THE UNIVERSITY OF BRITISH COLUMBIA

Department of Electrical and Computer Engineering

ELEC 343: Electromechanics

Mid-Term Exam
Spring Term 2020
February 25

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:____

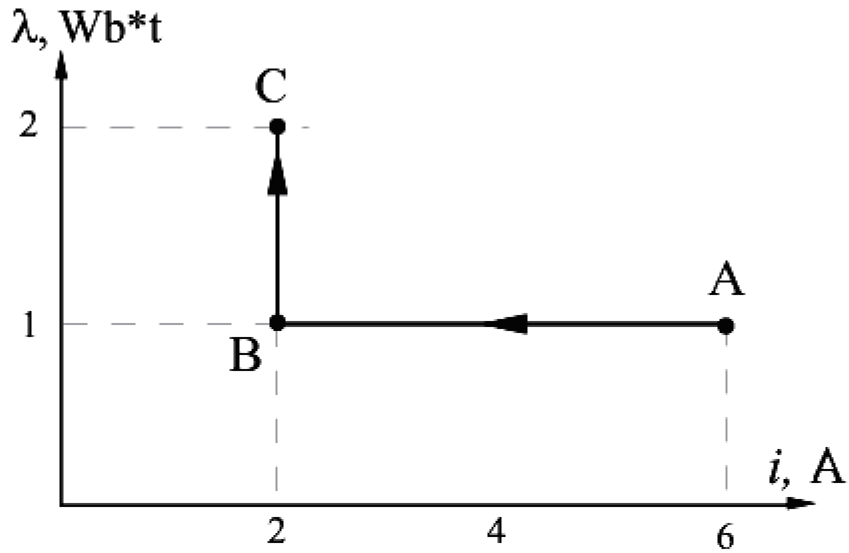
Solution

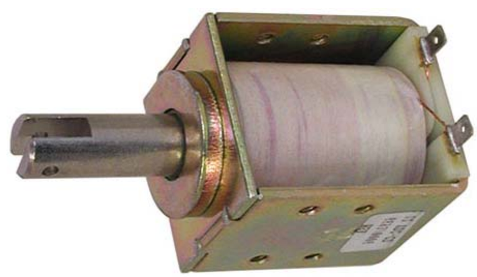
Problem	Points	Max.
1		26
2		24
3		25
4		25
Total		100

- **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**
(3pts) Change in coupling field energy, ΔW_f	(2pts) 1-3= -2 J	(2pts) 2-1 = +1 J
(2pts) Change in co-energy, ΔW_c	(1pts) -2 J	(1pts) +1 J
(3pts) Change in electrical input, ΔW_e	(2pts) 0 J	(2pts) 2 J
(3pts) Change in mechanical input, ΔW_m	(2pts) -2 J	(2pts) -1 J
(4pts) The energy was taken from **(and how much)**	(2pts) From coupling field 2J mech. system 1 J, and from coupling field 1 J	(2pts) From elec. system 2 J
(4pts) The energy was supplied to **(and how much)**	(2pts) To mech. system, 2 J	(2pts) To coupling field 1 J, and to mech. system 1J
(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) -2J = 0 -2J IN	(2pts) +1J = 2J - 1J IN

(3pts) Briefly, in one or two sentences, state the meaning of co-energy W_c?

Co-energy is an algebraic companion quantity to the energy stored in the coupling field, W_f. This relationship through flux linkage and current, $W_f + W_f = \lambda \cdot i$

Problem 2 (24pts):

Consider a 24V **Separately-Excited DC Machine** with the armature resistance $R_a = 1\Omega$, field winding resistance $R_f = 64\Omega$, and field-to-armature inductance $L_{af} = 0.5$ H. The machine is supplied from a constant dc source $V_t = 24$ V and the shaft is connected to a mechanical system with constant speed $n = 1800$ rpm in CCW direction. Friction can be neglected.

