Name/NetID:

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(circle one)

Experiment 7: Modeling Your Motor

Laboratory Outline:

Up until this point we've used devices that can be treated as ideal for most practical purposes. Yet, even non-ideal devices are very practical in many applications and these will prove useful in your final design challenge as well as a host of projects you might take on after ECE 110. Motors and batteries are two such devices. As engineers, we must recognize non-ideal behavior and ask pertinent questions…Does a motor behave like a resistor? It not, what? Can our battery provide enough current to drive our motor? Can it provide enough for two motors? Can it provide enough current for two motors and the rest of the circuitry? You'll now understand some of the limitations of these devices when used in a circuit.

Learning Objectives

- Measure, analyze, and model the IV characteristics of the motor, noting that hysteresis (different behaviors in two different stimulus directions) requires two Thevenin models.
- Make note of the current drawn by the motor in normal operation and at a stall point.
- Estimate the waste power (large percentage!) for an inefficient voltage-divider-style motor speed controller.

Characterizing Batteries

The DC power supply on your bench can be treated as an ideal voltage source for a great deal of its voltage range with typical circuits used in class. This is not the case with batteries. In the prelab, you characterized how our battery pack behaved under a load and you used a simple linear approximation of a battery that allows us to analyze this non-ideal device with a not-quite-linear IV curve.

Characterizing Motors

Motors convert electrical energy into kinetic energy. For the remaining experiments in this semester, we'll be using motors to drive the small vehicle included in your electronics kit. Today we'll characterize the chassis motor by varying the voltage that is applied to the motor terminals. In addition, we'll develop a linear model that approximates the motor's behavior over a range of input voltages. This will simplify analysis for the motor-drive circuit.

Notes:

Procedure

Batteries

- ✓ Make sure you check out the tool box containing the 7.2-V NiMH battery so that it is ready when you need it. The box should also have a potentiometer with a higher power rating than those in your kit.

Question 1: From your prelab, find the values of R_B and V_B for the NiMH battery model and record them here.

Motors

Let's examine a couple of simple methods for controlling the speed of a small DC motor. In past labs we primarily dealt with resistors, which have a linear voltage-current relationship. Today we'll look at the voltage-current relationship of a DC motor and see how it differs from resistors and develop a simplified linear model of the motor that we can use for basic circuit analysis.

Understand Your Motor: IV Characterization

Connect the circuit as shown in **Figure 1**.

- ✓ Use the box with alligator clips (test box) to connect the power supply directly to your motor.
- ✓ Make sure that the output on the power supply is set to "off" when you are constructing or making changes to your circuit. Use the $+$ and $-$ ports of the **+6V supply** on the HP3631A DC power supply. This port will allow more current to flow when needed than the +25V supply.
- ✓ The DC motor is one of the drive motors on your car chassis (not the extra DC motor in your ECE110 electronics kit). You do not need to remove the motor from the chassis. Instead, use the small wooden block as a "car lift" to keep the wheels off the ground.

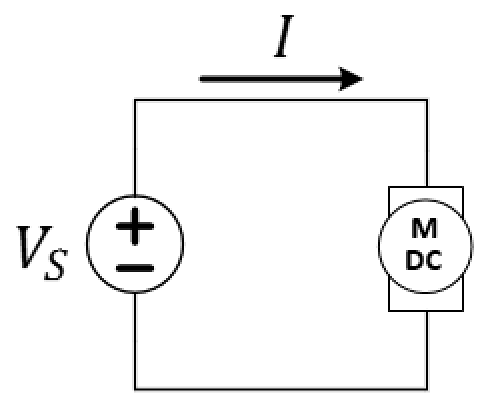


Figure 1: *Circuit schematic of the variable voltage source motor drive method.*

Notes:

Before we begin taking measurements using our motor, it's good practice to perform a quick test run with our circuit. In this case, we want to collect as many measurements as possible just before and just after the motor begins to turn (or stops turning).

Question 2: Starting at zero volts, sweep the voltage of the power supply up to 6V and make note of the approximate voltage at which the motor begins to spin. Once you have hit 6V, sweep the voltage back down and make another note of the approximate voltage at which the motor stops. Record your approximate "turn-on" and "stall" voltages here.

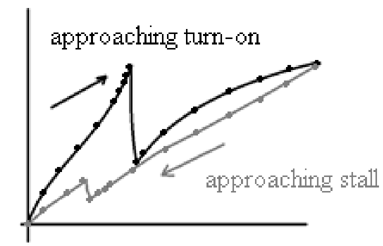
Which voltage is larger? You will find that when the supply voltage is too low, the motor will remain stopped due largely to static friction and inertia. When the voltage is increased enough, the motor will turn on. Once the motor is moving and the voltage is decreased, the motor will not stop (stall) at the same turn-on voltage level because of the different *kinetic* friction and inertia. **Starting from $\mathbf{0}\ \boldsymbol{V}$** again, measure the voltage and current of the motor at increments no larger than $0.5\ V$ (start with 0.1 and move to 0.5 shortly after the motor starts moving). Since the motor behavior changes with the internal friction, it is important that you always collect your data in with increasing voltage. If you need to go back and collect a certain data point, you need to start over from a voltage that produces a stalled position.

