Name ______________________

EE 56

Mid Term Examination

Autumn 2018

Problem 1 (30 Points) _______

Problem 2 (30 Points) _______

Problem 3 (30 Points) _______

Problem 4 (30 Points) _______

Problem 5 (30 Points) _______

Total (150 Points) _______

THIS IS AN OPEN BOOK, 120 MINUTE EXAMINATION

Good luck!

Problem 1 (30 Points)

Your friend races radio-controlled cars which use permanent magnet brush DC motors. She knows you have expertise in DC motors and asks you to quantify the performance of a motor that she has. The motor is powered by an 8.6V battery. You don't have a dynamometer to directly measure the speed vs. torque curve, but you can measure stall torque and currnt. Given your expertise, you know you can easily predict the speed vs. torque performance.

Given the following parameters:

$V_a = 8.6V$

$T_{stall} = 45$ in-oz (1 N-m = 141.612 in-oz)

$I_{stall} = 100$ A

Answer the questions below:

a) Find the armature resistance:

R_a = ___________ Ω

b) Find the back EMF constant:

K_e = ___________ $\frac{V}{\left(\frac{rad}{sec}\right)}$

c) Find the no-load speed of the motor at 8.6V:

ω_{nl} = ____________ rpm

d) Find the motor constant:

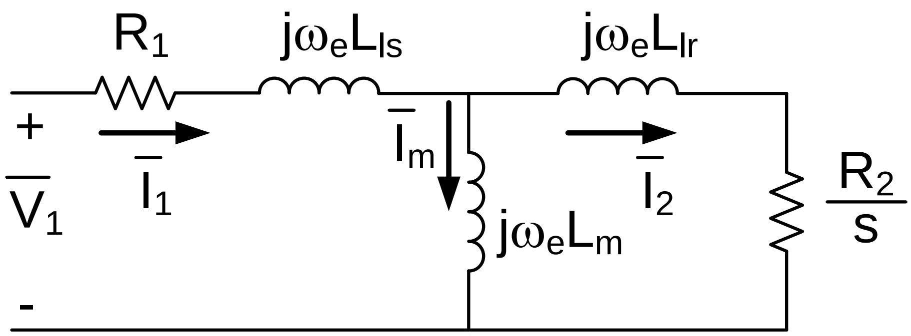
K_m = ____________ $\frac{in-oz}{\sqrt{watt}}$

e) Find the speed of the motor at a load torque of 20 in-oz:

$\omega_{20\ \text{in-oz}}$ = ____________ rpm

f) Plot the speed vs. torque curve, labeling the no-load, stall, and 20 in-oz operating points:

Problem 2 (30 Points)
Given a 4 pole, 3 phase Induction Motor operated at 60 Hz with the following per phase equivalent circuit parameters:



R_1 = negligible ($0\ \Omega$) $R_2 = 0.8\ \Omega$

$L_{ls} = 1$ mH $L_{lr} = 1$ mH

$L_m = 35$ mH $V_1 = \frac{480}{\sqrt{3}}\ V_{rms}$ $f_e = 60$ Hz

rated speed of motor: $\omega_{rm} = 1750$ rpm

Find:

a) The rated stator current of the motor (current at rated speed):

$\left|\overline{I}_{s\_rated}\right|$ = ___________ A

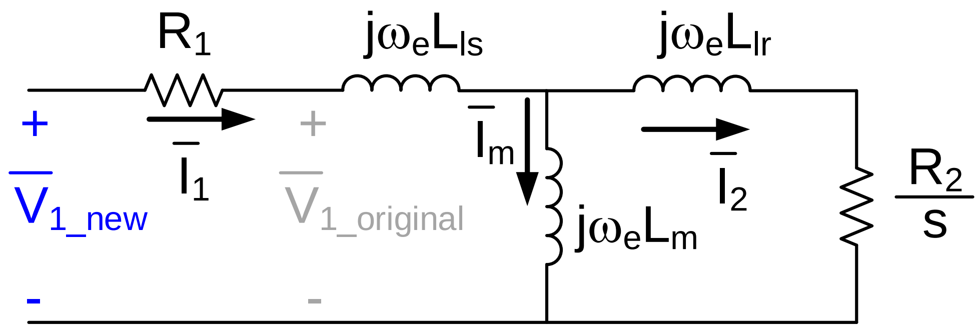
b) The rated rotor current of the motor (current at rated speed):

$\left|\overline{I}_{r\_rated}\right|$ = ___________ A

c) The rated torque of the motor (torque at rated speed):

T_{em_rated} = __________ N-m

d) You found out that the stator resistance cannot be neglected and that it's actually 1 Ω (R_1 = 1 Ω). You still want to produce the same torque as above (when you assumed the stator resistance was negligible). You want to adjust the stator voltage V_{1_new} in order to achieve the same current and torque in the machine. $V_{1\_originnal}$ represents the original voltage applied at the circuit with R_1 = 0Ω.



