RENSSELAER MECHATRONICS
DC Motor Parameter Identification

Part 1: Motor Steady state response

Objectives:

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

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

Where:

- 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

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

- K_t – torque constant
- b – viscous damping coefficient
- J – armature Inductance (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:

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

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

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

Parameter Estimation Background

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

Torque and Back EMF constants:

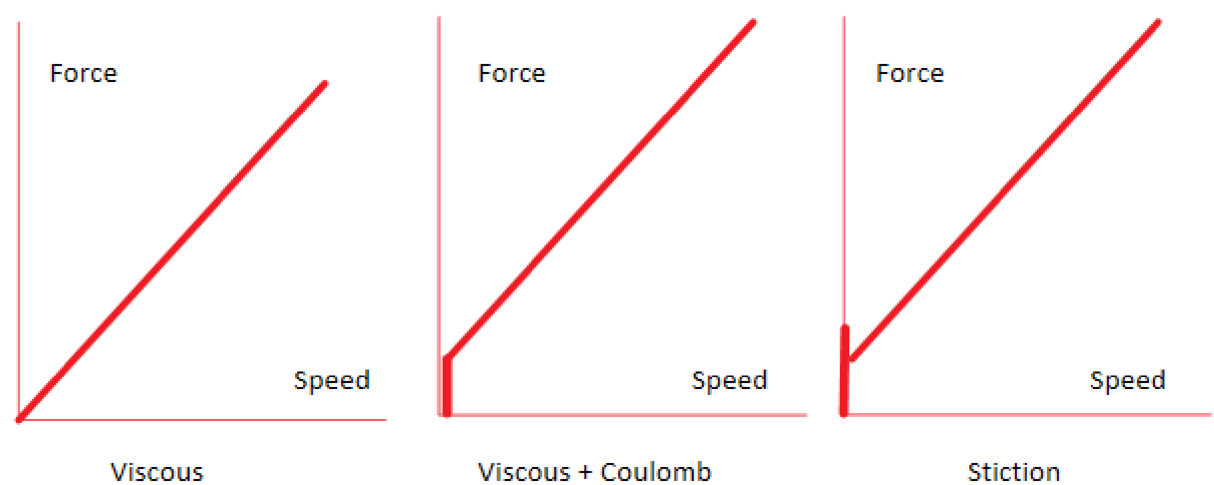
First assume that energy is conserved in the motor in which case $K_b = K_t$ and only one needs to be estimated. From the steady-state electrical equation:

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

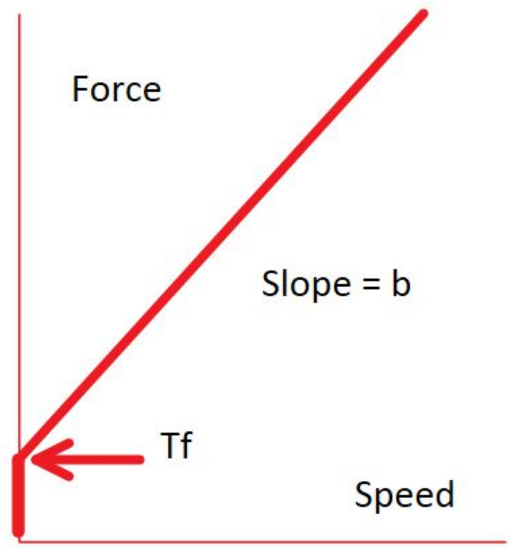
If resistance is known, speed is measured and current and voltage are measured these equations can be used to calculate K_b which, by assumption equal to K_t. For the Lego NXT motors, since they contain a gear train and have significant losses assume K_t is about 65% of K_b. This value can be obtained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

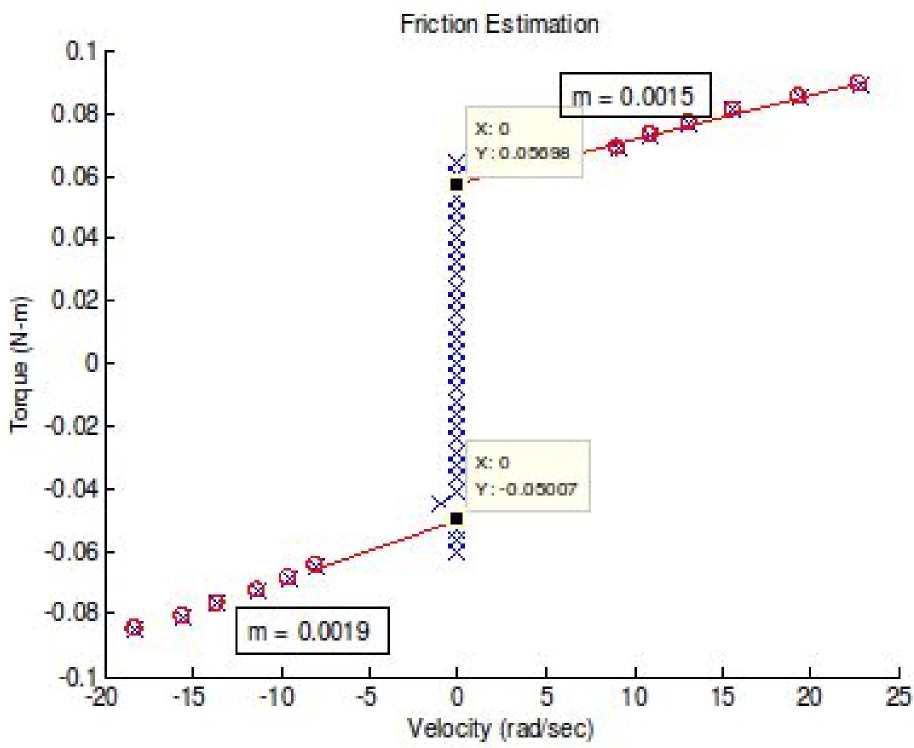


For a motor curves can be obtained by plotting steady state speed and measured torque $K_t i$.