Question 3: Record measurements in the table below. Make sure to note when you see a change in behavior in the motor (i.e. "motor whines audibly but doesn't move", "motor starts to spin", etc.). **Take finer measurements as you approach the turn-on voltage**.

Voltage (V)	Current	Notes:

*Table 1: Current flow for the motor for **increasing** DC voltage with comments.*

Notes:



Example motor IV data without curve fits. Your figure may look quite a bit different.

Notes:

Now let's see what happens when we **sweep the voltage from high to low**. Measure the current flowing through the motor starting at 5V and gradually reduce to 0V. As with the last set of measurements, only adjust the voltage in a decreasing direction and remember to take extra (finer) measurements as you approach the stall (stop) voltage recorded earlier.

Question 4: Record measurements in the table below. Once again, make note of any changes in the motor's behavior as they happen. **Take finer measurements as you near the stall voltage**.

Voltage (V)	Current	Notes:

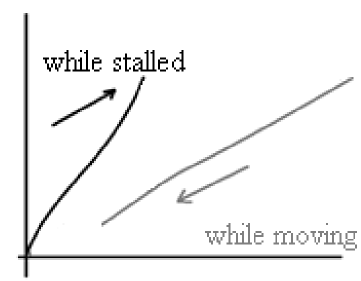
***Table 2**: Current flow for the motor for **decreasing** DC voltage with comments.*

Notes:

Question 5: Explain in your own words why the **turn-on** and **stall** voltage/currents are different from each other.

Question 6: Use MATLAB to generate a single graph of both sets IV data (two curves on one graph).

Question 7: Perform a linear curve-fit to the **5V-to-stall** portion of this data (labeled “while moving” on the image to the right). You may use a straight edge to draw your linear curve-fit on your printout. Alternately, in MATLAB, you might use the *polyfit* command to do a first-order (*n=1*) fit to that data.



Example motor IV data showing the two portions where you should perform curve fits.

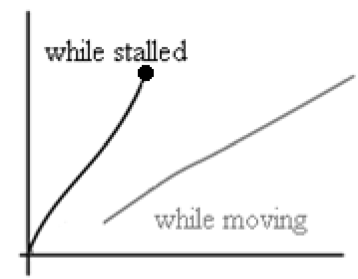
Question 8: Determine a linear equation (slope-intercept form) corresponding to ***each*** linear curve-fit generated. Explain how you found the missing values below.

While Moving: $I =$_________$V_{motor} +$__________

Notes:

Question 9: Using this equation, determine a Thevenin-equivalent circuit for your motor to model it when it's moving.

Question 10: How much power is drawn from the power supply just below the turn-on voltage (while still stalled)? See the operating point suggested in the image on the right.



The stall point will draw a large amount of power from the battery!

Question 11: When stalled, all energy from the battery is wasted. How long will your battery last if it were to sit continuously *just below* the turn-on state?

Notes:

Conclusion

Question 12: Summarize what you have learned regarding the linearity of the I-V curves you measured today.

What You Learned

You should now know how to think about circuits that include both batteries and motors as you now understand several limitations of these devices when used in a circuit. You have seen that models can help us produce accurate estimates of the actual performance of these devices. Motors and batteries are a central part of our future experiments and will be necessary for the final design project.

Explore More!

At the end of each regular lab procedure, as time permits, you will be provided with materials to continue to improve your mastery of the materials. The suggested modules for this week include ***Explore More!*** **Using the Arduino to Drive Vehicle**, ***Explore More!*** **Resistive Sensors**, and ***Explore More!*** **Interfacing Resistive Sensors Digitally**. You are to work on these as long as time permits. The modules will be submitted to your TA when finished and a number of them will count in your final grade.

Notes:

Lab Report Rubric

The following rubric will be provided at the end of each lab procedure. As a final step in preparing your lab report, you should use this rubric to analyze your own performance.

Section	**Criterion**	**Comments:**
Experimental Setup and/or Design Description	Circuit Schematics are drawn neatly, accurately, and properly labeled. Decisions regarding experimental setup and design are clearly explained.	
Measurements	Tables include units and proper precision. Any *new device* introduced should be characterized using measurements!	
Computations	Computations performed on raw data are *explicitly* described and follow rules for significant figures.	
Analysis	Graphs have title, labels, units, scale, legend; Lines for curve-fitting appear in the graph when needed and parameters like the intercepts and the slope are labeled.	
Modeling	A mathematical model for the curve-fit graph allows for more abstract references to the device's behavior. The expected behavior is explained in the context of the graph.	
Conclusion	Conclusions are drawn from your experimental results to support the reason(s) for completing the experiment. Closes the loop on the Introduction.	
General Formatting	Answers to questions clearly labeled. The overall appearance of the report is professional.	
Self-assessment	This table has been thoughtfully completed.	