RSA Lab #2: 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. Consider a hypothetical standard DC brush motor with the following motor parameters:
   1. Resistance: R = 3Ω
   2. Back-EMF constant: kbemf = 0.05V/(rad/s)
   3. Torque constant: kT = 0.05Nm/A
   4. Inductance: L = 200μH
   5. Friction: kD = 0.01Nm/(rad/s)
   6. Mass moment of inertia JM = 2.5×10−4 kg m2

For the operating condition of 2.5Nm of load torque at a speed of 1rad/s, compute the following: (Show work for credit.)

1. Input Voltage (assume an ideal voltage source, not a battery).

I was able to find the input voltage by using KVL:

Since this is in steady state, the change in current can be eliminated from the equation:

(b) Motor Current.

(c) Electrical power into the motor.

(d) Mechanical power out of the motor via the output shaft.

(e) Power lost in the motor itself. What happens to this lost power?

(f) Efficiency.

(g) Using a spreadsheet, plot the steady-state efficiency of the motor as a function of the load torque (now a variable, not 2.5Nm) normalized by the stall torque. Use an input voltage of 10V, and let the load torque vary from 0 to stall. Describe briefly what the plot tells you.

1. Experiment by bringing a permanent magnet in close proximity with the sensing surface of the SS49E – observe the change in output voltage as you manipulate the magnets’ position and orientation. Use the horizontal (time axis) scale knob on your scope to make the time scale slow enough to capture a sufficient length of time, and print and annotate one scope plot showing both positive and negative variations in voltage (i.e. variations from the quiescent voltage).

See attached annotated scope. By moving a small magnetic near the hall sensor, I was able to scrutinize changes in the output voltage (voltage increased as magnet was brought to the sensor and decreased when it moved away from it).

1. Use the sensitivity specification of the SS49E from the datasheet and your experimental observation of the output voltages obtained to estimate the maximum magnetic field strength of the magnet provided. (What unit are they using for B, the magnetic flux density?)

According to the datasheet, the typical value for the sensitivity of the sensor is 1.8mV/G. The datasheet uses Gauss (G) as units, which equates to 1/10000 Tesla (T). In order to estimate the magnetic field strength, we simply divide the change in voltage from the scope by the sensitivity.

# Part 2: Experiment

In this section I constructed the circuit to show the functionality of both the DC motor and its embedded digital encoder. I then used measured results from observing the motor speed to derive the angular velocity of the motor shaft.

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 increasing the faster I rotated the motor shaft, along with the output voltage fluctuating from 5V to 0V.

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.

1. Given the encoder specification of 12 cycles per revolution on each channel, derive formula for omega, the motor shaft angular velocity as a function of the single-channel square wave frequency. Show your work.

The motor shaft angular velocity can be derived using the standard formula, dividing a full revolution (2pi radians) by the period, which simplifies to multiplying the frequency by 2pi. Note that since the period of the motor shaft is 12 times the period of the square wave, the frequency will be 1/12 as much (since it’s inversely proportional):

1. Derive the equation for f in units of motor shaft revolutions per second as a function of the square wave frequency fscope in Hertz (cycles per second).

The new frequency is simply 1/12th of the square wave frequency, since the period is 12x larger and frequency is inversely proportional to period.

1. Derive the equation for omega in units of motor-shaft radians per second as a function of square wave frequency fscope in Hertz (cycles per second).

The motor shaft angular velocity can be derived using the standard formula, dividing a full revolution (2pi radians) by the period, which simplifies to multiplying the frequency found in the previous problem by 2pi.

1. Drive the motor at a slow speed with a voltage of about 1V. Measure the time (in seconds) it takes for the output shaft to complete, say, 10 revolutions. Given your measurement output shaft speed, compute the corresponding motor shaft speed.

By putting the DC voltage of the motor to ~1V, I was able to measure an elapsed time of 46 seconds for 10 revolutions. Note that since the gearbox provides a 34:1 reduction between the motor shaft and the output shaft, we need to multiply this starting frequency by 34. Thus:

1. Measure the corresponding frequency of the square wave signal from CH A on your scope. Given the encoder specification of 12 cycles per revolution, compute the motor’s rotation velocity. Make a scope plot of your measurement.

See attached scope. I was able to get a frequency reading of 88.25 Hz. This can be plugged in to the previously derived equation to get the actual motor angular velocity:

1. How do your two measurements of motor shaft rotation velocity (one based on observations of output shaft, and one based on observation of an encoder channel) compare?

The encoder channel’s derivation was much larger than the observed value; one possible explanation could be a discrepancy between the speed of the motor when observing versus what the encoder read.

1. What is the minimum angular resolution (in degrees) with which the motor/encoder detects changes in the position of the motor shaft? Show briefly how you calculated this.

The minimum angular resolution was derived by using the features of the square wave. Since there are two distinct states per period, and there are twelve periods for the motor shaft, the angular resolution would simply be the total angle divided by these 24 fluctuating states: