M.E. 530.420 Lab 3: DC Brush Motor Dynamic Parameters

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Laboratory Due Date: 5PM Wednesday September 22, 2010 at 115 CSEB

Reading: CH 10.1-10.5, and 10.7.

Your class lecture notes.

Pittman GM9234C212-R3-2C1533 Spec Sheet – available on the course homepage: https://dscl.lcsr.jhu.edu/ME530420_2010_Fall_Term

Spec sheets for Maxon 43.032.000-22.00-146 motor/tachometer (available on the course homepage) comprised of

- Maxon motor model #2332.967-51.236-200 (identified as "967" in the spec sheet).
- Maxon tachometer model #118910

TDS3014 Oscilloscope User Manual – available on the course homepage.

TDS3014 Oscilloscope Training Manual – available on the course homepage

Apparatus: Pittman GM9234C212-R3-2C1533 motor assembly, Maxon 43.032.000-22.00-146 motor assembly, Tektronix power supply, scope, and DMM.

Show your work. In derivations and computations, be sure to circle your final answer. The questions in this lab are numbered. You must use these numbers in your lab writeup to identify your derivations and answers.

Part 1: Computational and Modeling Questions

1 Motor Theory: DC Permanent Magnet Brush Motors - (Pre-Lab Questions)

Answer the following in advance of doing the lab. Assume the motor is connected to a voltage power supply V_s.

Questions 1 through 13 are pre-lab questions.

For Q1: Include dynamic (viscous) friction, and assume that static (coulomb) friction is negligible.

For Q2-Q13: Assume all friction is negligible.

1) What is the equation of motion for a DC permanent magnet brush motor when the *input* is a **voltage**, i.e. it is driven by a voltage power supply? Use symbolic constants for motor parameters. Is this a differential equation or algebraic equation? What is its order? How many degrees of freedom does it have? What is the *state vector* of this system?
2) Derive the expression for the steady-state stall torque of the motor.
3) Derive the expression for the steady-state no-load speed of the motor.
4) Derive the expression for steady-state (in N-m) torque as a function of steady-state angular velocity (in rad/sec).
5) Sketch and label a plot of your function from the previous question. Describe briefly what it tells you.
6) Derive the expression for the steady-state electrical power input of the motor as a function of steady-state angular velocity.
7) Sketch and label a plot of your function from the previous question. Describe briefly what it tells you.
8) Derive the expression for the steady-state mechanical power output of the motor as a function of steady-state angular velocity.
9) Sketch and label a plot of your function from the previous question. Describe briefly what it tells you.
10) Define the efficiency of an electric motor.

11) Derive the expression for the steady-state efficiency of the motor as a function of steady-state angular velocity.

12) Sketch and label a plot of your function from the previous question. Describe briefly what it tells you.

13) Consider a hypothetical standard DC brush motor with the following motor parameters, powered by a voltage power supply capable of delivering 0V-75V at up to 30 Amps:

Resistance:	R = 2.5 Ohm
Back-Emf Constant:	K_e= 0.5 Volt/(radian-sec)
Torque Constant:	K_t = 0.5 (Newton-Meter)/Amp
Inductance:	L = 100 μ Henry
Friction:	0 (zero).
Inertia:	I = 1.5 * 10^{-4} kg-m^2

For the operating condition of 7.5 Newton-Meters of torque at 75 radians per second, compute the following:

a) Motor Voltage.

b) Motor Current.

c) Electrical power into the motor.

d) Mechanical power out of the motor via the output shaft.

e) Power lost in the motor itself. What happens to this lost power?

f) Efficiency.

g) Can you use this motor and power supply to provide a continuous shaft output of 7 Newton-Meters of torque at 75 radians per second? Explain why or why not. Be specific.

h) Can you use this motor and power supply to provide a continuous shaft output of 8 Newton-Meters of torque at 75 radians per second? Explain why or why not. Be specific.

Part 2: Lab Work

2 D.C. Motor Winding Resistance

14) Use your DMM to measure the resistance of your motor – the resistance between the motor's red and black leads. Make your measurement with the shaft NOT moving. Observe that the resistance values will vary with motor position due to variation in the internal resistance of the brush commutator. Record the lowest measured resistance value.
15) Determine the manufacturer's specification for winding resistance from the Pittman Spec Sheet for this *exact* model of motor.
16) Compare your measured motor resistance value to that listed in the Pittman specification sheet for this motor.

3 Motor Back EMF and Torque Constant

17) Read from the Pittman spec the values of the torque constant, $k_{t,}$, and the back-emf constant, $k_{e,}$. If necessary, convert these constants to SI units of N-m/Amp and V/(rad/sec), respectively. Show your work. *Hint: In the SI units suggested, k_t and k_e have identical numerical values!*

- Hook up the motor's encoder CH A output to the oscilloscope's CH1 input. Recall that this involves the following steps:
  - ☐ Carefully insert the free end of the encoder ribbon cable into your breadboard.
  - ☐ Find the pin connection specification in the HEDS-9100 Data sheet. Note the pin number and associated signal for each of the device's five electrical pin connections.

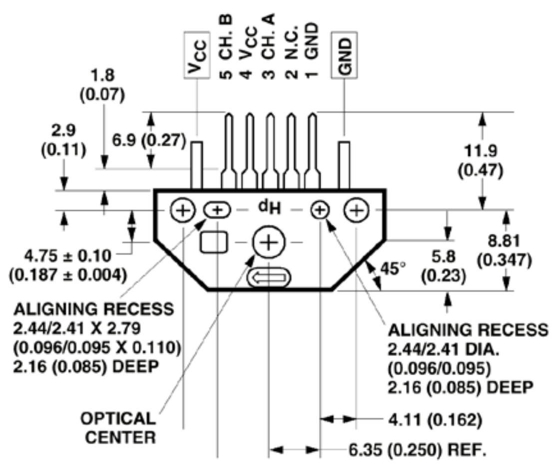

Figure 1: Pinout detail from HEDS-9100 encoder datasheet.

  - ☐ Connect the encoder pin labeled Vcc to the power supply's fixed 5V "+" output lug.
  - ☐ Connect the encoder pin labeled GND to the power supply's fixed 5V "–" output lug.
  - ☐ Set up the oscilloscope. Be sure to check each channel to verify that it is functioning properly as per Laboratory 1. Verify that the probe type is set to 10X, and that the trigger is set to CH1.
  - ☐ Connect the encoder output pin labeled CH A to CH 1 of your scope. Hook up the scope's CH 1 ground appropriately.
  - ☐ Connect the motor's red and black leads directly to CH 2 and CH 2 ground, respectively, of your oscilloscope. As you turn the motor by hand, verify that you can see both the motor back-emf voltage on CH 2, and the encoder square-wave output on CH 1.

18) Comment on the relation you observe between the motor's shaft speed (magnitude and sign) and the corresponding voltage (magnitude and sign) you observe on the oscilloscope. It may be convenient to have the scope time-axis set to roll-mode (i.e. 1.0 or 0.5 seconds per division) for this exercise.

19) With help from the laboratory instructor, use a variable speed drill drill to carefully rotate your motor at an (approximately) constant angular velocity. Use the scope to measure the motor back-emf voltage (on CH 2) and the encoder output frequencey (on CH 1). Note these values. Print and annotate the scope screen.

20) Repeat to collect at least four data points – i.e. two different positive (clockwise) angular velocities and two different negative (counterclockwise) angular velocities. Print and annotate a scope screen shot for each data point.

Direction	SPEED encoder pulse/sec	Angular Velocity radians/sec (signed)	Back-EMF (volts)

21) Plot your data for back-emf (in Volts) versus **signed** angular velocity in rad/sec.

22) Use your experimental data to compute an experimental value for the motor's back-emf constant. $k_{e.}$

- Compute values for $k_{e.}$ in (a) units of Volts/krpm and (b) units of Volts/(rad/sec).
- How does your experimentally determined value compare to the manufacturer's spec?

4 Mechanical Friction

With CH2 still connected to the motor leads, now also connect the motor power leads to the variable output of your power supply *in series* with your DMM. Use your DMM to measure the DC current (**use the DMM's 0-400 mA setting if available**) supplied to the motor by the power supply. Set the current limit of the variable output power supply to maximum (i.e. a 2A current limit when the "current" knob is turned fully clockwise).

