ME – 190 MECHATRONICS SYSTEM DESIGN

Lab 8: DC Motor Parameter Identification

Part 1: Motor Steady state response

Objectives:

- Perform different experiments on a DC motor to determine its parameters

Background Information:

A DC motor can be modeled with an electrical system coupled to a mechanical system by a magnetic field. The equation for the electrical system is:

$$L\frac{di}{dt} + Ri + K_b\omega = V$$

Where:

- V – Applied voltage
- K_b – back emf constant
- R – armature resistance
- L – inductance
- i – the current through the motor windings

The coupling is seen from the voltage generated by the spinning motor $K_b\omega$. The equation for the electrical system is:

$$J\frac{d\omega}{dt} + b\omega = K_t i$$

- K_t – torque constant
- b – viscous damping coefficient
- J – motor inertia (or combined motor and load Inertia if load is attached)
- ω – the velocity of the motor shaft

In the steady-state (no change with time) the equations become:

$$Ri_{ss} + K_b\omega_{ss} = V_{ss}$$

$$b\omega_{ss} = K_t i_{ss}$$

These equations, with the steady state current and voltage measurements can be used to determine the motor parameters.

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*Courtesy of Dr. Joshua Hurst at RPI/MinSeg

Parameter Estimation Background

Resistance: If there is access to the motor leads this can be measured with a multimeter.

Torque and Back EMF constants:

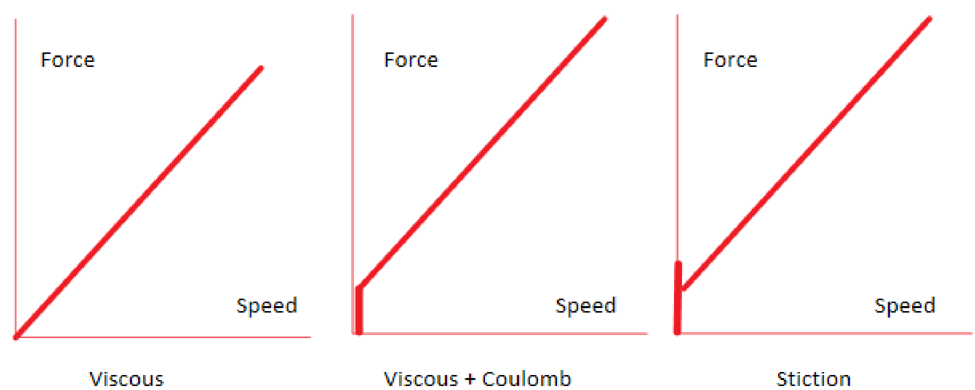
First assume that energy is conserved in the motor in which case $K_b = K_t$ and only one needs to be estimated. From the steady state electrical equation:

$$Ri_{ss} + K_b\omega_{ss} = V_{ss}$$

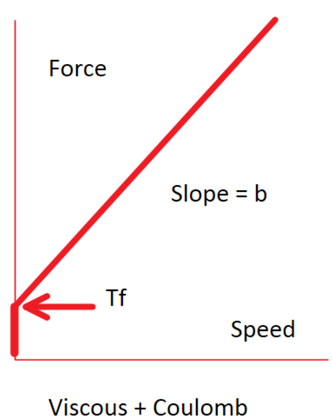
If resistance is known, speed is measured and current and voltage are measured this equations can be used to calculate K_b which, by assumption equal to K_t. For the Lego NXT motors, since they contain a gear train and have significant losses **assume K_t is about 65% of K_b**. This value can be obtained by an experiment where a known load is applied, and the current is measured.

Viscous and Coulomb Friction Estimation:

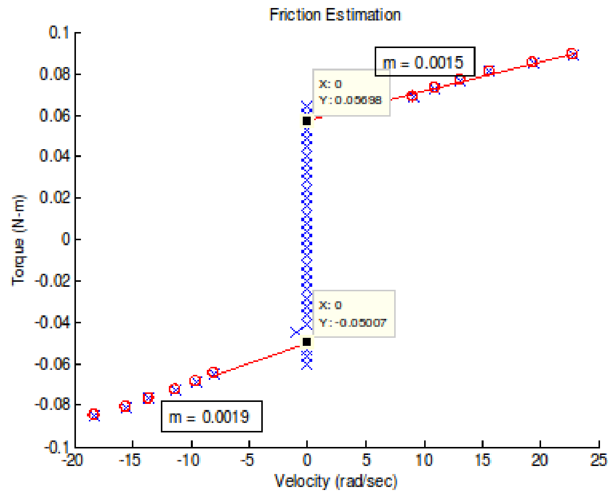
There are typically 3 different components of friction: viscous, coulomb, and static. This leads to three different types of friction models:



For a motor curves can be obtained by plotting steady state speed and measured torque$K_t i$.