Viscous + Coulomb

An experimental example is:



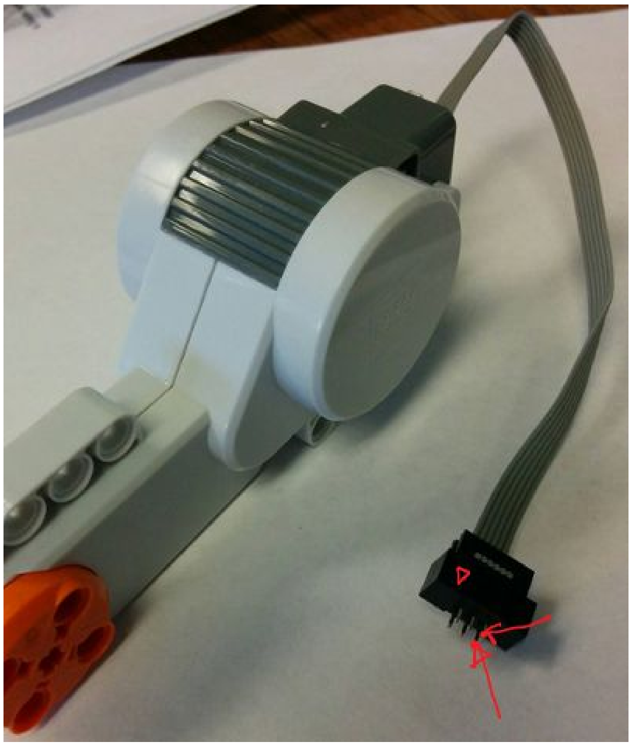
This will require steady state measurements of voltage and current at a couple different speeds. Once this graph is obtained then the viscous damping coefficient b is the slope of the line, and the constant coulomb friction is the y-intercept.

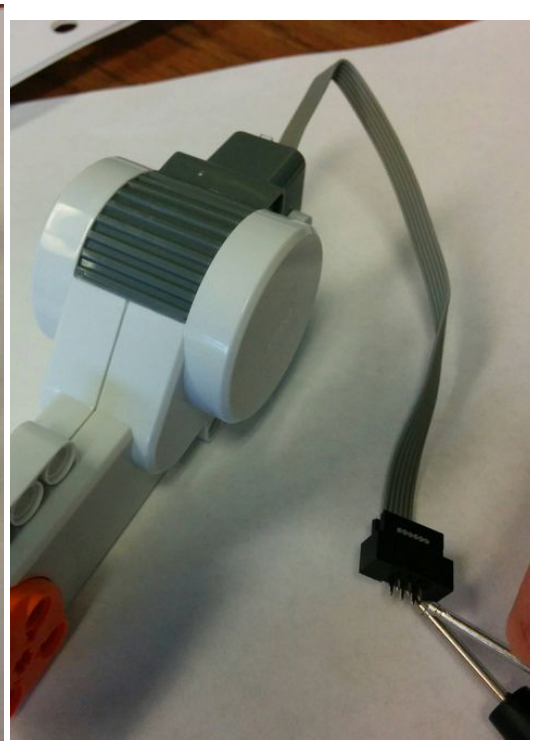
System Measurements

<u>Resistance and Voltage:</u>

Resistance and voltage can be measured by using a multimeter and measuring between the two motor leads.

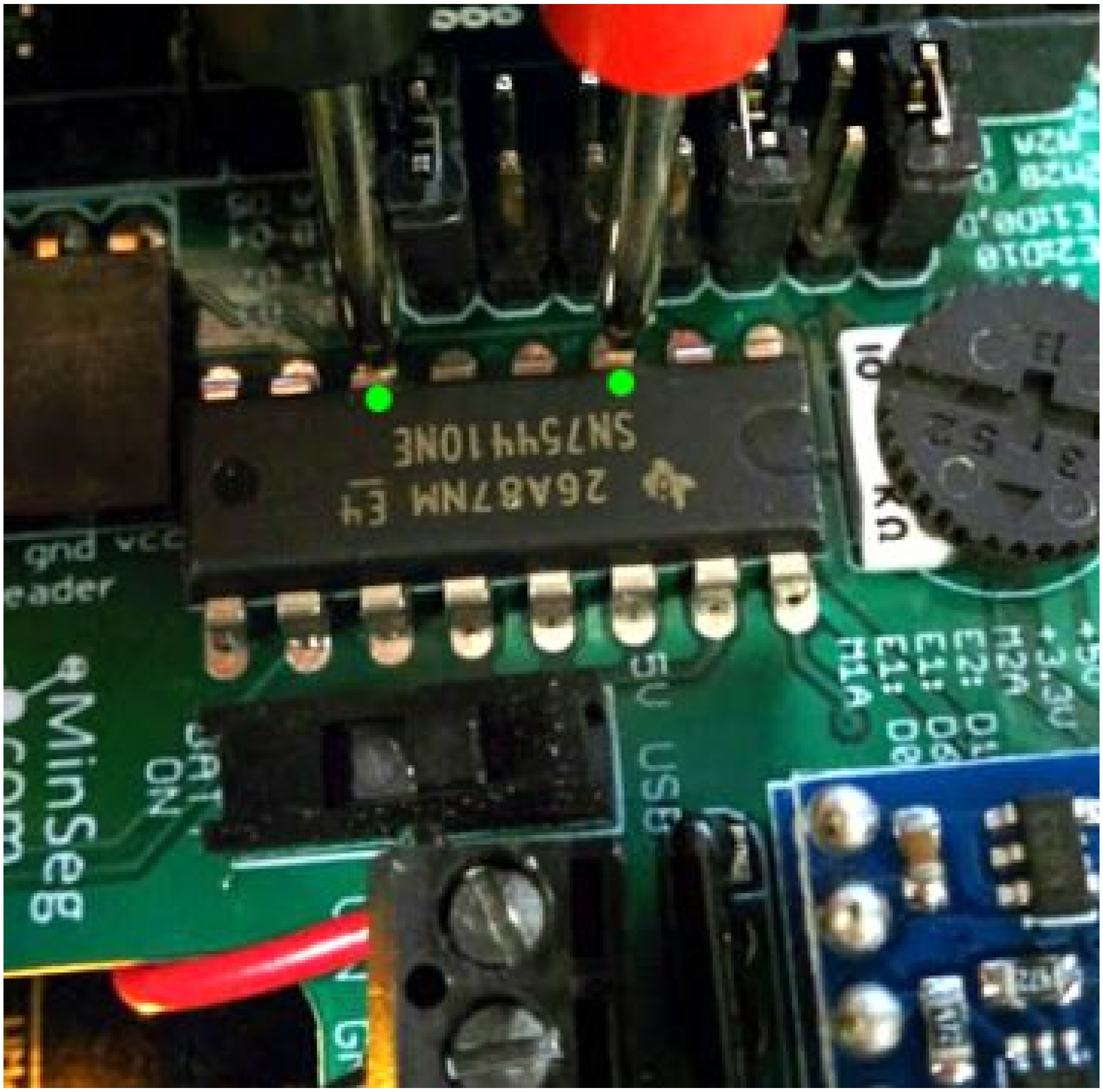
If an adapter cable is available you can disconnect the motor and us the adapters to measure the resistance. For example if a header socket is provided it is the two end terminals:





- **If** no tools or cables are provided you can make the measurement while the motor is connected. **First make sure your board is completely powered off – it is not connected to the USB cable, and**

there are NO batteries installed. To do this find where you have access to the motor leads; shown below:


SN754410NE
26A87NM
gnd vcc
MinSeg
ON
5V

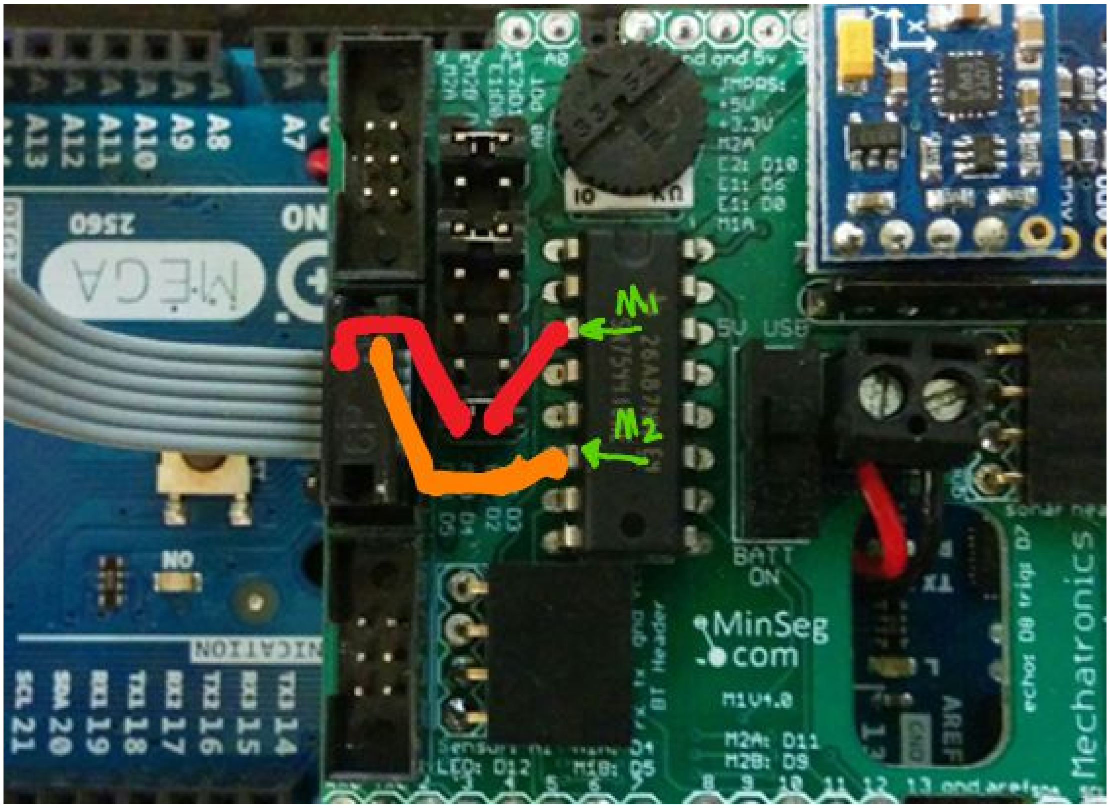


Figure 1: Motor wire connections on M1V4 board – resistance and voltage measurement from pins 3 and 6 of the motor driver.

