THE UNIVERSITY OF BRITISH COLUMBIA

Department of Electrical and Computer Engineering

EECE 373: Electromechanical Energy Conversion and Transmission

Final Exam
April 21, 2004

Magnetic Circuits, Transformers, DC Machines, Induction Machines, Synchronous Machines, Stepper Motors

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First Name:____________________________

Student ID:____________________________

Signature:_____________________________

Solution

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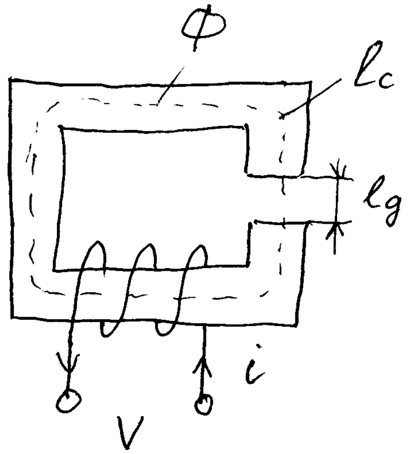
Problem	Points	Max.
1		16
2		17
3		17
4		17
5		17
6		16
Total		100

- **Close notes and books.**
- You are allowed to have only a **calculator** and a **pen/pencil**.
- Show you work including **derivations**, **comments**, **assumptions**, and **units** whenever appropriate.
- Use back side of each page or ask for additional pages if you need extra space to write your answers.
- Exams suspected of cheating and/or turned in late will not be marked – **failed exam**.
- You have about 90 minutes to answer the following questions:

Problem 1 (16pts)

Consider the magnetic system shown below. The length of the air-gap is such that the air-gap reluctance is $\Re_g = 8.75\times10^5\ At/Wb$. The effective length and material of the core are such that the effective reluctance of the magnetic path inside the core is $\Re_c = 1.25\times10^5\ At/Wb$. The cross-sectional area of the core and air-gap is $A_c = A_g = 10cm^2$. The coil has 100 turns and dc resistance of $3\,\Omega$. Neglect flux leakage, fringing, and core losses. Assume that an external voltage source is connected to the coil.



(a) (8pts) Draw an equivalent **magnetic** circuit, show the direction of mmf F and the flux Φ

(b) (8pts) Calculate the rms value of ac voltage required to produce the flux density in the air-gap $B_g = 1\,\text{T}$ rms

Problem 2 (17pts)

Consider a single-phase 60-Hz transformer with the following parameters: $R_1 = 1\,\Omega$, $X_1 = 3\,\Omega$, $X_m = 30\,\Omega$, $R_2 = 1.2\,\Omega$, and $X_2 = 5\,\Omega$, respectively. Assume that both windings have the same number of turns and that the primary side is connected to a 240-V ac source.

(a) (8pts) Based on the given information, sketch the T-equivalent circuit and label all its elements

(b) (9pts) Assume a resistor load $R_{load} = 40\ \Omega$ is connected to the secondary side. Calculate the voltage regulation VR expressed in percent.

Recall: $VR = \dfrac{V_{no\_load} - V_{load}}{V_{load}} \cdot 100\%$

Problem 3 (17pts)

Consider a **Permanent-Magnet DC Machine** with the armature resistance $R_a = 1\,\Omega$. When the machine is connected to a 12-V battery it draws the armature current $I_a = 0.2$-A and the shaft speed is $n = 1800$ rpm CCW at no load. The battery voltage and friction torque can be assumed constant.

(a) (8pts) Calculate the torque constant K_t and the friction torque T_{fric}

(b) (9pts) Assume that you need to use this DC Machine as a generator to charge the battery. Calculate the external mechanical torque T_m required to produce the charging current of 1A. In what direction, CW or CCW, should this torque be applied? What is the resulting speed n?

Problem 4 (17pts)

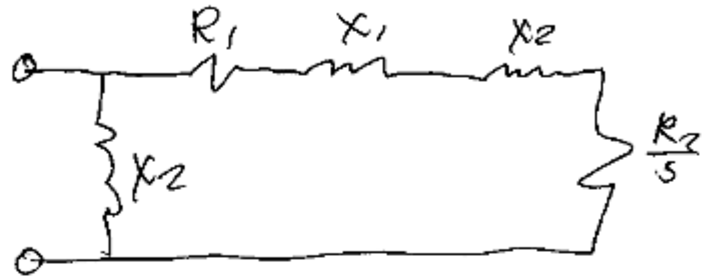
Consider a 60Hz, 208V (line-to-line), Y-connected, NEMA Clsass B (Squirrel-Cage) Induction Motor with the following per-phase parameters: $R_1 = 1\,\Omega$, $R_2 = 1.5\,\Omega$, $X_1 = X_2 = 3\,\Omega$, and $X_m = 40\,\Omega$ (all referred to the stator). The motor is supplied with the nominal (rated) voltage and is driving a mechanical load. The speed of the motor shaft is n = 840 rpm. You can neglect core and friction losses and use an approximate equivalent circuit. Determine the following:

(a) (4pts) Number of poles p
(b) (4pts) Slip s
(c) (5pts) Stator current I_1 and power factor PF
(d) (4pts) Total (3-phase) input real power

3600 – 2
1800 – 4
1200 – 6
900 – 8

$\underline{p = 8}$

$$S = \frac{900-840}{900} = 0.0667 = 6.67\,\%$$



$$Z = \frac{jX_m\left(R_1 + \frac{R_2}{s} + jX_1 + jX_2\right)}{R_1 + \frac{R_2}{s} + j\left(X_1 + X_2 + X_m\right)} = 14.09 + j12.4$$

$$I_1 = \frac{V_1}{Z} = \frac{208}{\sqrt{3}\,(14.09 + j12.4)} = 4.79 - 4.22j$$

$$pf = \cos\varphi = \cos(\text{angle}(I_1)) = 0.75$$

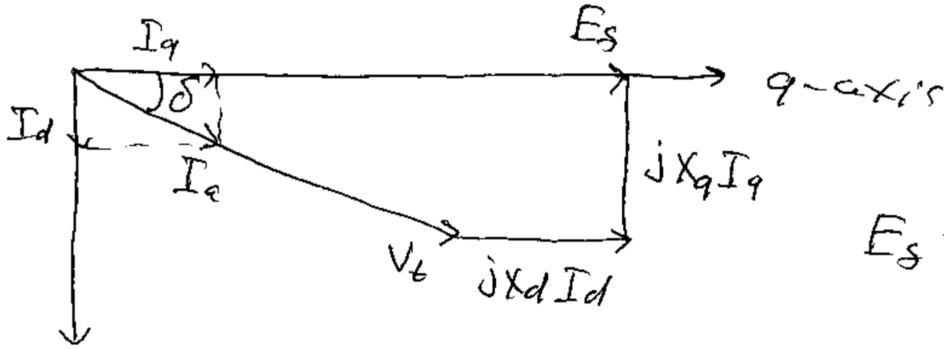
$$P_{3\varphi} = 3 I_1 V_1 \cdot \cos\varphi = 1.728\ \text{KW}$$

Problem 5 (17pts)

Consider a Salient-Pole Synchronous Generator with the following parameters: $X_q = 0.5pu$, $X_d = 0.9pu$ (the stator winding resistance is negligible). The excitation is adjusted so that the open-circuit voltage is $E_f = 1.2969pu$. The generator is supplying a resistive load that draws rated (nominal) current $I_a = 1pu$ and the terminal voltage is $V_t = 1pu$.

(a) (8pts) Sketch a phasor diagram and label all relevant axes, angles, and phasors

(b) (9pts) Calculate the rotor angle δ in degrees



$$E_s = V_t + jX_d I_d + jX_q I_q$$

$$V_t \cdot \sin\delta = X_q \cdot I_q = X_q \cdot I_a \cdot \cos\delta$$

$$\tan\delta = \frac{X_q I_a}{V_t} = X_q = 0.5; \quad \delta = \operatorname{atan}(X_q) = 26.6°$$

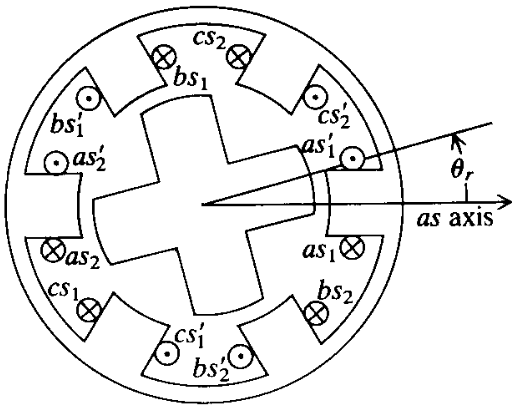
$$E_f = V_t \cdot \cos\delta + X_d \cdot I_a \cdot \sin\delta$$

$$\sin\delta = \frac{X_q I_a \cdot \cos\delta}{V_t}$$

$$E_f = V_t \cdot \cos\delta + X_d I_a \cdot \frac{X_q I_a \cdot \cos\delta}{V_t} = \left[V_t + \frac{X_d X_q I_a^2}{V_t}\right]\cos\delta$$

$$\delta = \operatorname{acos}\left[\frac{E_f}{V_t + \frac{X_d X_q I_a^2}{V_t}}\right] = \underline{26.6°}$$

Problem 6 (16pts)
Consider a single-stack stepper motor shown below. Complete the following table:



2pts	Stator tooth pitch (STP)	60 degrees
2pts	Rotor tooth pitch (RTP)	90 degrees
3pts	Step length $\Delta\Theta$	-30 degrees
3pts	Number of steps per revolution (Resolution)	12
3pts	Assume sequence of pulses as B – C – A, determine the direction of rotation (CW or CCW)	CCW
3pts	Assume you have a 3-phase pulse generator to supply this motor. The generator produces 6 pulses per second. What is the motor speed in rpm?	30 rpm