An experimental example is:

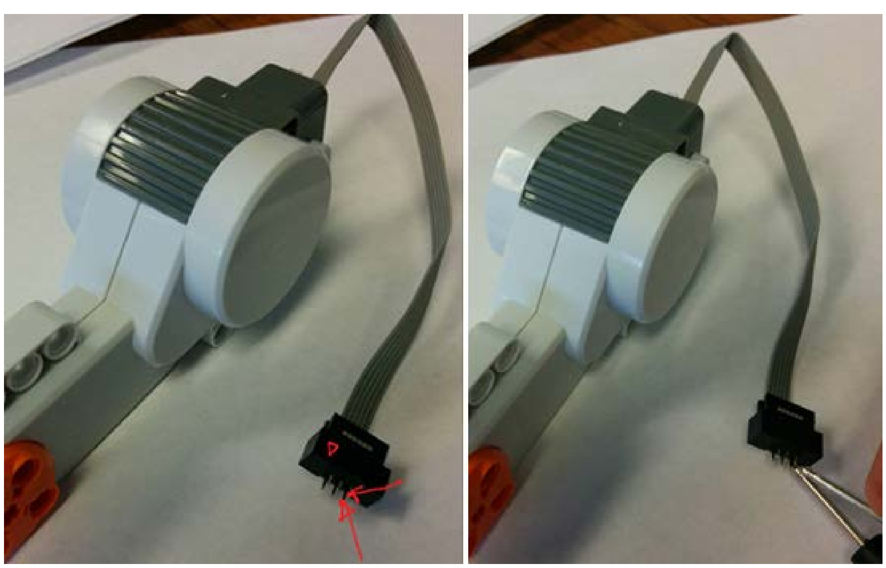


This will require steady state measurements of voltage and current at a couple different speeds. Once this graph is obtained then the viscous damping coefficient b is the slope of the line, and the constant coulomb friction is the y-intercept.

System Measurements

<u>Resistance:</u>

First you can measure the motor resistance by using a multimeter and measuring the resistance between the two motor leads. If an adapter cable is available you can disconnect the motor and us the adapters to measure the resistance. For example if a header socket is provided it is the two end terminals:



Resistance measurement locations on Motor

Record the value of the motor resistance: R=____________

Speed, Voltage and current:

The current and voltage need to be measured at different speeds. The Simulink diagram below can be used in the external mode at 0.03 seconds to record the steady state velocity.

For the Driver Block, copy all the stuff from the block with pin 4 and 5 and change the PWM blocks to Pin 44 and 45.

