THE UNIVERSITY OF BRITISH COLUMBIA

Department of Electrical and Computer Engineering

ELEC 343: Electromechanics

Mid-Term Exam
Spring Term 2019
February 26

Topics Covered: Magnetic Circuits, Electromechanical Energy Conversion, Transformers, and DC Machines

Surname:____

First Name:______________________________________

Student ID:______________________________________

I understand the principles of academic integrity and I will not be cheating on this exam.

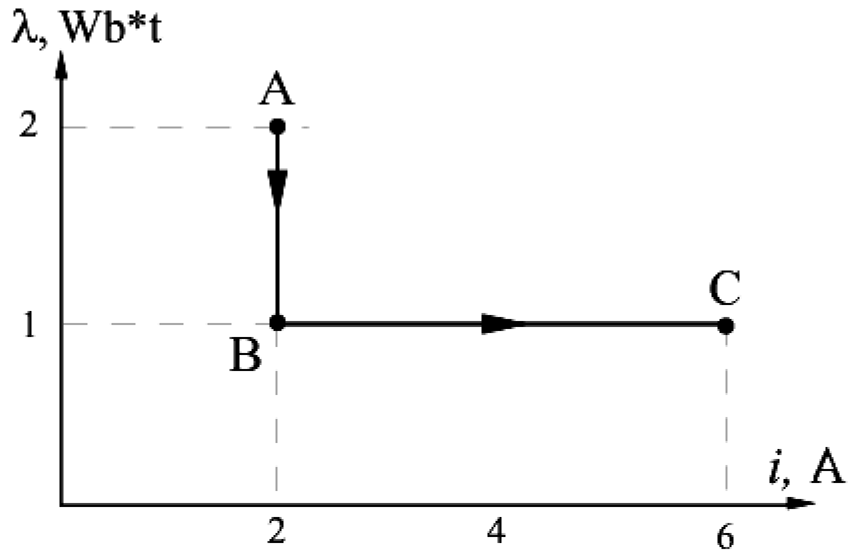
Signature:_______________________________________

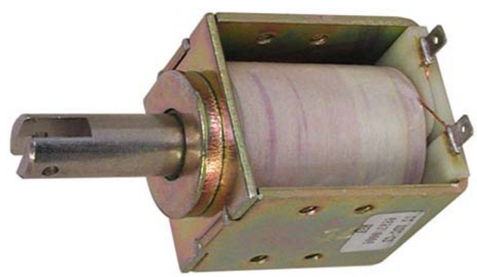
Problem	Points	Max.
1		26
2		24
3		25
4		25
Total		100

- **Close notes and books.**
- You are allowed to have only a **calculator** and a **pen/pencil**. **(no formula sheet!)**
- 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 **60** minutes to answer the following questions:
- Good luck!

Problem 1 (26pts):

Assume an electromechanical system shown on the figure. The system may be assumed **magnetically linear** (similar to a solenoid in Lab-1). The system's state is shown in the $\lambda - i$ figure below, wherein the system has moved from point A to point B, and from point B to point C. Using the numerical values given on this figure (which are different in each axis), **calculate the change in** W_f, W_c, W_e, and W_m. In other words, complete the Table given below. Remember, according to our convention, positive sign (value) of W_e and W_m means into the system. Also remember that: $W_f = \int i d\lambda$; and $W_c = \int \lambda di$; **Be sure to include the units and check the energy conversion balance! For each transition, also state if the plunger was pulled in or out?**

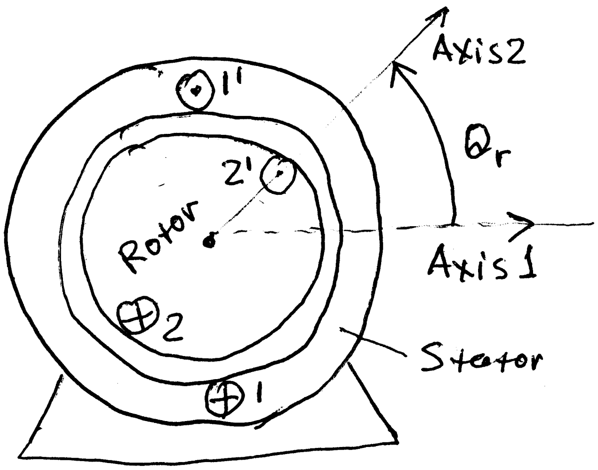




Transition	**From A to B**	**From B to C**
(4pts) Change in coupling field energy, ΔW_f	(2pts) -1 J	(2pts) +2 J
(2pts) Change in co-energy, ΔW_c	(1pts) -1 J	(1pts) +2 J
(4pts) Change in electrical input, ΔW_e	(2pts) -2 J	(2pts) 0 J
(4pts) Change in mechanical input, ΔW_m	(2pts) +1 J	(2pts) +2 J
(4pts) The energy was taken from **(and how much)**	(2pts) From mech. system 1 J, and from coupling field 1 J	(2pts) From mech. system, 2 J
(4pts) The energy was supplied to **(and how much)**	(2pts) To elec. system, 2 J	(2pts) To coupling field 2 J
(4pts) Check the energy balance! $\Delta W_f = \Delta W_e + \Delta W_m$, and conclude if the plunger was pulled IN or OUT?	(2pts) -1J = -2J + 1J Out	(2pts) +2J = 0 + 2J Out

Problem 2 (24pts):

Consider an electro-mechanical device with the **round**-rotor as shown in the figure. The rotor position θ_r is determined by the angle between stator **Axis 1** and rotor **Axis 2**, as shown. The stator and rotor currents i_1 and i_2 have directions shown by dot and cross, respectively. Use common notations and approximations regarding the leakage and magnetizing/mutual inductances as we did in class. Also, assume magnetically-linear system.



(a) (6pts) Express the self inductances $L_{11}(\theta_r)$ and $L_{22}(\theta_r)$

(b) (6pts) Express and plot (sketch) the mutual inductance $L_{12}(\theta_r)$

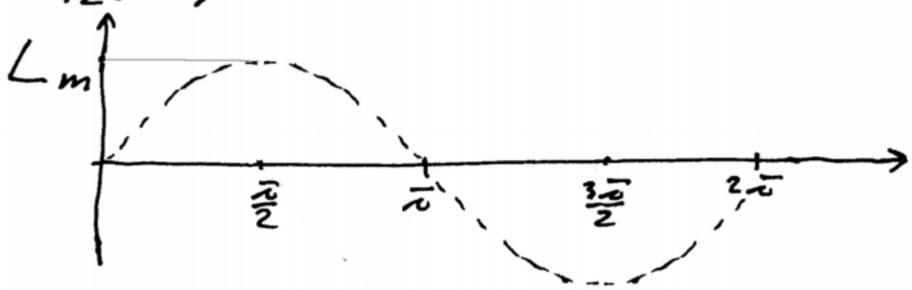
(c) (6pts) Express the induced electromagnetic torque $T_e(\theta_r)$

(d) (6pts) Sketch the $T_e(\theta_r)$ obtained in (c) and mark the **stable** and **unstable** equilibrium points

a) $L_{11} = L_{\ell_1} + L_{m_1} = \text{const.}$

$L_{22} = L_{\ell_2} + L_{m_2} = \text{const.}$

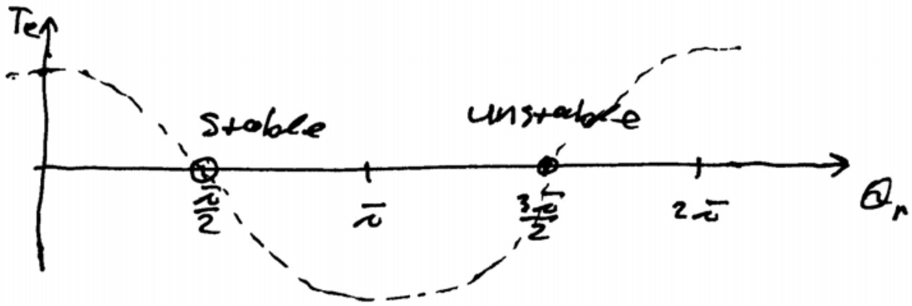
b) $L_{12} = L_m \cdot \sin(\theta_r) = L_{sr} \cdot \sin(\theta_r)$



c) $W_c = W_f = \frac{1}{2} L_{11} \cdot i_1^2 + L_{12} \cdot i_1 \cdot i_2 + \frac{1}{2} L_{22} \cdot i_2^2$

$$T_e = \frac{\partial W_c}{\partial \theta_r} = L_m \cdot i_1 \cdot i_2 \cdot \cos(\theta_r)$$

d)



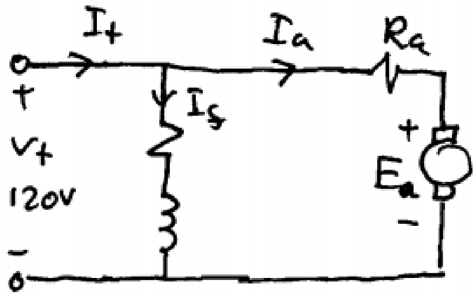
Problem 3 (25pts):

Consider a 120V **Shunt DC Motor** with armature resistance $R_a = 0.5\,\Omega$ and field winding resistance $R_f = 120\,\Omega$. The motor operates at nominal speed of 1800 rpm drawing the armature current of 10A. Friction and rotational losses constitute 50 W.

