THE UNIVERSITY OF BRITISH COLUMBIA

Department of Electrical and Computer Engineering

EECE 376: Electromechanics

Practice Final Exam
Spring 2015

Topics Covered: Magnetic Circuits, Electromechanical Systems, Brushed DC Motors, Stepper Motors, Rotating Magnetic Field, Brushless DC Motors, Synchronous Motors, and Induction Motors.

Surname:____________________________________

First Name:__________________________________

Student ID:__________________________________

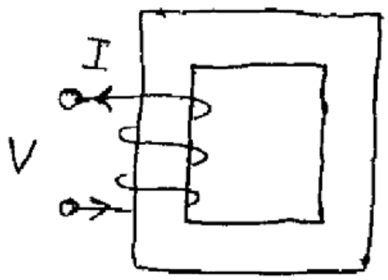
Signature:___________________________________

- **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** wherever 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 **90** minutes to answer the following questions:

Problem	Points	Max.
1		
2		
3		
4		
5		
6		
7		
Total		100

Problem 1 (15pts):

Consider the magnetic system shown below. The core has permeability and dimensions such that the reluctance of magnetizing path is $\Re_m = 10^5 At/Wb$. The coil has 100 turns, dc resistance of 2Ω, and is connected to a dc source $V_{dc} = 10V$. It is also known that 20% of the total flux Φ leaks into the air.



(a) (5pts) Draw an equivalent **magnetic** circuit, show the direction of mmf and the fluxes

(b) (5pts) Calculate flux linkage λ, and inductance L

(c) (5pts) Find the rms value of the current if the coil is supplied from an ac source $V_{ac} = 10V(rms)$ with the frequency $f_e = 5.093Hz$

Problem 2 (14pts):

Consider a regular (brushed) **Permanent-Magnet DC Machine** with the armature resistance $R_a = 0.1\Omega$. When the machine is connected to a 12-V battery it draws the armature current $I_a = 0.5$ A and the shaft speed is $n = 1800$ rpm CCW at no load. The battery voltage and friction torque can be assumed constant.

(a) (7pts) Calculate the torque constant K_t and the friction torque T_{fric}

(b) (7pts) Assume that you need to use this DC Machine as a generator to charge the battery (e.g. regenerative braking on a bicycle). Calculate the external mechanical torque T_m required to produce the charging current of 10A. In what direction, CW or CCW, should this torque be applied? What is the resulting speed n?

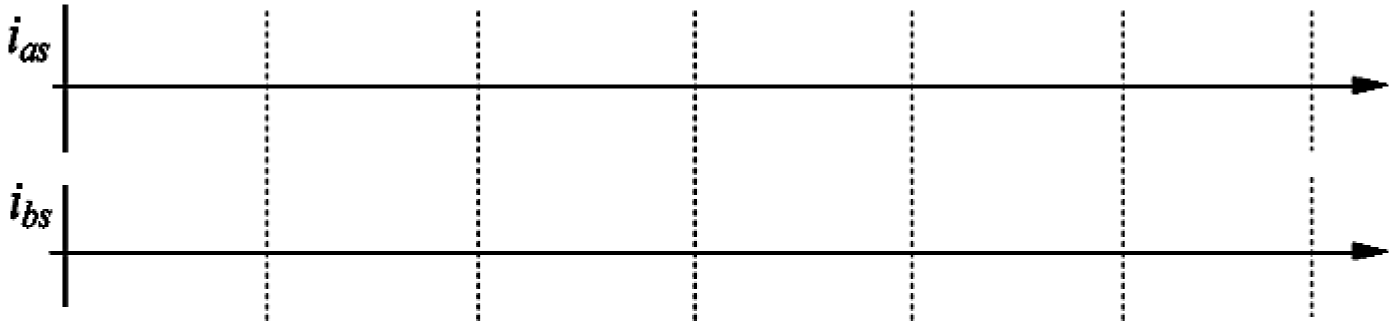
Problem 3 (14pts):

Consider a 2-phase **Permanent Magnet Stepper Motor** with bipolar windings and number of rotor teeth $N_{RT} = 100$. Assume a full-step operation with duration of current pulses $T_{step} = 1/f_{step} = 0.1\sec$.

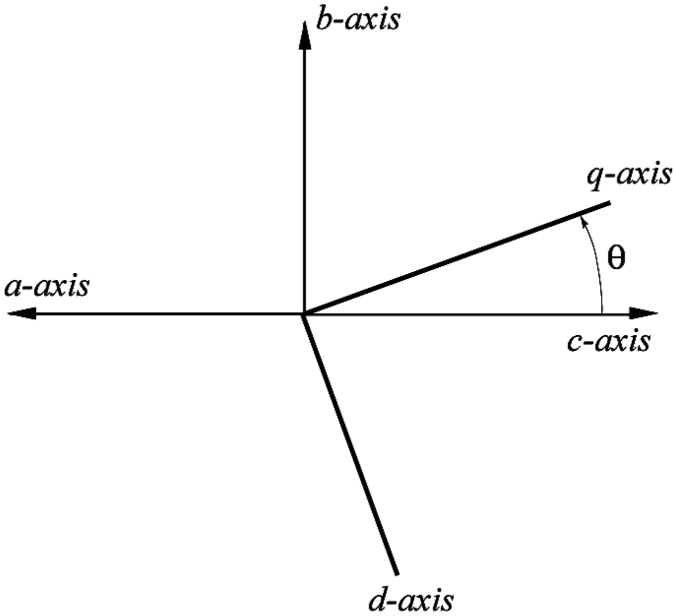
(a) (5pts) Sketch the currents i_{as} and i_{bs} assuming the as, bs sequence for forward rotation

(b) (5pts) Although the currents i_{as} and i_{bs} are not sinusoidal, they have a significant fundamental component with the frequency denoted by ω_e. Derive the expressions for ω_e and the rotor mechanical speed ω_{rm} in terms of f_{step}, and calculate their values. Also relate ω_e and ω_{rm}

(c) (4pts) Sketch a possible driver circuit required to operate this motor



Problem 4 (14pts):
Consider the abc and qd coordinate systems depicted below. Note that the abc system is not symmetric in the usual sense. Derive the transformations that relate these two systems of coordinate (fill in the corresponding boxes in the expressions below).



(a) (7pts) from abc to qd, $f_{qd} = K(\theta) f_{abc}$

$$\begin{bmatrix} f_q \\ f_d \end{bmatrix} = \boxed{5} \begin{bmatrix} & & \\ & & \end{bmatrix} \cdot \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$$

(b) (7pts) from abc to qd, $f_{abc} = [K(\theta)]^{-1} f_{qd}$. Here, $[K(\theta)]^{-1}$ is the pseudo inverse of $K(\theta)$

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \boxed{} \begin{bmatrix} & \\ & \\ & \end{bmatrix} \cdot \begin{bmatrix} f_q \\ f_d \end{bmatrix}$$

Problem 5 (14pts):

Consider a 6-pole, 2-phase **PM <u>Brushless</u> DC Motor** with the armature resistance $r_s = 5\,\Omega$. When the motor is spinning at $n = 1800$ rpm it has a sinusoidal back emf of 10 V rms.

(a) (5pts) Determine the constant λ_m (flux due to permanent magnet)

(b) (5pts) Determine the maximum torque T_e at stall when the motor is supplied from a 12V battery

(c) (4pts) If the friction is neglected, what would be the no-load speed n in rpm?

Problem 6: (14pts)

Consider a 3-phase, 60Hz, 600rpm, 208V (line-to-line) **Permanent Magnet Synchronous Motor** with the following parameters: per-phase stator resistance and synchronous reactance are $R_S = 1\,\Omega$ and $X_s = 5\,\Omega$, respectively. The motor operates at 0.8 lagging power factor and the total input electrical power $P_{in} = 1600$ W.

(a) (5pts) How many magnetic poles does this motor have (circle: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16)

(b) (5pts) Sketch a per-phase equivalent **electric circuit** and label its elements

(c) (4pts) Calculate the induced back emf voltage E_f and the rotor angle δ (circle **leading** or **lagging**)

Problem 7 (15pts)

Consider a 60Hz, 120V (line-to-neutral), Y-connected, NEMA Clsass B (Squirrel-Cage) Induction Motor with the following per-phase parameters: $R_1 = R_2 = 1\,\Omega$, $X_1 = X_2 = 3\,\Omega$, and $X_m = 40\,\Omega$ (all referred to the stator). The nominal (rated) speed of the motor is $n_{nom} = 1128\text{ rpm}$. You can neglect the friction losses and use an approximate equivalent circuit (like you did in your homework). Determine the following:

(a) (5pts) Number of poles P and nominal slip s_{nom}

Assume that the motor was loaded with a mechanical torque $T_m = 10\text{ N}\cdot\text{m}$

(b) (10pts) Find the slip s and the actual motor speed n under this load