(a) (4pts) Draw an equivalent circuit and label all its elements.

(b) (10pts) The field current is set to $I_f = 0.25$ A. Calculate the armature current I_a and torque T_e. Determine whether machine is motoring or generating.

(c) (10pts) The field current is reduced to $I_f = 0.2$ A. Calculate the armature current I_a and torque T_e. Determine whether machine is motoring or generating.

a)

$$\omega = \frac{n \cdot \pi}{30} = 188.49 \ \frac{rad}{sec}$$

$$E_a = \omega \cdot L_{af} \cdot I_f = 188.49 \cdot 0.5 \cdot 0.25 = 23.56\text{ V}$$

$$E_a < V_t \Rightarrow \boxed{\text{Motoring}}$$

$$I_a = \frac{V_t - E_a}{R_a} = \frac{24 - 23.56}{1} = \boxed{0.438\text{ A}}$$

$$T_e = L_{af} \cdot I_f \cdot I_a = 0.5 \cdot 0.25 \cdot 0.438 = \boxed{0.0548\text{ N-m}}$$

b)

$$E_a = \omega \cdot L_{af} \cdot I_f = 188.49 \cdot 0.5 \cdot 0.2 = 18.85\text{ V}$$

$$E_a < V_t \Rightarrow \boxed{\text{Motoring}}$$

$$I_a = \frac{V_t - E_a}{R_a} = \frac{24 - 18.85}{1} = \boxed{5.15\text{ A}}$$

$$T_e = L_{af} \cdot I_f \cdot I_a = 0.5 \cdot 0.2 \cdot 5.15 = \boxed{0.515\text{ N}\cdot\text{m}}$$

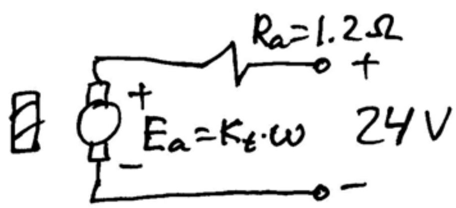
Problem 3 (25pts):

Consider a **Permanent-Magnet DC Motor** with the following parameters: rated/nominal voltage $V_t = 24\,\text{V}$; armature resistance $R_a = 1.2\,\Omega$. Under the NO-LOAD test the armature current is $I_{a\_nl} = 0.5\,\text{A}$ and the motor speed is $n_{nl} = 1800\,\text{rpm}$.

(a) (10pts) Calculate the induced armature emf E_{a_nl}, torque constant K_t, and the friction torque T_{fric}

(b) (15pts) Assume T_{fric} is constant (does not depend on speed). A mechanical load with the torque $T_m = 9 \cdot T_{fric}$ is connected to the motor shaft. Calculate the motor speed n in **rpm** and efficiency η in % under this load

a)



$$\omega_{ne} = \frac{n_{ne} \cdot \pi}{30} = 188.49\ \frac{\text{rad}}{\text{sec}}$$

$$E_{a,ne} = V_t - I_{a,ne} \cdot R_a = 24 - 0.5 \cdot 1.2 = \boxed{23.4\ \text{V}}$$

$$K_t = \frac{E_{a,ne}}{\omega_{ne}} = \frac{23.4}{188.49} = \boxed{0.1241\ \frac{\text{V}\cdot\text{sec}}{\text{rad}}}$$

$$T_{fric} = T_e = K_t \cdot I_{a,ne} = 0.1241 \cdot 0.5 = \boxed{0.0621\ \text{N}\cdot\text{m}}$$

b)

$$T_e = T_m + T_{fric} = 9 \cdot T_{fric} + T_{fric} = 0.6207\ \text{N}\cdot\text{m}$$