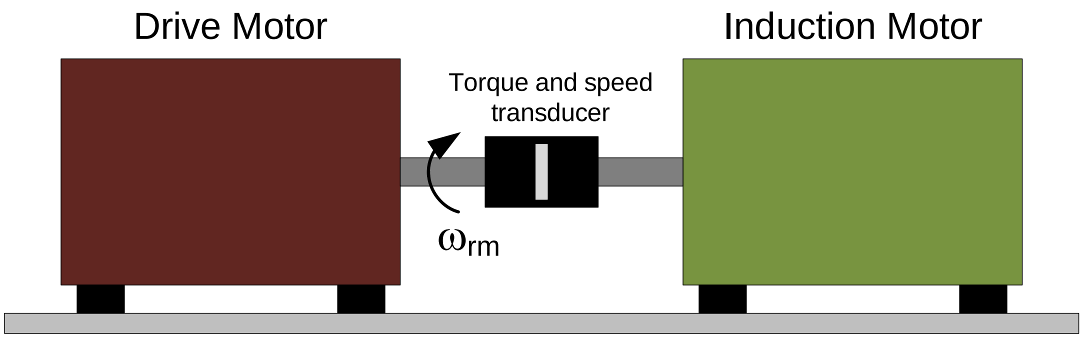
Describe how you would calculate the required voltage necessary to achieve the same currents and torque in the machine:

e) Calculate the required voltage necessary V_{1_new} to achieve the same currents and torque in the machine given the stator resistance is now 1 Ω. **Express the voltage as a magnitude and a phase (relative to the phase of $V_{1\_original}$).**

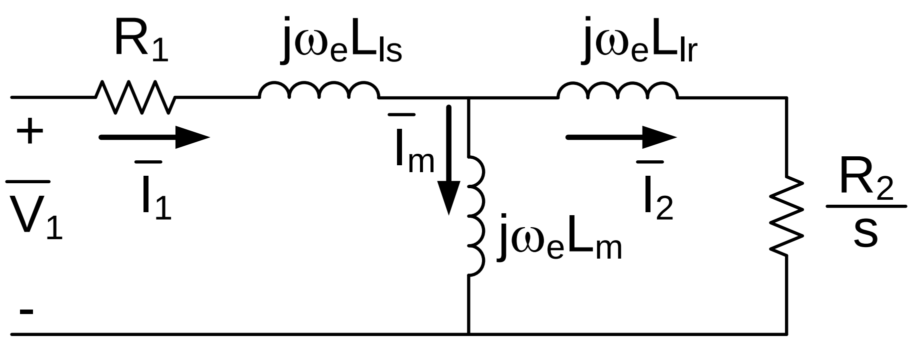
magnitude $|\bar{V}_{1\_new}|$ = __________ V

phase $\angle\bar{V}_{1\_new}$ = __________ deg

Problem 3 (30 Points)
A drive motor is directly coupled to an induction motor that you are testing (shown below). The drive motor can be controlled to maintain any desired speed, and there is a transducer which measures the shaft speed and torque. You decide to test torque produced by the induction motor at different speeds.



The induction motor has the following parameters:

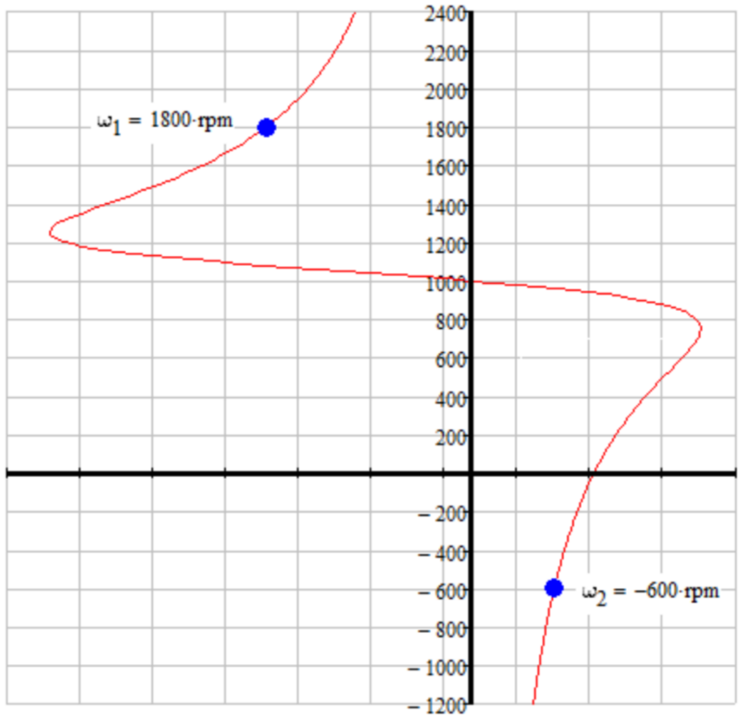


$R_1 = 0.5\,\Omega$ $\quad$ $R_2 = 0.4\,\Omega$ $\quad$ $P = ?$

$L_{ls} = 2.5$ mH $\quad$ $L_{lr} = 2.4$ mH

$L_m = 75$ mH $\quad$ $V_1 = \dfrac{208}{\sqrt{3}} V_{rms}$ $\quad$ $f_e = 50$ Hz

You are testing the motor at your European division so you have 50 Hz instead of 60 Hz excitation frequency. You measure the speed vs. torque curve over a wide speed range and record the following speed vs. torque curve:



a) Determine the number of poles for this induction motor:

P = ___________

b) Find the slip when operating at 1800 rpm:

$\omega_1 = 1800 \text{ rpm} \rightarrow s_1 =$ ___________

c) Find the torque when operating at 1800 rpm. What is the operating mode of the induction machine?

