National Exams December 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. Candidates may also bring in ONE aid sheet 8.5" x 11," hand-written on both sides, containing notes and formulae (no figures). Example problems and solutions 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 50 kVA, 2400/600 V, 60 Hz, single-phase transformer provides the following test results:

	Voltage	**Current**	**Power input**
Open-circuit test	600 V	3.34 A	484 W
Short-circuit test	76.4 V	20.8 A	754 W

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

b. Determine the approximate parameters of the transformer, with all values referred to the high-voltage winding, and make a sketch of the approximate equivalent circuit.

c. Using the equivalent circuit determined in part (b), determine the efficiency and voltage regulation at rated load and 0.92 power factor lagging.

Question 2 - DC Machines

A 30 hp, 240 V, 1150 rpm DC shunt motor, operating at rated conditions, has an efficiency of 88.5 percent. The armature resistance is 0.064 Ω and the field resistance is 93.6 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 175 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 4000 hp, 13.2 kV, 60 Hz, two pole, 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 49.33 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;
d. the power angle; and,
e. maximum output torque available from this motor.

Question 4 - Synchronous generator

A 1000kVA, 4800 V, three-phase, two-pole, 60 Hz, synchronous generator with a synchronous reactance of 14.2 Ω per phase supplies 600 kVA at 4800 V to a bus load operating at a power factor of 0.952 lagging. The magnetization curve for the generator is shown in Figure 1 (on the next page - you must provide your own scaling). Determine:

a.. the excitation voltage (magnitude and angle);
b. a phasor diagram for the given operating condition;
c. the open-circuit line voltage if a sudden short circuit trips the generator breaker.

Question 5 - Induction motors

A 60 Hz, 25 hp, 460 V, three-phase, four-pole, Y-connected induction motor has the following motor parameters, referred to the stator:

$R_1 = 0.641\ \Omega$ $R_2' = 0.332\ \Omega$ $X_m = 26.3\ \Omega$

$X_1 = 1.106\ \Omega$ $X_2' = 0.464\ \Omega$

The total rotation losses are 1100 W and assumed constant, and core losses have been lumped in with them. Draw an equivalent circuit for this motor, and determine, for a rotor slip of 2.2% at rated voltage and rated frequency:

a. the motor speed;
b. the stator current;
c. the power factor of the motor;
d. air-gap power;
e. the output power (may be different than the rated power); and,
f. the efficiency.

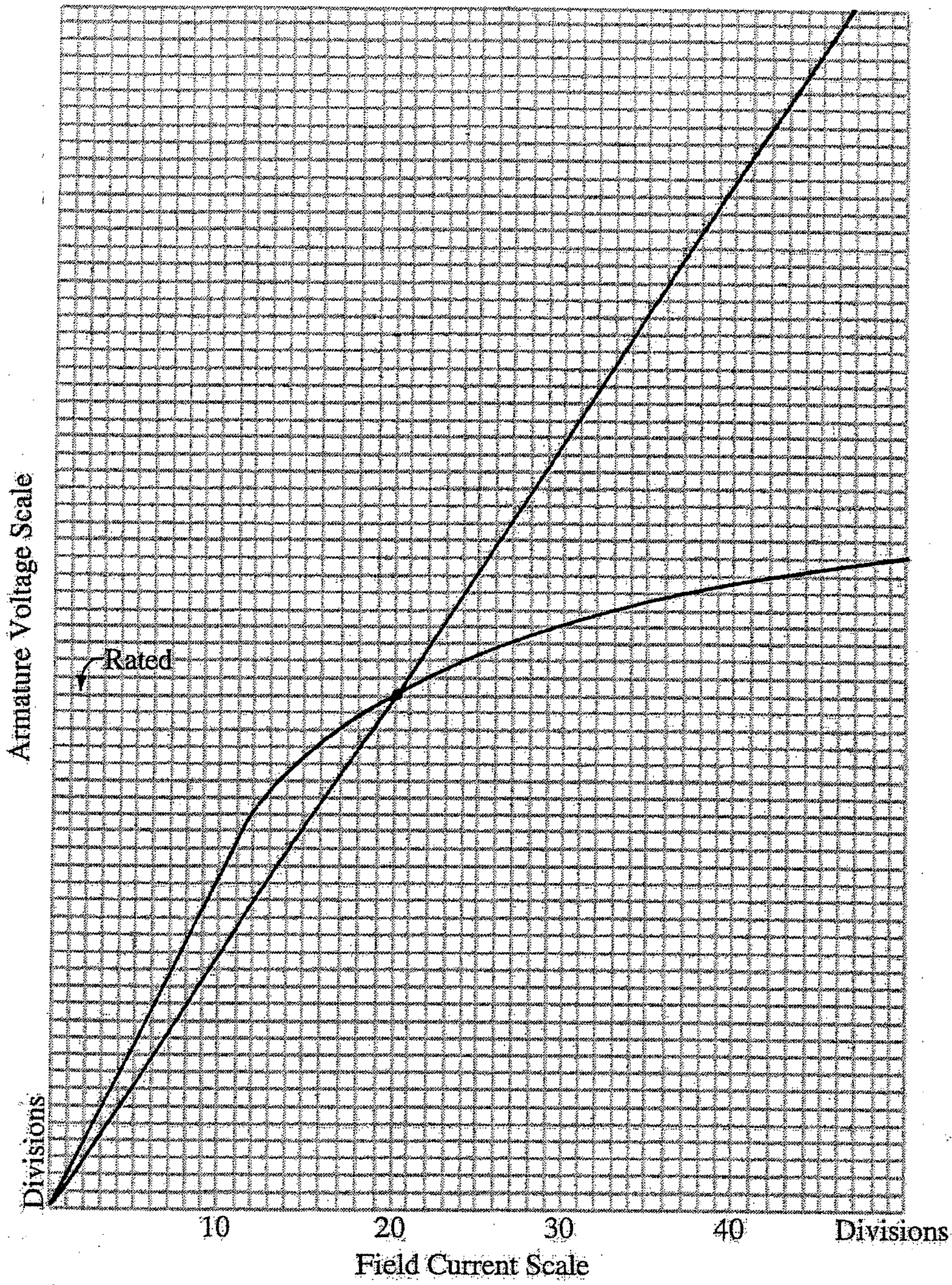
Armature Voltage Scale
Rated
Divisions
10
20
30
40
Divisions
Field Current Scale

