RSA Lab #3: Brushed DC Motor Performance

# Part 1: Theory: Permanent Magnet Brushed DC Motors

For this section of the lab, I was able to construct a circuit verifying the functionality of the SS49E by using the oscilloscope to measure the output voltage given an input of 5V.

1. Write a program that uses the delay() function, the pinMode() function, and the digitalWrite() function, to generate a 1 Hz square wave output on digital pin 2 of the Arduino. Run it, and verify that it accomplishes this objective with the oscilloscope. Hand in a printout of your program.
2. Annotate a scope plot of your 1Hz output. Be sure to annotate voltage level, peak-topeak “amplitude”, and period of the signal.
3. Use your multimeter to measure the diode voltage drop of your LED.
   1. Can you use this motor and battery to provide a continuous shaft output of 0.1Nm of torque at 4rad/s? Explain why or why not. Be specific.

Now the total resistance of the system is:

This can be used to find the no-load angular velocity and the stall torque.

This produces a linear relationship between the angular velocity and load torque:

At and angular velocity of 4 rad/s, the load torque should be 0.09 Nm according to the equation above. This approximates to 0.1 Nm, which means this battery **can run the shaft.**

* 1. Can you use this motor and battery to provide a continuous shaft output of 5Nm of torque at 6rad/s? Explain why or why not. Be specific.

Using the equation derived above, an angular velocity of 6 rad/s should yield an output torque of 0.07 Nm. This does not equate to 5 Nm, thus this batter **cannot run the shaft.**

# Part 2: Experiment

In this section I constructed the circuit test the motor at both a (relatively) constant angular velocity and a variable angular velocity (using a power drill) in order to measure the back-emf voltage and the frequency, which were both used in subsequent derivations.

1. Use your DMM to measure the resistance of your motor - the resistance between the motor’s red and black leads. Rotate the output shaft a bit to check that the resistance value is fairly stable.

I was able to measure the internal resistance of the motor by using the setting on the DMM.

1. Rotate the motor shaft clockwise and counter-clockwise manually. Comment on the relationship 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 s per division) for this exercise.

Upon connected the CHA and CHB terminals, I was able to scrutinize the output waveforms’ frequencies and their voltages increasing the faster I rotated the motor shaft.

1. CAREFULLY use a variable speed drill to rotate your motor at MODERATE SPEED at an (approximately) constant angular velocity. Use the scope’s measurement capabilities to find the mean motor back-emf voltage (on CH 2) and the encoder output frequency (on CH 1). Note these values, and note the direction. Print and annotate the scope screen.

See attached scope. The direction I was rotating the motor was counterclockwise (which produced a negative output voltage).

1. Repeat to collect at least six data points - i.e. three different positive (clockwise) angular velocities and three different negative (counterclockwise) angular velocities. Put your data into a spreadsheet. Plot your data for back-emf (in Volts) versus signed (positive and negative) angular velocity in rad/sec.

See table and plot below. Note that although the voltage was negative for negative frequency values, only the frequencies were signed values.

|  |  |  |  |
| --- | --- | --- | --- |
| Voltage (V) | Freq (Hz) | Ang Vel (rad/s) | Direction |
| 1.73 | -188 | -1181.24 | CCW |
| 2.4 | -240 | -1507.96 | CCW |
| 3.5 | -370 | -2324.78 | CCW |
| 5.2 | 540 | 3392.92 | CW |
| 6 | 620 | 3895.575 | CW |
| 7 | 740 | 4649.557 | CW |

1. Use your experimental data to compute an experimental value for the motor’s back-emf constant kbemf.

By making all the values in the table above unsigned, I was able to plot a linear model of the frequency versus the back-emf voltage. The slope of this model corresponds with the back-emf constant.

