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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 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_T and V_T 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.

Notes:

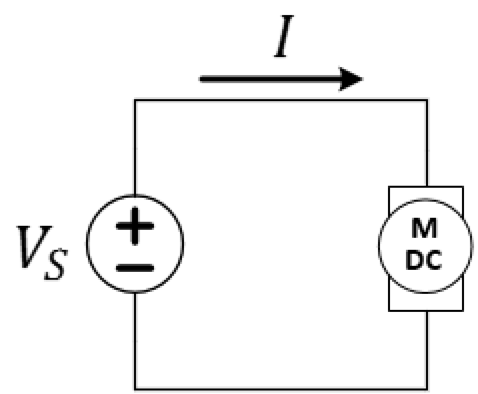


Figure 1: *Circuit schematic of the variable voltage source motor drive method.*

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.

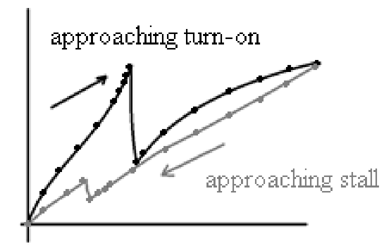
Which voltage is larger? You will find that when the supply voltage is too low, the motor will remain stopped due largely to static friction and inertia. When the voltage is increased enough, the motor will turn on. Once the motor is moving and the voltage is decreased, the motor will not stop (stall) at the same turn-on voltage level because of the different *kinetic* friction and inertia. **Starting from 0V** 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.

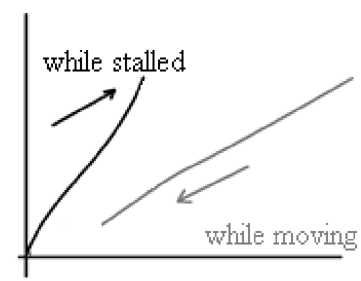
Question 6: Use MATLAB to generate a single graph of both sets IV data (two curves on one graph).

Question 7: Perform a linear curve-fit to the **0V-to-turn-on** portion of this data. Perform a second linear curve-fit to the **5V-to-stall** portion of this data. You may use a straight edge to draw your linear curve-fits on your printout.

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

Stalled: $I =$_________$V +$__________

Moving: $I =$_________$V +$__________



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

Notes:

Question 9: Using these two linear equations, determine the Thevenin-equivalent circuit for a motor when it's stalled and when it's moving.

Question 10: How much power is drawn from the power supply just below the turn-on voltage (while still stalled)?

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:

DC Motor Speed Control through VDR

Controlling the speed of your motor will be very important in our future experiments. A vehicle that moves too quickly may overrun the path before path correction can be applied. We will eventually use a variable resistor called a "flex sensor" to control speed. Today, we will use a (lower resistance, higher-rated) potentiometer instead to consider the possibility of speed control by the voltage divider rule (VDR).

Let's take a moment and analyze the circuit shown in figure below using Kirchhoff's voltage law (KVL). According to KVL, $V_{pot} + V_{motor} = V_S$. This implies that each of the loads in the circuit only get a fraction of the total supplied voltage. With this in mind, we can then use a small resistor in series with the motor to steal some of the supplied voltage, thus controlling the voltage across the motor. Furthermore, we can use the Thevenin equivalent to the DC motor that we developed in the previous section to choose the appropriate resistance for setting the motor voltage to some desired value.