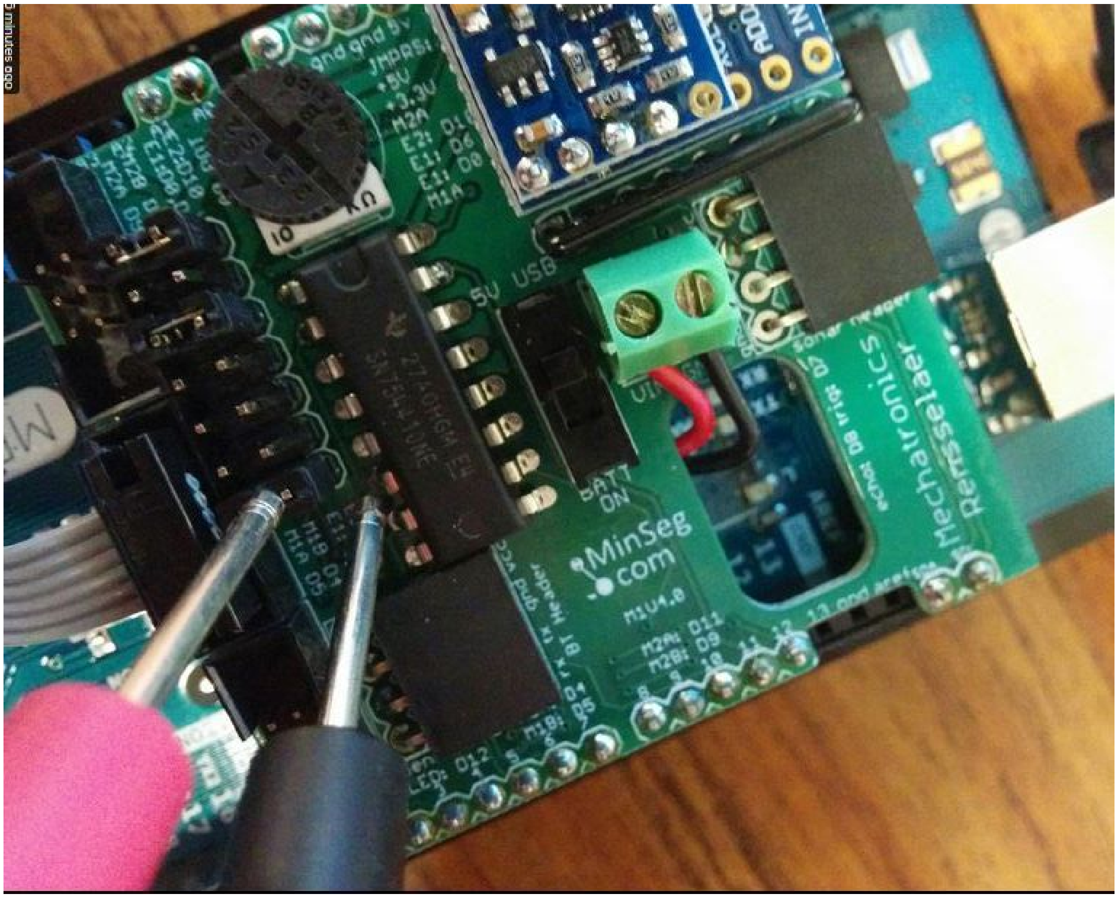


Figure 2: Alternate location for resistance or voltage/resistance measurements

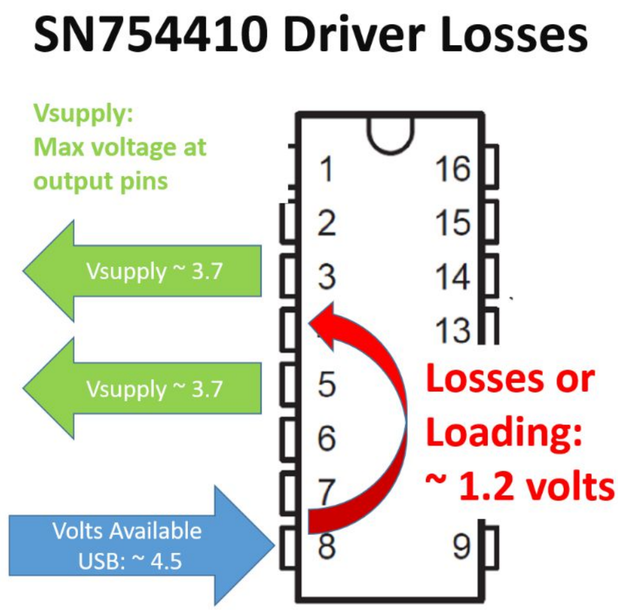
You need to measure the resistance between between the two motor leads; M1 and M2. You can do this from the last jumper (connected to M1 – one of the motor leads, also connected to the 3rd motor driver chip) and the 6th pin on the driver chip. Alternately you can simply measure between pin 3 and pin 6 on the driver chip:

With the powered completely off (usb disconnected) and the motor connected this will allow measurement of the resistance.

Record the value of the average motor resistance (turn the motor by hand between measurements):

R_avg = ___________

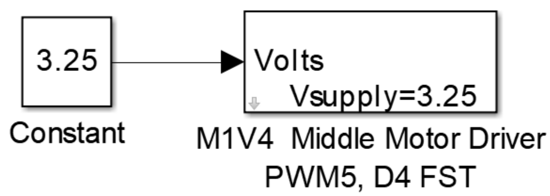
Driver Supply Voltage (direct measurement):



The Motor driver block computes the approapriate PWM value based on the desire voltage. To do this it has to scale the actual available voltage at the ouput of the actual driver, to the correct PWM value.

The value of Vsupply in this block needs to be the maximum voltage available to your device, in this case the motor. To find this value turn the driver completely ON, and measure the voltabe at the output pins of the driver. This value is the maximum voltage you can obtain from the output of the driver Vsupply.