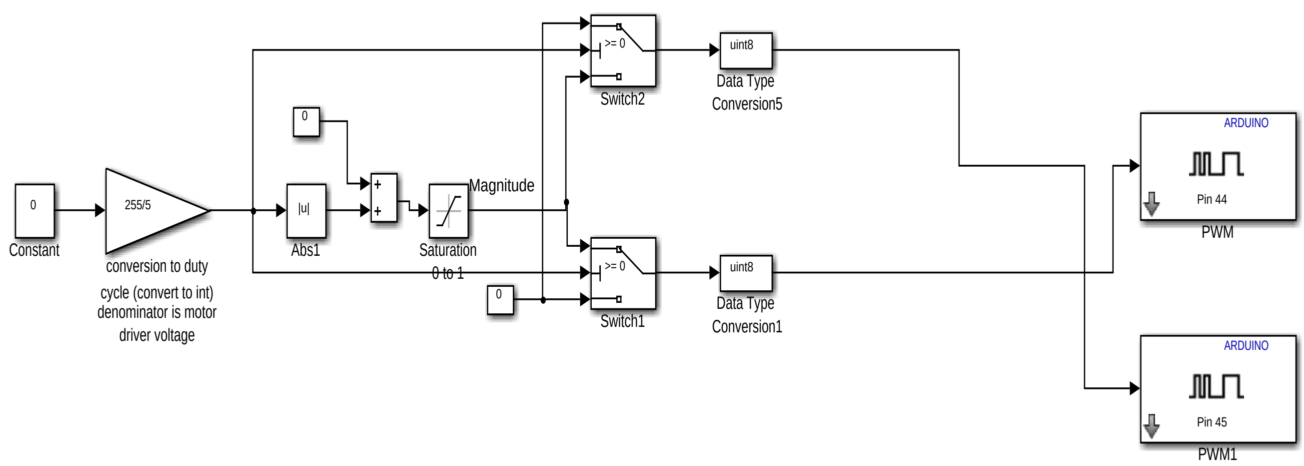


Figure 3: Driver Circuit

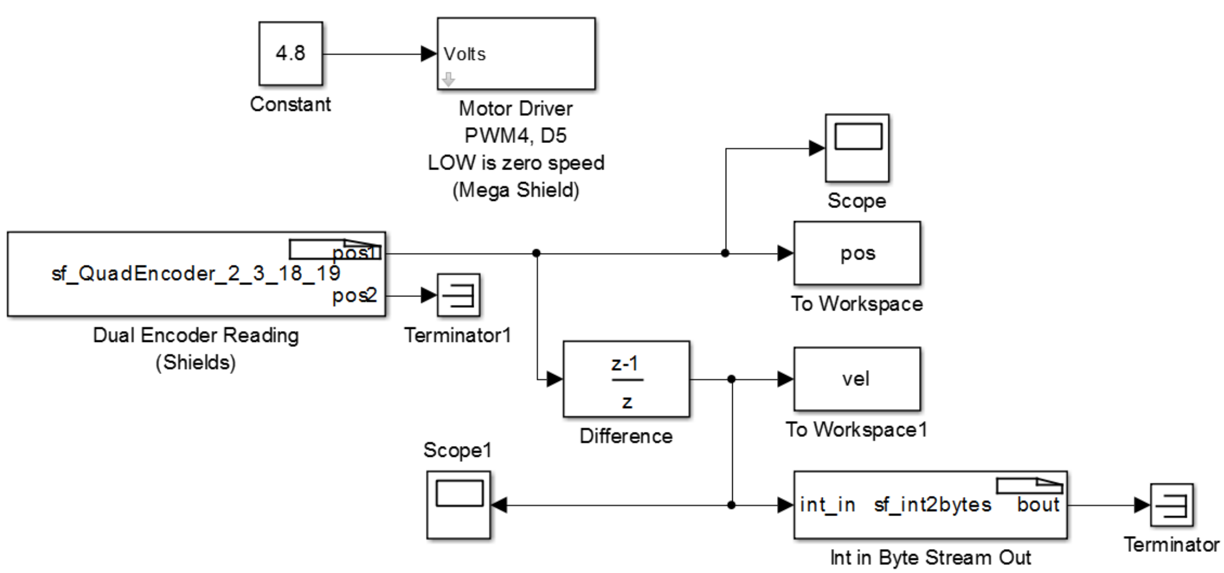


Figure 1: Simulink diagram for speed measurement

Voltage Measurement:

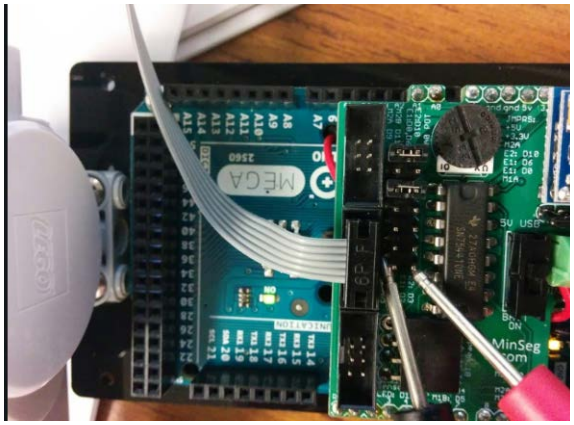
When the motor is spinning at steady state the voltage can be measured between the motor leads:

- Put Multi-meter in the voltage measurement mode
- Measure the voltage across the jumper pin (just behind the motor connection port) and the ground. There will be current flowing so be VERY careful where you place the multi-meter leads.