1. Set the power supply output to 1.0V. Note the exact voltage (using your scope CH 2 to measure the mean motor input voltage), the motor rotation velocity (from the frequency of the encoder trace on CH 1 of your scope), and the average motor current (from your DMM). Repeat these measurements for a range of power supply voltage from -3V to 3V

See table and plot below. I measured the voltage and frequency using the oscilloscope and the current using the DMM, with four measurements for each direction (8 in total)

|  |  |  |  |
| --- | --- | --- | --- |
| Voltage (V) | Freq (Hz) | Current (A) | Ang Vel (rad/s) |
| -0.434 | 27 | -0.02 | 169.646 |
| -1.04 | 86 | -0.023 | 540.3539 |
| -1.94 | 175 | -0.029 | 1099.557 |
| -3.05 | 287 | -0.034 | 1803.274 |
| 0.403 | 28 | 0.022 | 175.9292 |
| 0.934 | 83 | 0.022 | 521.5044 |
| 2.000 | 184 | 0.028 | 1156.106 |
| 2.960 | 284 | 0.035 | 1784.425 |

|  |  |  |  |
| --- | --- | --- | --- |
| Voltage (V) | Freq (Hz) | Current (A) | Ang Vel (rad/s) |
| -0.434 | -27 | -0.02 | -14.1372 |
| -1.04 | -86 | -0.023 | -45.0295 |
| -1.94 | -175 | -0.029 | -91.6298 |
| -3.05 | -287 | -0.034 | -150.273 |
| 0.403 | 28 | 0.022 | 14.66077 |
| 0.934 | 83 | 0.022 | 43.4587 |
| 2.000 | 184 | 0.028 | 96.34217 |
| 2.960 | 284 | 0.035 | 148.7021 |

1. Using the value for kT that you determined experimentally in step (18) and your measured values for motor current, Im, compute another column in your table for the motor torque , at each of these data points. Plot a graph of motor torque (on the Y axis) as a function of motor angular velocity (on the X axis). Discuss the graph: what is the unusual feature of this plot?

See table and plot below, long with discussion of graph.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | |  | |  | |  | |  | |
| Voltage (V) | | Freq (Hz) | | Current (A) | | Ang Vel (rad/s) | | Tm (Nm) | |
| -0.434 | | -27 | | -0.02 | | -14.1372 | | -0.00003 | |
| -1.04 | | -86 | | -0.023 | | -45.0295 | | -3.5E-05 | |
| -1.94 | | -175 | | -0.029 | | -91.6298 | | -4.4E-05 | |
| -3.05 | | -287 | | -0.034 | | -150.273 | | -5.1E-05 | |
| 0.403 | | 28 | | 0.022 | | 14.66077 | | 0.000033 | |
| 0.934 | | 83 | | 0.022 | | 43.4587 | | 0.000033 | |
| 2.000 | | 184 | | 0.028 | | 96.34217 | | 0.000042 | |
| 2.960 | | 284 | | 0.035 | | 148.7021 | | 5.25E-05 | |
|  | |  | |  | |  | |  | |

Something unusual I noticed from this graph is the non-zero y-intercept of the regression for positive angular velocities. For this model to be fully linear, the trendline must cross the origin; however, it seems as if the motor torque on the negative side starts out with a non-zero y-intercept.

1. From your graph, determine approximate experimental values for the motor Coulombic friction () and the motor dynamic (viscous) friction ():
   1. Give your experimentally determined value for kC in units of Nm

kC in this instance would correspond to the approximate unsigned y-intercept for both parts of the regression model.

* 1. Give your experimentally determined value for kD in units of Nm / (rad/sec)

kD in this instance would correspond to the approximate slope for both parts of the regression model.

1. Using the measured values for the motor’s parameters, calculate the stall torque (in Nm) and no-load speed (rad/s) of the motor (NOT the output shaft).

Since this is a 12V motor, the no-load speed can be calculated by inferring an input voltage of 12V and using the resistance (measured earlier) and the constant values calculated previously in this section:

The stall torque is defined as the mechanical torque of the motor when its angular velocity is zero. Since the y-intercept of the motor torque versus angular velocity model was derived already, this