Figure 1

Question 6 - Magnetic circuits

For the magnetic circuit shown below in Figure 2, the core material is 1% silicon iron, for which the magnetization curve is shown in Figure 3. The depth of all core members is a uniform 75 mm. The remaining dimensions are as follows: $\delta_1 = 3$ mm; $\delta_2 = 2$ mm; $w = 125$ mm; $h = 150$ mm; and, $l = 50$ mm. Coil 1 has 100 turns. If $\phi_2 = 1$ mWb, find the flux, ϕ_1, and the current, I_1.

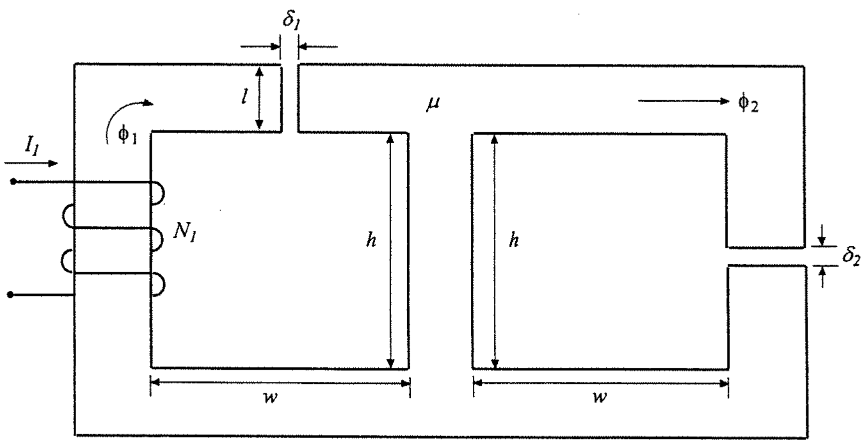

Figure 2

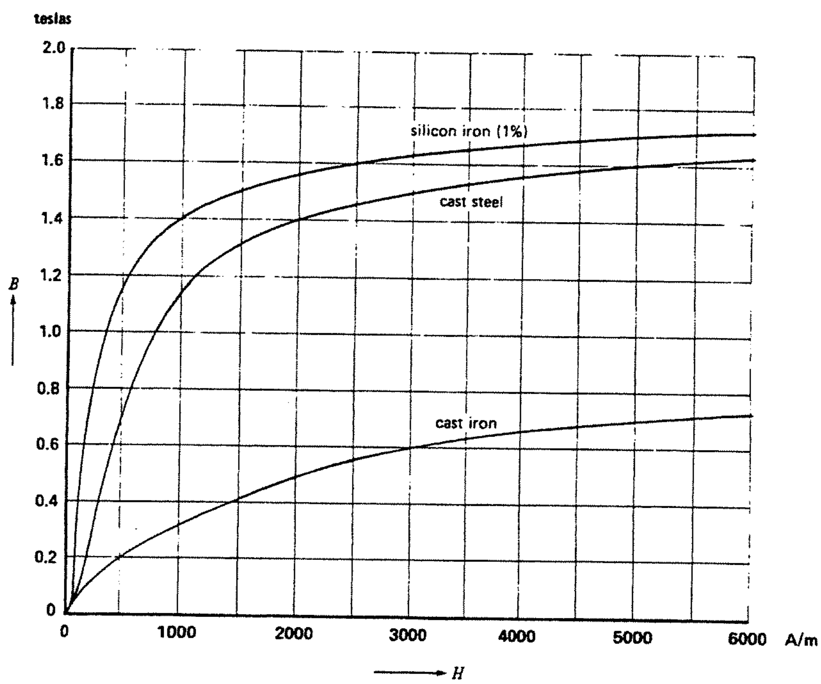

Figure 3

Potentially useful formulae

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

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

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

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

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

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

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

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

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

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

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

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

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

$$P_e = K_ef^2B^2_{\max}V_{vol} \qquad P_h = K_hfB^x_{\max}V_{vol}$$

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

$$I_L = I_f + I_a$$

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \omega$$

$$T = K_a \Phi I_a$$

$$P_{input} = V_t I_L$$

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

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

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

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

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

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

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

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

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

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

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

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