23) Set the power supply output to 1.0V. Note the exact voltage, the motor rotation velocity (from the encoder trace on CH1 of your scope), and the average motor current (from your DMM). Repeat this measurement for the supply voltages listed in the following table:

Motor Supply Voltage	Motor Angular Velocity (no external load) encoder pulse/sec	Motor Angular Velocity (no external load) rad/sec	Motor Current (no external load) Amps	Motor Torque (no external load) N-m
3.0V				
2.0V				
1.0V				
0.0V				
-1.0V				
-2.0V				
-3.0V				

24) Using the manufacturer's specification for k_t and your measured values for motor current, i, compute a fourth column in your table for the motor torque, $\tau = k_t \ i$, at each of these data points.

25) Plot a graph of motor torque (on the Y axis) as a function of motor angular velocity (on the X axis).

26) Discuss your graph of motor torque versus motor velocity. Discuss the curious feature of this plot. What is going on here?

27) From your graph, determine approximate experimental values for the motor static friction

$$\tau_{static} = k_s \, sgn(\omega)$$

and the motor dynamic friction

$$\tau_{dynamic} = k_D \, \omega$$

28) Compare your experimentally determined friction coefficients to those listed in the Pittman spec sheet for your motor. Note that motor static friction is labeled "motor friction torque in the Pittman spec sheet, and motor dynamic friction is labeled "viscous damping factor" in the Pittman spec sheet.

5 Motor Speed-Torque Curves

29) Use your DMM to measure the DC current (**use the DMM's 10A setting**) supplied to the motor by the power supply. Carefully immobilize the motor output shaft with the supplied knob, and note the stall current at each of the supply voltages given in the following table:

Motor Supply Voltage	Motor Angular Velocity (no external load) rad/sec	Motor Current (stall current) Amps	Motor Torque (stall torque) N-m
3.0V	**0**		
2.0V	**0**		
1.0V	**0**		
0.0V	**0**		
-1.0V	**0**		
-2.0V	**0**		
-3.0V	**0**		

30) Using the manufacturer's specification for k_t and your measured values for motor current, i, compute a fourth column in your table for the motor torque, $\tau = k_t \ i$, at each of these data points.

31) Plot the data points from the 3.0V rows of your two tables for speed and torque at (a) no-load and (b) stall on a graph showing angular velocity (in radians per second) on the X axis and torque (in Newton-Meters) on the Y axis. Graph paper is fine. Connect the two data points with a line.

32) Discuss the relation indicated by this line.

33) On the same graph, plot the points and corresponding lines for the remaining supply voltages you tested. Discuss this family of curves.

6 Visualizing Speed-Torque Curves – For 530.420 Students

Your lab instructor will set up a Maxon 43.032.000-22.00-146 motor/tachometer comprised of Maxon motor model #2332.967-51.236-200 (identified as "967" in the spec sheet) and tachometer model #118910 to a power supply and an oscilloscope. The scope is set up in XY mode. The Y-axis displays a voltage proportional to motor current (which as you will recall is proportional to torque). The X axis displays the tachometer voltage which is proportional to motor angular velocity.

34) The Y axis displays motor current. Based upon your examination of this lab setup, what is the scale factor of Amps per screen division?

35) The X axis displays tachometer voltage. Based upon your examination of this lab setup, what is the scale factor of radians-per-second per screen division?

36) The instructor will show you how to plot a speed-torque curve for two motor supply voltages: +5V and +10V. Print and annotate scope plots of each.

37) From the scope plots, determine (a) the stall current and (b) no-load speed (in SI units!) of the motor for both motor supply voltages.

38) Use the spec sheet value of kt and the experimentally observed value for stall current (from #37) to compute the stall torque.

39) From the motor spec sheets, determine (a) the stall torque and (b) no-load speed (in SI units!) of the motor for both motor supply voltages.

40) Compare the experimentally observed values (#37+#38) with the derived-from-specification values (#39). How do they compare? Give your answer as a difference (in SI units) and as a percent difference.