$\omega_1 = 1800 \text{ rpm} \rightarrow T_{em1} =$ ___________

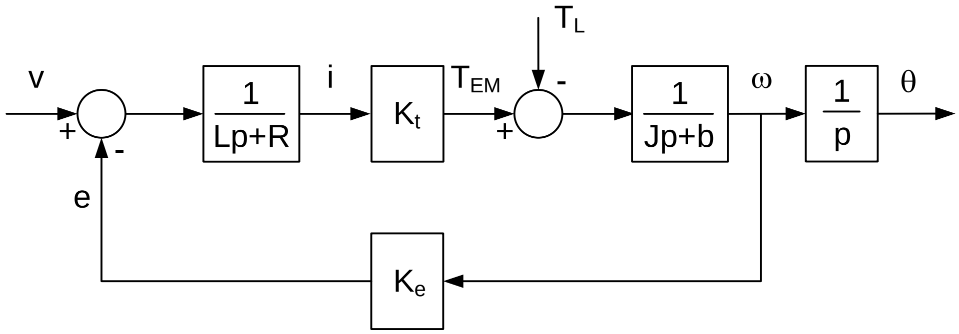
d) Find the slip when operating at –600 rpm:

$\omega_3 = -600\text{ rpm} \rightarrow s_3 = $ ____________

e) Find the torque when operating at –600 rpm. What is the operating mode of the induction machine?

$\omega_3 = -600\text{ rpm} \rightarrow T_{em3} = $ ____________

Problem 4 (30 Points)
You are given the block diagram of a dc motor (as shown below) with the following parameters. You will be designing a position controller for the motor, but you first wanted to understand the motor position sensitivity to sinusoidally varying input voltage and load torque perturbations.



$K_e = 0.85 \dfrac{\text{volts}}{\left(\dfrac{\text{rad}}{\text{sec}}\right)}$ $\qquad R = 1.0\ \Omega$ $\qquad L = 1.0\ \text{mH}$

$J = 1.0 \times 10^{-4}\ \text{kg-m}^2$ $\qquad b = 1.0 \times 10^{-5} \dfrac{\text{N-m}}{\left(\dfrac{\text{rad}}{\text{sec}}\right)}$

a) Derive the transfer function of motor position as the output with the voltage taken as the input for a dc machine operated with constant flux. **Express the transfer functions in terms of the motor parameters K (back emf and torque constant), L, R, J and b.**

$$\frac{\theta}{V} = \underline{\hspace{6cm}}$$

b) Derive the transfer function of motor position as the output with the load torque taken as the input for a dc machine operated with constant flux. **Express the transfer functions in terms of the motor parameters K (back emf and torque constant), L, R, J and b.**

$$\frac{\theta}{T_L} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

c) The input DC voltage is supplied from a rectified single-phase AC source. As such, you know that the voltage will not only have a DC component, but there will be noise on the supply at a frequency of 120 Hz. You wish to evaluate how much this 120 Hz noise will affect the output position. Assuming there is a peak change of 10V at 120 Hz, **find the peak change in output position.** (Hint: use the appropriate transfer function magnitude evaluated at f_o = 120 Hz multiplied by the amplitude of the voltage disturbance).

$\Delta\theta$ = __________ deg

d) Next you want to evaluate the change in output position due to a fluctuating load torque. Assume the load torque varies sinusoidally with a peak value equal to 0.5 N-m at a frequency of 120 Hz. **Evaluate the peak change of motor position for the machine with the parameters given above with this load torque variation.** (Hint: use the appropriate transfer function magnitude evaluated at f_o = 120 Hz multiplied by the amplitude of the torque disturbance).

$\Delta\theta$ = ___________ deg

Problem 5 (30 Points)
Answer the following questions with short responses:

a) Your friend who races radio-controlled cars wants the no-load speed of the motor to be faster. She said she was going to replace the original motor magnets with "more powerful" magnets. By "more powerful", she means they have a higher flux density. Do you agree that the more powerful magnets will increase the no-load speed of her motor? Why?

b) In an induction motor, at a given load point, would increasing resistance cause the speed to increase or decrease? Why?

c) To improve starting torque in an induction machine, do we want to increase or decrease the rotor resistance, why?

d) Universal (series wound) DC motors are used for many household applications such as drills, blenders, vacuum cleaners, etc. Why can this DC motor be powered by an AC source?

e) An induction motor is controlled by a V/Hz drive. The ratio of stator voltage to excitation frequency remains constant throughout its operation. At 10% voltage and 10% frequency, will the torque remain constant?

f) You colleague at work would like to slow down a DC motor in the lab. He decides to add a resistor in series with the armature circuit. Will this slow down the motor? What other suggestions would you give him to reduce the speed of the motor?