$$T_m = 9 \cdot T_{fric} = 0.5586\ \text{N}\cdot\text{m}$$

$$I_a = \frac{T_e}{K_t} = \frac{0.6207}{0.1241} = 5\ \text{A}$$

$$E_a = V_t - R_a \cdot I_a = 24 - 1.2 \cdot 5 = 18\ \text{V}$$

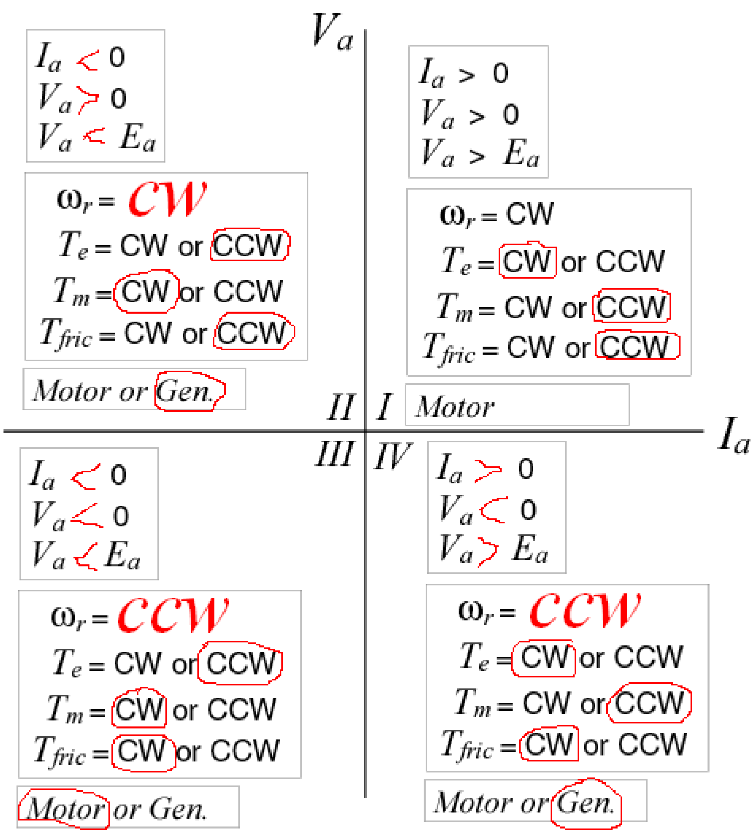
$$\omega = \frac{E_a}{K_t}; \quad n = \omega \cdot \frac{30}{\pi} = \boxed{1384.6\ \text{rpm}}$$

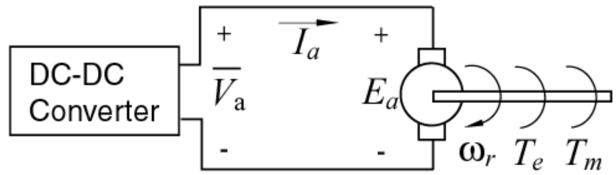
$$P_{in} = V_t \cdot I_a = 24 \cdot 5 = 120\,\text{W}$$

$$P_{out} = \omega \cdot T_m = 81\ \text{W}; \quad \eta = \frac{P_{out}}{P_{in}} = 0.675 = \boxed{67.5\%}$$

Problem 4 (25pts):

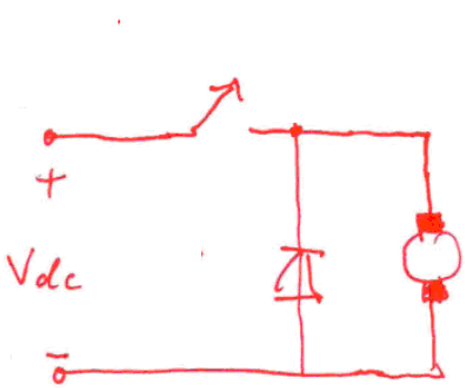
a) (15pts): Assume a PM dc machine operating in a steady-state. Based on the information given in the first Quadrant in the chart below and the directions of voltages and currents shown on the figure, first identify (circle the correct answer) the direction of torques in Quadrant I. Then complete the 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