Voltage measurement locations on the MinSeg board

Current Measurement:

- First ensure the motor is spinning at a constant velocity
- Remove the last jumper (it will stop spinning)
- Then put the multi-meter in current mode and connect the two leads that were connected with the jumper with the multi-meter. The motor will start to spin as the multi-meter completes the circuit and you can measure the current. There will be current flowing so be VERY careful where you place the multi-meter leads so you do not short them.



Current measurement with jumper removed.

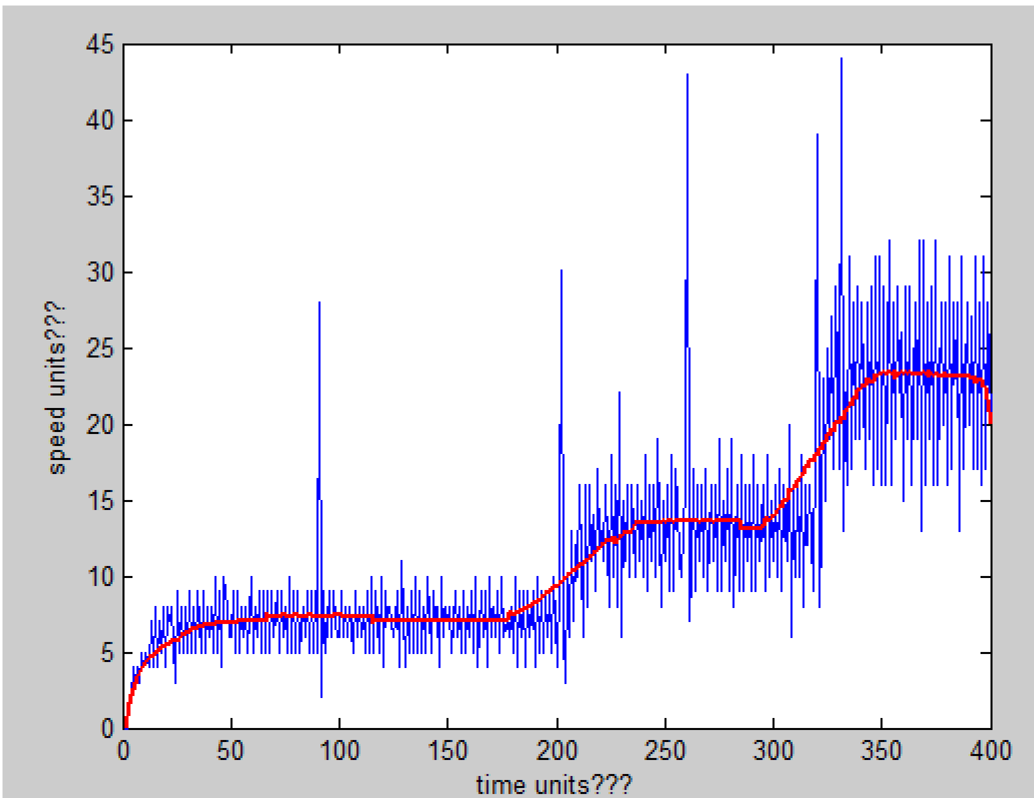
Speed versus Torque Graph:

- Run the motor at 3 different steady state speeds, and record the speed data (2.5, 3.5, and 4.5 volts would be good values to start with)
  - At the steady state speeds measure the velocity, voltage, and current. This may require multiple tests. Record voltage and current at each speed.

