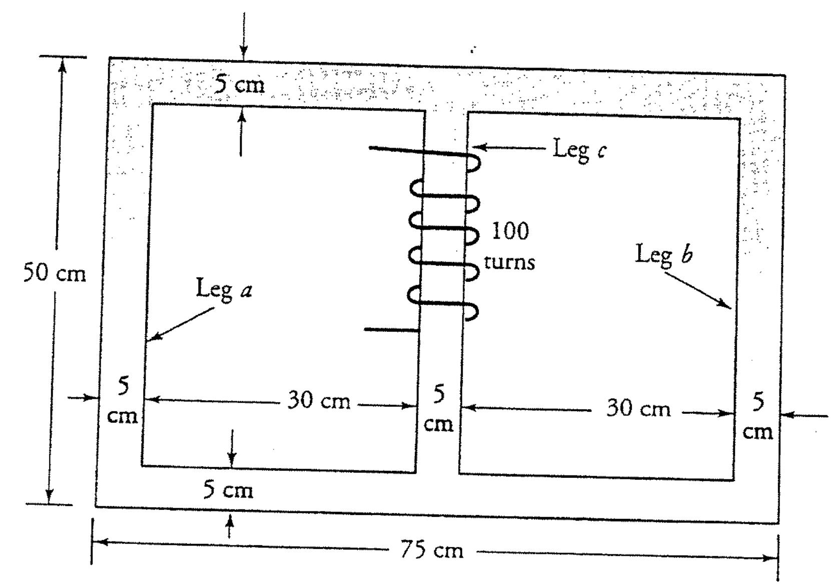


Figure 2

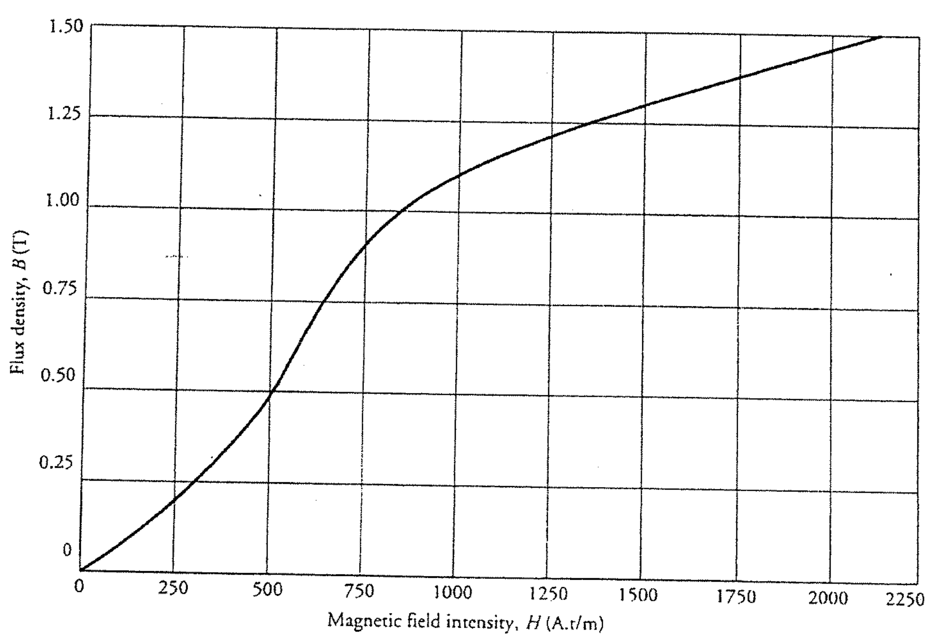


Figure 3

Potentially useful formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

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

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