7 Visualizing Speed-Torque Curves – For 530.620 Students

- Review the spec sheet for for the Maxon 43.032.000-22.00-146 motor/tachometer comprised of Maxon motor model #2332.967-51.236-200 (identified as "967" in the spec sheet) and tachometer model #118910 to a power supply and an oscilloscope.
- Design a simple circuit consisting of a 0.1Ω resistor in series with the motor power lead such that you can monitor the motor current by measuring the voltage across the 0.1Ω resistor with your oscilloscope.
- Read the scope manual section on XY mode. Configure the scope in XY mode.
- Connect the the 0.1Ω to the scope channel that drives the Y-axis, i.e. so that the Y-axis displays a voltage proportional to motor current (which as you will recall is proportional to torque). Increasing current should result in increasing Y position of the scope trace – i.e. up.
- Connect the motor tachometer output leads such that they drive the X-axis of the scope display, i.e. so that the X axis displays the tachometer voltage which is proportional to motor angular velocity. Increasing angular velocity should result in increasing X-position of the scope trace – i.e. to the right.

41) Give a complete circuit diagram showing your circuit, its connection to the power supply, and how your scope's two leads (each lead has TWO connections!) are connected to the circuit. Be specific on which lead is CH1 and which is CH2.

42) The Y axis displays motor current. Based upon your examination of this lab setup, what is the scale factor of Amps per screen division?

43) The X axis displays tachometer voltage. Based upon your examination of this lab setup, what is the scale factor of radians-per-second per screen division?

44) Use your setup to capture and plot a speed-torque curve for two motor supply voltages: +5V and +10V. Print and annotate scope plots of each.

45) From the scope plots, determine (a) the stall current and (b) no-load speed (in SI units!) of the motor for both motor supply voltages.

46) Use the spec sheet value of kt and the experimentally observed value for stall current to compute the stall torque.

47) From the motor spec sheets, determine (a) the stall torque and (b) no-load speed (in SI units!) of the motor for both motor supply voltages.

48) Compare the experimentally observed values (#45+#46) with the derived-from-specification values (#47). How do they compare? Give your answer as a difference (in SI units) and as a percent difference.

49) Configure your scope back in normal Y-T mode. Create a MATH trace which plots the product of the motor current signal (voltage across the 0.1 Ohm resistor) and the motor speed (tachometer output). It may be convenient to set your scope time–axis to ROLL mode.

   a) What physical quantity does this MATH trace represent?
   b) What are SI unit scale factors of the derived unit for each of the three traces e.g. (rad/sec)/div for motor speed, amps/div for current, and XXX/div for the math trace.
   c) With a 5V power supply voltage, manually vary the load on the motor output shaft.
   d) At what motor velocity or velocities is the MATH trace minimum? Does this observation agree with motor theory? Why or why not? Print and annotate scope plot(s) at each condition.
   e) At what motor velocity or velocities is the MATH trace maximum? Does this observation agree with motor theory? Why or why not? Print and annotate scope plot(s) at each condition.

50) With you scope still in normal Y-T mode, add a third scope probe to measure the power supply voltage. Create a MATH trace which plots the product of the motor current signal (voltage across the 0.1 Ohm resistor) and the power supply voltage. It may be convenient to set your scope time–axis to ROLL mode.

   a) What physical quantity does this MATH trace represent?
   b) What are SI unit scale factors of the derived unit for each of the three traces e.g. (rad/sec)/div for motor speed, amps/div for current, and XXX/div for the math trace.
   c) With a 5V power supply voltage, manually vary the load on the motor output shaft.
   d) At what motor velocity or velocities is the MATH trace minimum? Does this observation agree with motor theory? Why or why not? Print and annotate scope plot(s) at each condition.
   e) At what motor velocity or velocities is the MATH trace maximum? Does this observation agree with motor theory? Why or why not? Print and annotate scope plot(s) at each condition.

- Note your secret code on your lab report.
- Note your lab partner's secret code on your lab report.
- Note your workstation number on your lab report.
- Remember to show your work.
- Typed or hand-written lab reports are OK. Messy or ambiguous lab reports will be rejected.
- **Please clean up your workstation to perfection when you are done.**

Cover Sheet for 530.420 Lab #3

Use this cover sheet for your lab writeup.

My Secret Code: _______

Fill in the secret code which was provided to you on your graded lab#1.

My Lab Station: _______

My Partner's Secret Code: _______

Lab Station Clean! TA's Signature & Date:

Your TA will sign here after you have finished your lab, cleaned up your lab station to perfection, and shown your lab station to your TA.,

Note: We grade labs anonymously. Please do not include personal identity information within you lab (name, etc). Use your secret code in place of personal identity information.