To find this, run the following Simulink diagram:



Since the Vsupply is 3.25 and the input is 3.25 the PWM duty cycle will be 100% (fully on). With the motor connected and freely spinning measure the voltage between the motor leads (pins 3 and 6 on the driver - Figure 5: Voltage Measurement location for M1V4).

Vsupply=_______________

This value is the driver voltage supply available to the motor when it is fully ON. This value needs to be specified in the motor driver block so it can correctly scale the voltage to the correct PWM value. **If your specified Vsupply in the driver block is different than the measured value, change the value in the driver block to what you measured.**

Driver Supply Voltage (indirect approximation):

If the supply voltage was estimated directly in the previous step you do not have to do this.

The SN754410 loses approximately 1.2 volts from what it has available; the DRV8833 driver the loss is about 0.6 volts. If you know what the voltage to the driver chip you can estimate its maximum output voltage. For example if USB is used, 4.5 volts, then the max output expected for the SN754410 driver would be approximately 4.5-1.2 = 3.7 volts. You can estimate the available volts by measuring pin 8, which should be about 4.5 volts for USB.

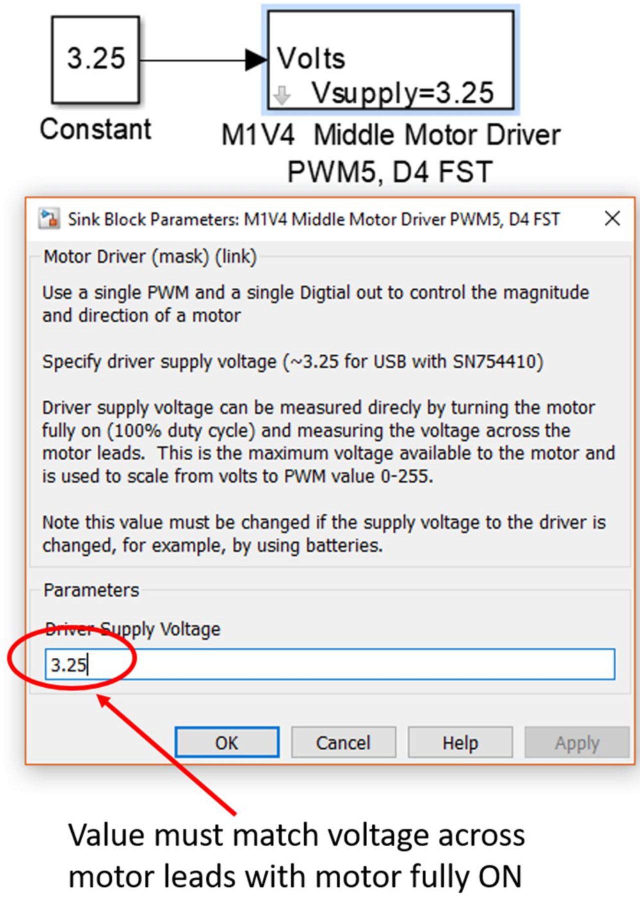


Figure 3: Specification of Driver supply voltage Vsupply for motor driver block

<u>Speed, Voltage and current:</u>

The current and voltage need to be measured at different speeds. The Simulink diagram below can be used in external mode at 0.03 seconds to record the steady state velocity. Make sure "send single Port0" is commented out when using external mode. This same diagram can be used later to capture the step response in normal mode.

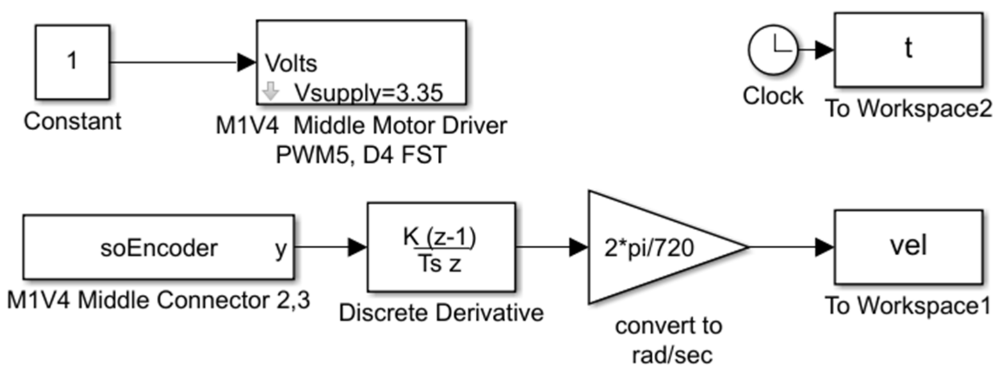


Figure 4: Simulink diagram for speed measurements

Voltage Measurement:

When the motor is spinning at steady state the voltage can be measured between the motor leads the same way the resistance was measured. from the last jumper that connects to pin #6 on the driver chip: There will be current flowing so be VERY careful where you place the multimeter leads. Alternatively, you can measure between pin #6 and #3 on the driver chip.