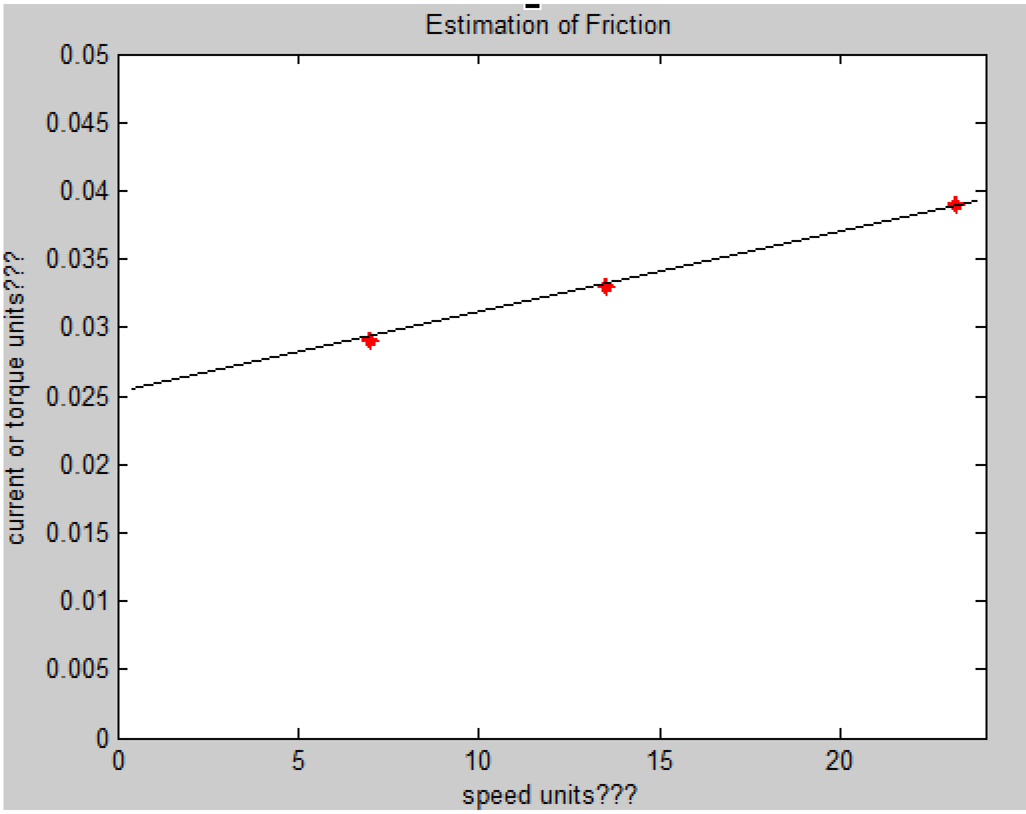
    $\omega_1 =$__________ $V_1 =$__________ $I_1 =$__________

    $\omega_2 =$__________ $V_2 =$__________ $I_2 =$__________

    $\omega_3 =$__________ $V_3 =$__________ $I_3 =$__________
  - You may need to smooth the velocity data to help determine the steady state speed:



  - Use the steady state equation to determine K_b, K_t from measured speed, current and voltage at the 3 different speeds:
    - $V_{ss} = Ri_{ss} + K_b\omega_{ss}$
  - Use the data to plot the speed torque curve (with the correct units) to determine the coulomb friction value, and the damping coefficient. An example graph is shown below (units and data are not correct):



Questions:

- Create a plot of Current (milliamps, y-axis) versus speed (rad/sec. x-axis) Clearly label the axes and provide a title for the graph
- Do the measured voltages match the voltage set in the Simulink diagram when you use the multi-meter to measure the voltage?
- What are your experimental values for (with units!!):
    - o R, K_b, b, T_f?

Part 2: Motor Transient Response

From the mechanical and electrical DC motor equations the 2nd order transfer function for a DC motor is:

$$G(s) = \frac{\omega(s)}{V(s)} = \frac{K_t}{LJs^2 + (JR + Lb)s + (Rb + K_t K_b)}$$

If the inductance is "small" it can be neglected (L=0) and the first order transfer function is obtained:

$$G(s) = \frac{\omega(s)}{V(s)} = \frac{K_t}{JRs + (Rb + K_t K_b)}$$

Where the motor parameters are:

- K_t – torque constant
- K_b – back emf constant
- b – viscous damping coefficient
- R – armature resistance
- J – Total Inertia (or combined motor and load inertia if load is attached)
- L – inductance

The equation in time constant form is:

$$G(s) = \frac{\omega(s)}{V(s)} = \frac{K_t/(Rb + K_t K_b)}{JR/(Rb + K_t K_b)s + 1} = \frac{K}{\tau s + 1}$$

From this equation the time constant and steady state gain can be identified. Calculate K from the parameters you identified (include units):

- **Time Constant**: $\tau = \frac{JR}{Rb+K_t K_b}$
- **Steady State Gain**: $K = \frac{K_t}{Rb+K_t K_b}$ ____________________ (Units _____)

Questions:

- What is your calculated values for the steady state gain K?

Parameter Estimation from step response

Obtain the step response of the motor in serial mode. An example step response is shown below (you may already have this data from a previous lab). You can modify the previous Simulink diagram to write the data to the serial port and record this data with RealTerm.