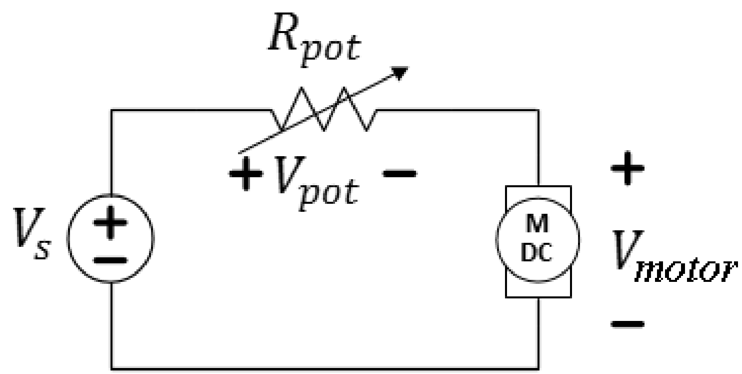


Figure 3: *Circuit schematic of a variable voltage source motor drive method.*

Question 12: Write down the voltage divider equation for this circuit if we assume a Thevenin model for the motor (series combination of V_m and R_m). That is, write an equation for the voltage across the motor (V_{motor}) in terms of the power supply voltage V_s, the Thevenin-equivalent motor resistance (R_m), the Thevenin-equivalent motor voltage (V_m), and the potentiometer resistance R_{pot}.

Notes:

Question 13: If you wish to make sure your motor always moves (but at varying speeds) when your NiMH *battery* is applied to the voltage divider, what approximate *range* of R_{pot} might be useful? Explain.

Question 14: For a voltage source of 7.2 V, and when the motor is drawing 110 mA, how much power is being dissipated in R_{pot}? How much power is being dissipated in the motor? HINT: You can ***either*** build the circuit and take measurements ***or*** you can look at your IV characterization of the motor at this operating point.

VDR is ***not*** commonly used for motor control. Poor power efficiency and the risk of stalling (while continuing to drain significant energy from the battery) are serious concerns. In two weeks, we will learn of a better and highly-utilized method of motor control, Pulse-Width Modulation (PWM).

✓ Turn the potentiometer to its **largest resistance (measure it on an Ohmmeter, don't trust the label which might be incorrect or confusing)** and build the circuit below **without the battery**. Have a TA check your circuit **before you add the rechargeable NiMH battery** to make sure you have your ammeter wired correctly. If you blow the ammeter fuse, it can lead to unnecessary delays while the TA replaces it.

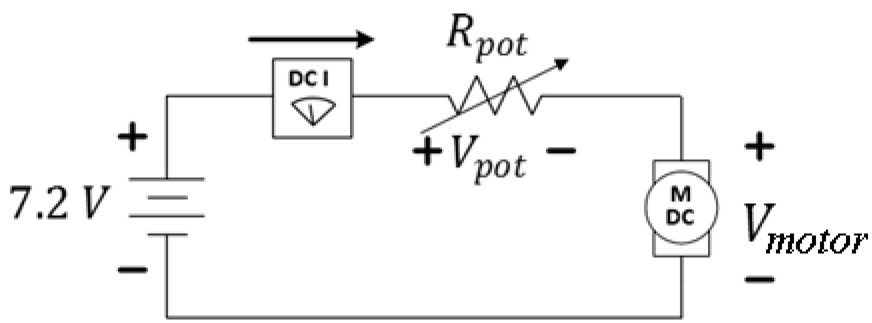


Figure 1: *Circuit schematic of the VDR motor drive method.*

- ✓ Reduce the potentiometer's resistance ***SLOWLY*** until the motor has reached turn-on. Then adjust the pot until the current through the motor is 110 mA or until the motor is running at a descent speed (somewhere between crawling and full blast). Make note of the current through the motor in the side margin if you were not able to achieve 110mA. Please try not to reduce the resistance to the point that the 3A fuse will blow in the ammeter…110 mA is merely a fraction of that!

Question 15: *Remove the potentiometer from the circuit* and measure its resistance. Be careful not to turn the knob as we wish to measure the resistance value that produces 110 mA through the motor.

Question 16: Compute the power supplied by the "battery", the power dissipated in the pot, and the power dissipated in the motor.

Notes:

Notes:

Question 17: Determine the efficiency of this system, $\eta = \frac{P_{motor}}{P_{source}}$

Conclusion

Question 18: Summarize what you have learned regarding the linearity of the I-V curves you measured today.

Question 19: Discuss VDR-based motor-speed control and make a conclusion regarding its power (energy) efficiency.

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.	