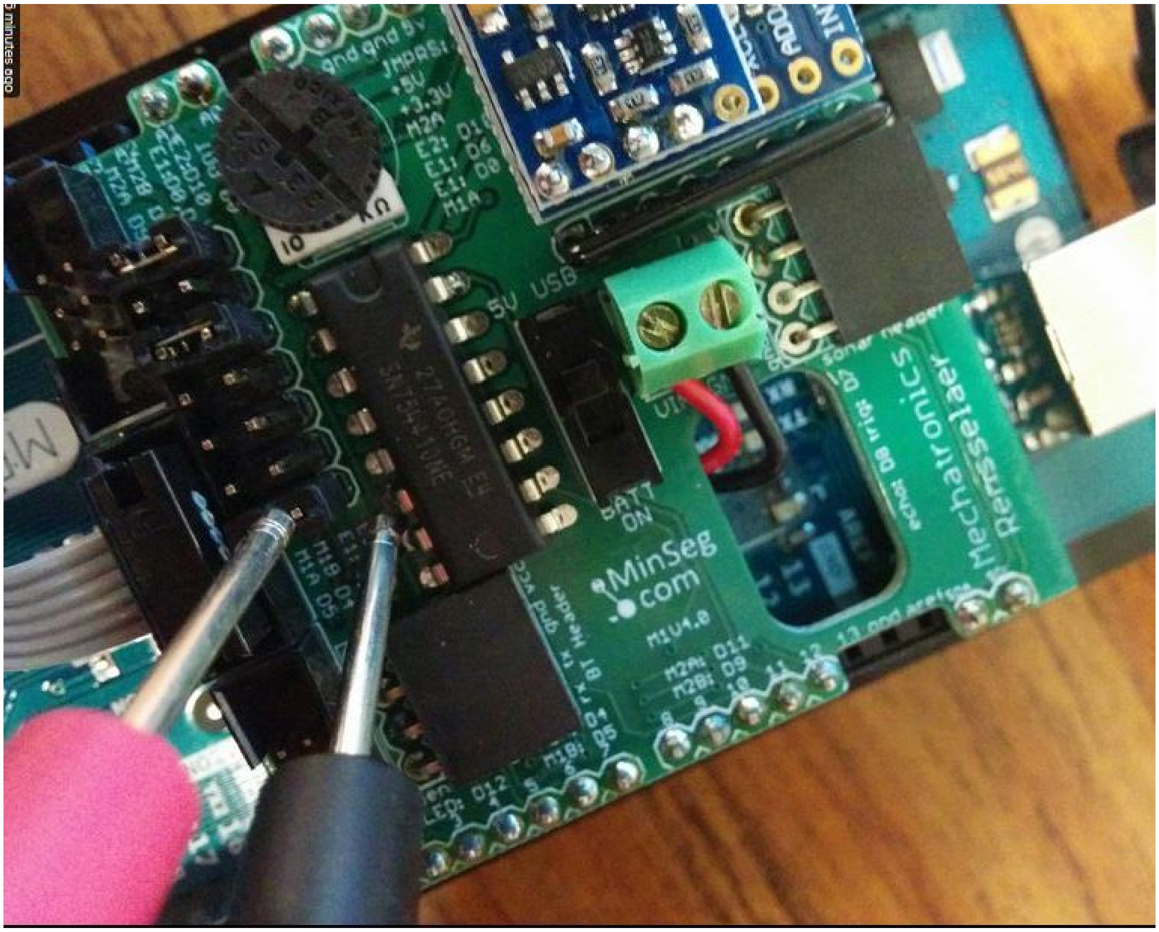


Figure 5: Voltage Measurement location for M1V4

Current Measurement:

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

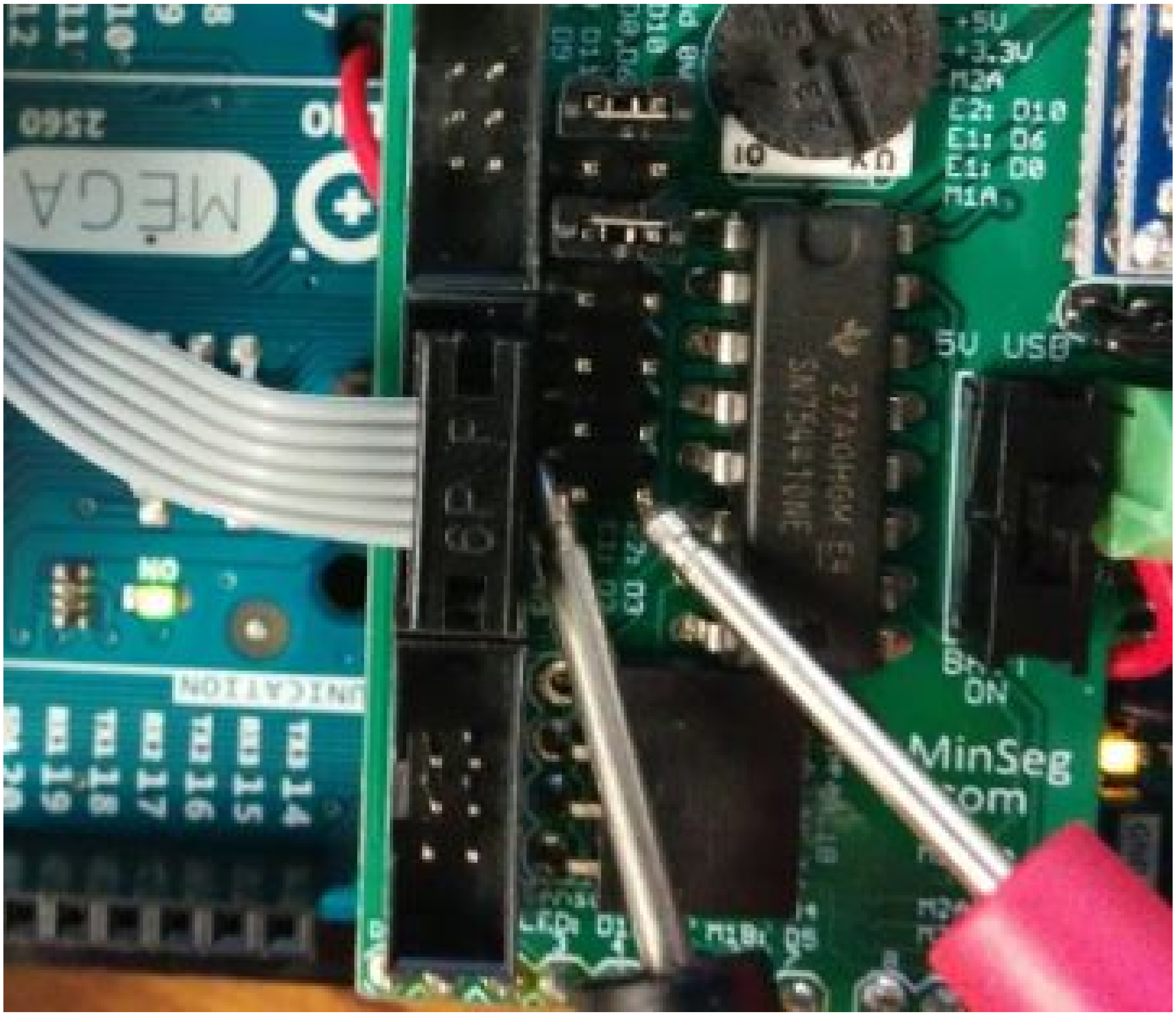


Figure 6: Current measurement with jumper removed.

Data Collection:

- Run the motor at least 3 different steady state speeds, and record the speed data (1.5, 2, and 3 volts would be good values to start with)
    - At the steady state speeds measure the velocity and current. This may require multiple tests. Record voltage and current at each speed.

$$V_{1specified} = \_\_\_\_\_\_\_\_ , V_{1meaured} = \_\_\_\_\_\_, \omega_1 = \_\_\_\_\_\_\_\_\_\_, I_1 = \_\_\_\_\_\_\_\_\_\_$$
$$V_{2specified} = \_\_\_\_\_\_\_\_ , V_{2meaured} = \_\_\_\_\_\_, \omega_2 = \_\_\_\_\_\_\_\_\_\_, I_2 = \_\_\_\_\_\_\_\_\_\_$$
$$V_{3specified} = \_\_\_\_\_\_\_\_ , V_{3meaured} = \_\_\_\_\_\_, \omega_3 = \_\_\_\_\_\_\_\_\_\_, I_3 = \_\_\_\_\_\_\_\_\_\_$$

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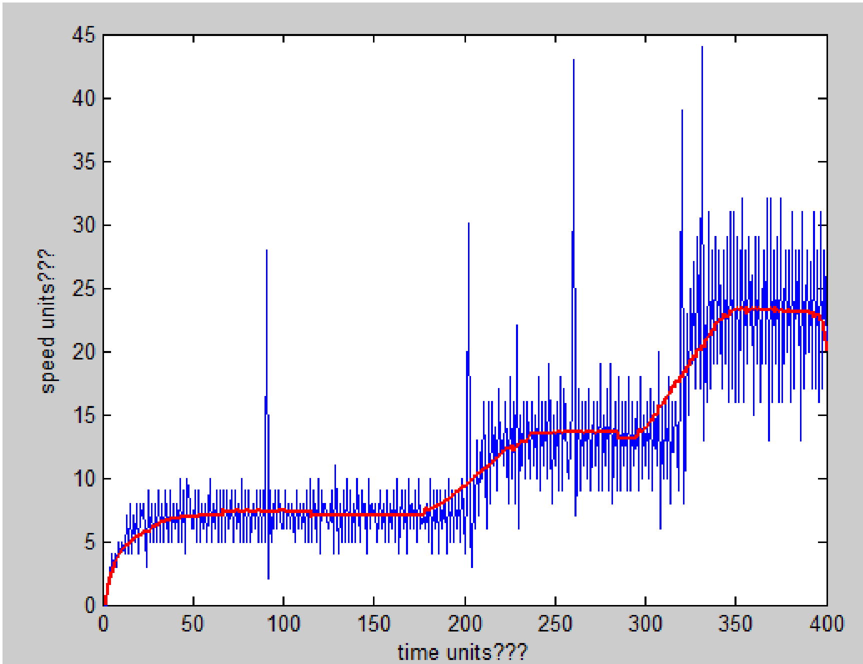
Depending on your MATLAB version and USB port, you may need to smooth the velocity data to help determine the steady state speed if external mode is used:

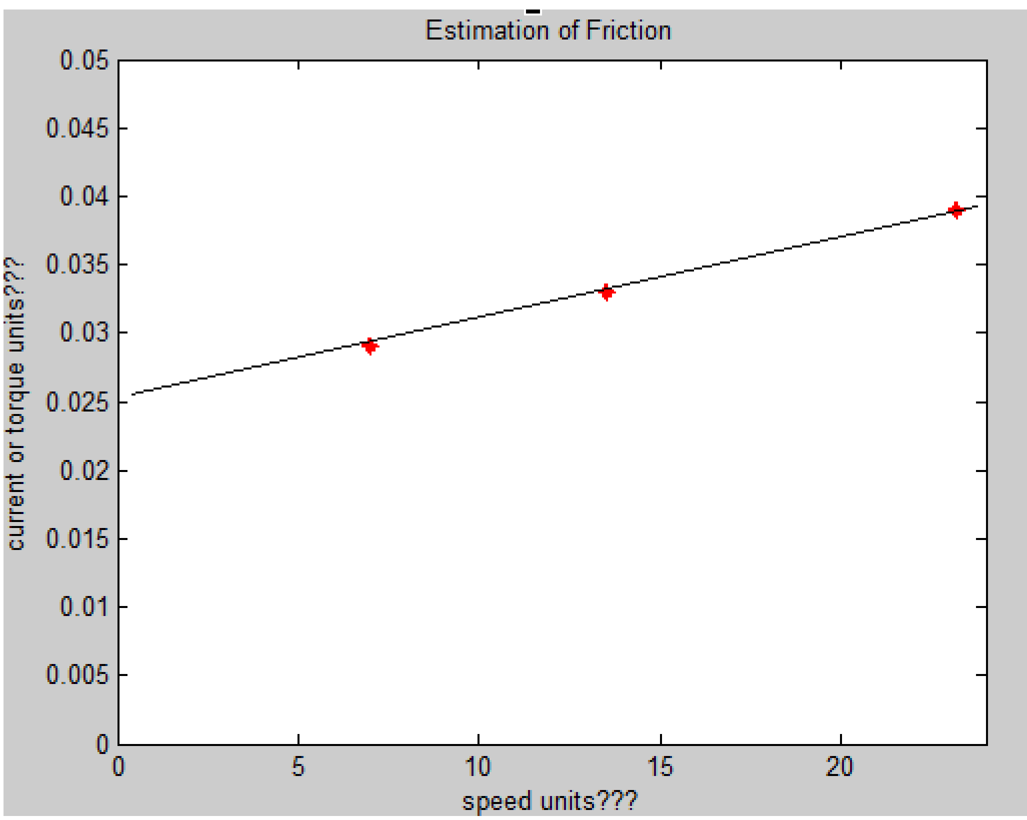


Parameter Identification

- Use the collected data and the steady state equation to determine K_b from measured speed, current and voltage at the 3 different speeds:
    - $V_{ss} = Ri_{ss} + K_b\omega_{ss}$

  $K_b =$____________________ (specify units)

- Use the data to plot the speed vs. 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 (amps, 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 multimeter to measure the voltage?
- What are your experimental values for (with units!!):
  - R, K_b, b, T_f, K_t?

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 – armature inductance (or combined motor and load inertia if load is attached)
- L – inductance

The equation in time constant form is:

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

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

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

- **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. An example step response is shown below (you may already have this data from a previous lab). (earlier versions of MATLAB would need to obtain this data with serial mode, later versions (2020a) only use Monitor and Tune (external) mode).

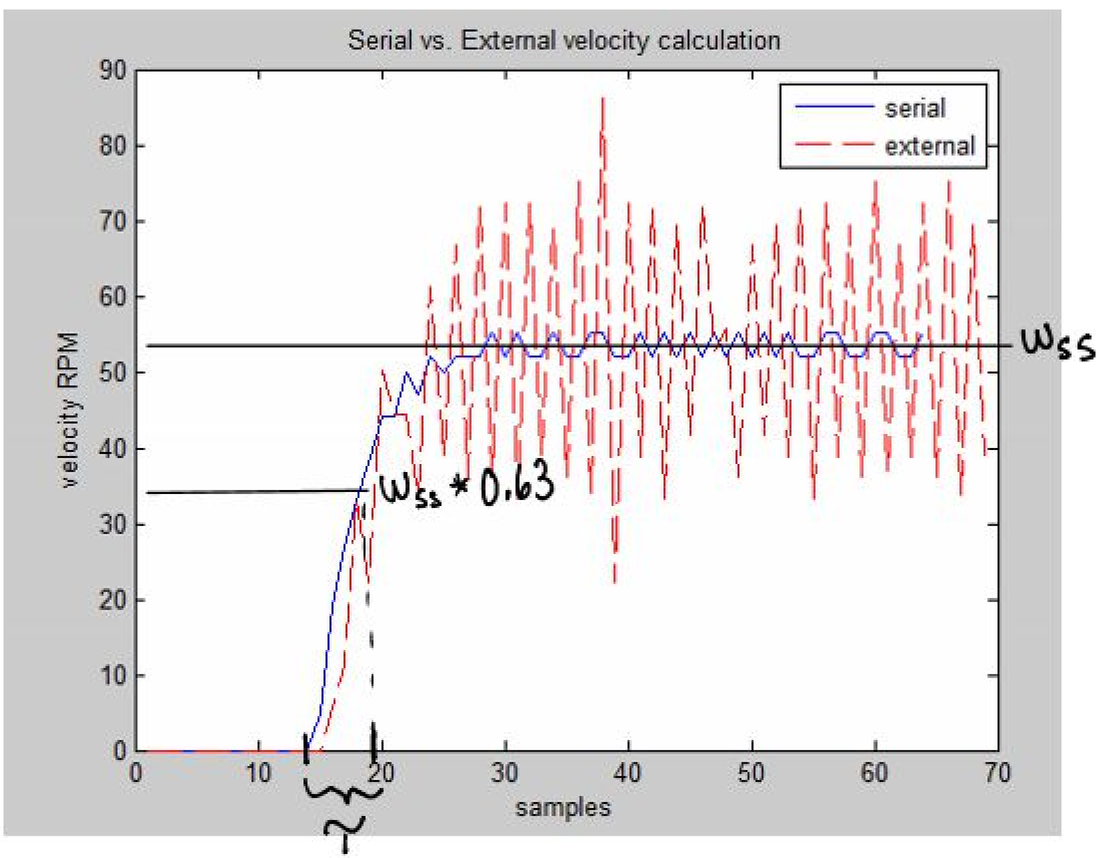


Figure 7: Sample Step response data obtained with 0.03 second sample time, 3 volt step

Take note of what voltage you used to generate this step response V_{in} (this should be the actual measured voltage):

V_{in} = ________________

Calculate the experimental steady state gain (the step must be from zero speed as in the graph above):

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

Where ω_{ss} is the steady-steady state value from the step response 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?