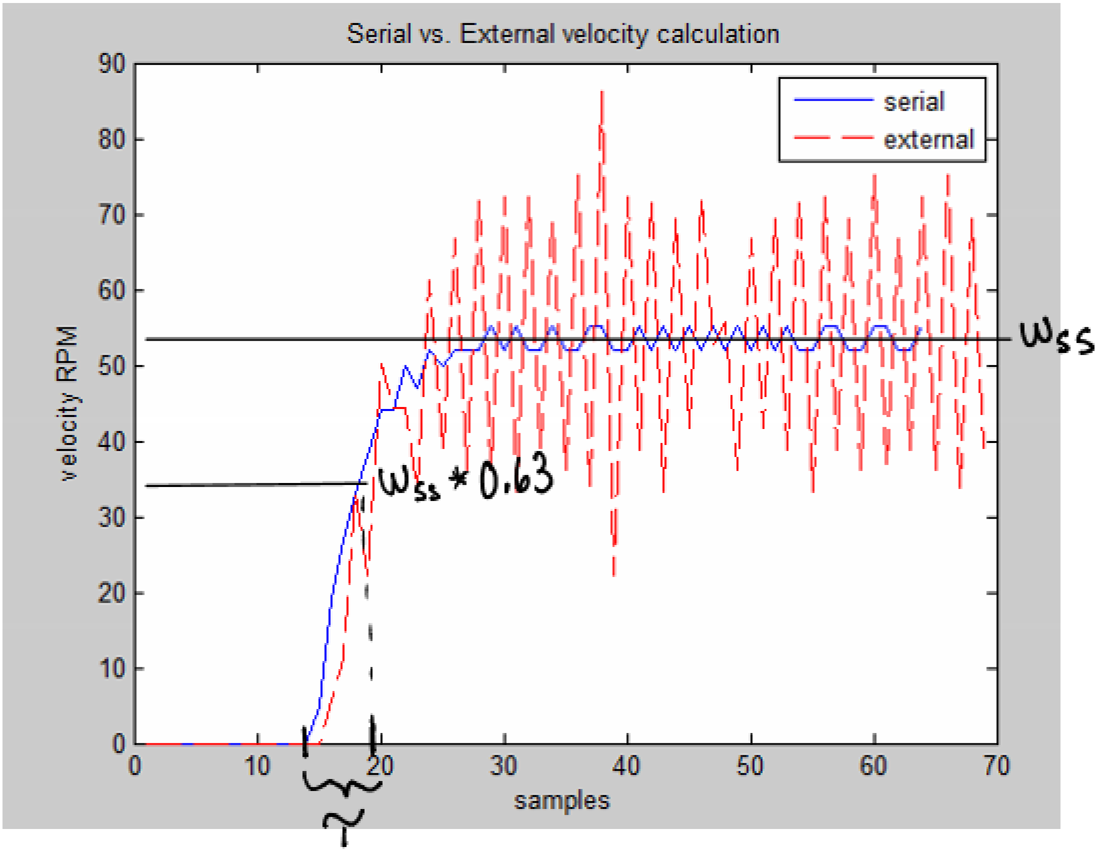


Figure 2: Sample Step response data obtained with 0.03 second sample time, 3 volt step

Take note of what voltage you used to generate this step response V_{in}:

V_{in} = ________________

Calculate the experimental steady state gain:

$K_{exp} = \omega_{ss}/V_{in} =$___________________

Where ω_{ss} is the steady-steady state value from the step reponse graph, and V_{in} is the voltage used to generate the step response.

Next experimentally compute τ by finding how long it takes for the step response to reach 63% of its steady state value:

$\tau_{exp} =$___________________

The only unknown in the formula for the time constant τ is the inertia. Use the formula for the step response to calculate the inertia J:

$J =$______________________ (be sure to include units)

Questions:

- What is your experimental values for the time constant and steady state gain τ, K?
- What is the inertia identified from the time constant?
- What is the percent error from the calculated K versus the K_{exp} value from the step response?
- Kt can be determined by applying known loads and measuring the current. For this motor it is determined that Kt is approximately 65% of Kb. Why?
- If all the linear motor parameters are determined from separate experiments, the computed time constant for the resulting linear model is approximately $\tau = .042$. How does your value for the time constant compare to this - why?