(a) Sketch equivalent circuit. Calculate the induced back emf E_a and conversion power P_e

(b) Determine the mechanical load torque T_m

(c) Determine the efficiency of the motor η



a) $E_a = V_t - R_a \cdot I_a = 120 - 0.5 \cdot 10 = \boxed{115V}$

Conversion power

$P_e = E_a \cdot I_a = 115V \cdot 10A = 1150\,W$

b) Useful mechanical power

$P_m = P_e - P_{fric} = 1150\,W - 50\,W = 1100\,W$

$\omega_r = n \cdot \frac{\pi}{30} = 1800 \frac{\pi}{30} = 188.5\ rad/s$

$P_m = \omega_r \cdot T_m \Rightarrow T_m = \frac{P_m}{\omega_r} = \frac{1100}{188.5} = \boxed{5.8\ N \cdot m}$

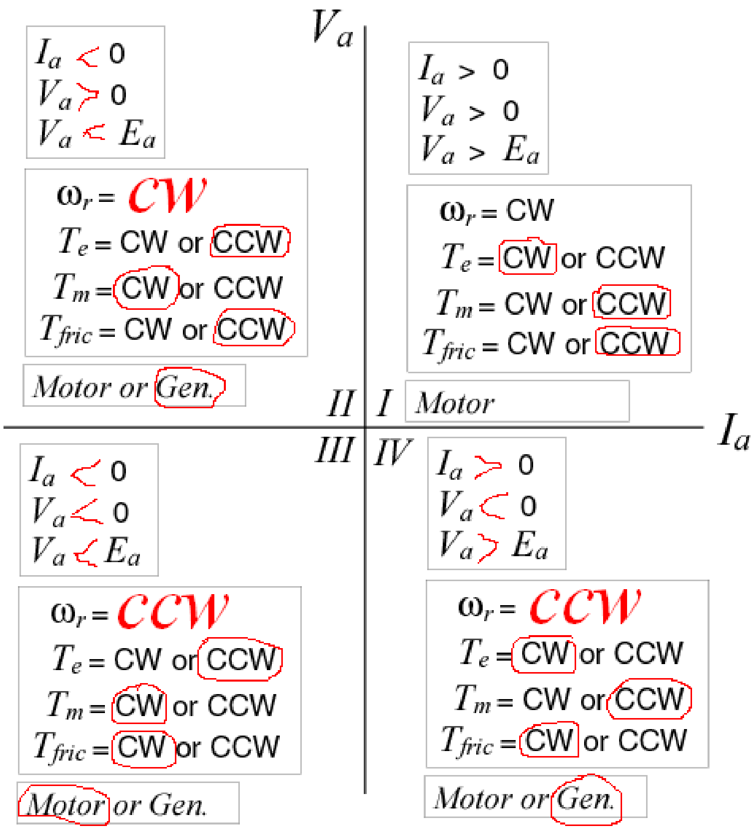
c) $\eta = \frac{P_{out}}{P_{in}} = \frac{P_m}{P_{in}}$; $I_f = \frac{V_t}{R_f} = \frac{120V}{120\Omega} = 1\,A$

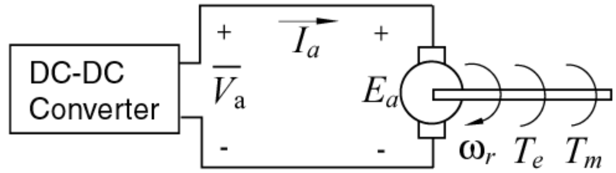
$P_{in} = V_t \cdot (I_a + I_f) = 120 \cdot (10 + 1) = 1320\,W$

$\eta = \frac{1100}{1320} = 0.833 = \boxed{83.3\ \%}$

Problem 4 (25pts):

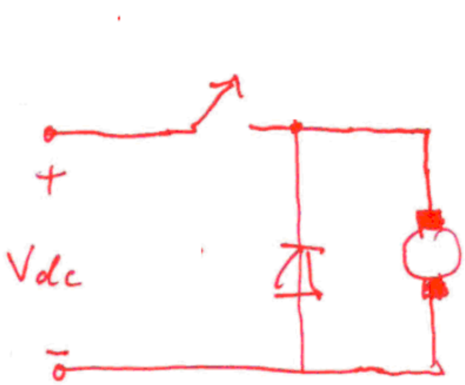
a) (15pts): Assume a PM dc machine operating in a steady-state. Based on the information given in the first Quadrant in the chart below and the directions of voltages and currents shown on the figure, first identify (circle the correct answer) the direction of torques in Quadrant I. Then complete the chart for **all four Quadrants**. Here, **CW** stands for **clockwise**, and **CCW** for **counterclockwise**, respectively.





b) (10pts): Assume the same PM dc machine as in **a)**. Sketch a DC-DC converter circuit and clearly label all its components assuming that that can drive this motor:

a) just in first quadrant



b) in all four quadrants