

Assignment 4: Motor Characterization Lab

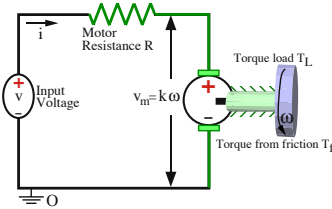
Due: Friday Jan 29, 5:00pm in d'Arbeloff lab

- Turn in one neatly written assignment per team.
- Please write each participant's name on the cover page.
- Follow the policies on turned-in work in the ME112 syllabus.

Most work can be completed during lab. You will need to consult the Motors notes and short video (see Modules/Motors on Canvas). Use MATLAB®, Python, or similar for calculations and plotting. Do the main tests below in any order. Although you probably want to divide work for preparing answers to Sections 1, 2, 3 (below), each of you are responsible for checking the entire report for accuracy and consistency.

1 Motor characterization

Since there are no detailed data sheets for the crawler motors, we must characterize them experimentally. As a starting point, recall the two essential motor equations from class notes:



Mechanical/electrical analysis when voltage V , current i , and angular speed ω are all constant.

$$\text{Motor electrical: } V - iR - k\omega = 0 \quad (1)$$

$$\text{Motor mechanical: } T_L = T_m - T_f \quad (2)$$

1.1 Stall measurements for Pololu 6-volt hobby motor ($\omega = 0$)

One way to stall a motor is to apply a large torque load T_L so it “stalls” the motor’s angular speed to zero. With $\omega = 0$, we can calculate the motor resistance R by using equation (1) and by measuring input voltage V and motor current i . However, there are practical considerations for accurately measuring R . Since R is small ($R < 50$ Ohms), the input voltage V needs to stay below normal operating voltage (e.g., $V < 6$ Volts). If V is too large, the temperature of the motor’s wires will increase (which increases their resistance R). Also, the current i from the power supply is limited and a large V at stall may try to draw more current than the power supply can deliver.

Stall testing tips

- Gather 4 data points from 0 to 3 volts.
Ensure the power supply does not “current limit” (a light will come on the power supply).
- Hold the motor shaft stationary (so $\omega = 0$). Read the voltage V and current i from the power supply.
- Cool the motor by allowing the motor to spin between successive measurements.
This will also allow different coils on the motor to come into play each time.
- Repeat the previous measurement with the **same** voltage (hopefully different motor coils will be in play).
- Continue with another voltage.
- Compare your results by measuring motor resistance R using a multimeter (measure once or twice).

Submit answers to the following.

1. Submit a table with columns for input voltage V and motor current at stall i_{stall} .
2. Submit a plot of V (y-axis) versus i_{stall} (x axis).
3. What should current i be for zero volts? Add a data point for this case.
4. Remove obvious outliers and make a best fit line (by hand or with a best-fit line function). Estimate motor resistance R from this plot iff higher V correspond to higher R , this may be due to heating.
5. Provide a rough estimate of error in your estimate of R (e.g., 1 Ohm, 0.1 Ohm)? **Explain.**

1.2 No-load measurements ($T_L = 0$)

No-load means $T_L = 0$ (output torque is zero). Gather data with the motor spinning freely and solve for k using:

Equation (1)	your estimate of R	measured V	measured i_{nl} (no-load current)	measured ω_{nl} (no-load angular speed)
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Note: Since $\omega \neq 0$, there is back-emf $v_m = k\omega$, so we can use higher voltages V because motor current i will be small.

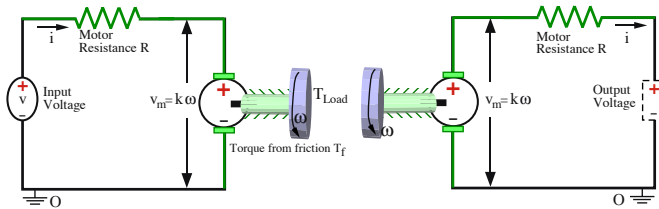
Submit answers to the following.

1. Before taking measurements, let the motor spin and notice what happens to the current through the motor if you gently grab the motor shaft, slowing it down. Explain what is happening.
2. Measure the input voltage V , motor current and angular speed for several no-load cases. One of the ME112 staff will help you. Getting a good value of ω with the tachometer is the hardest part.
3. Make a plot of NetVoltage $\triangleq V - i_{nl} R$ (y-axis) versus ω_{nl} (x-axis) in radians per second.
4. If i_{nl} is not constant, what does that suggest? (Hint, review equation (2)).
5. Should this plot also go through the origin (0, 0)?
6. As for stall, throw out any obvious outliers and fit a line to the data.
7. What is the estimated value of k and roughly estimate its accuracy? **Explain.**
8. Having found k , use eqn(2) to solve for T_f . Use scientific notation and appropriate significant figures.

2 Functional tests

2.1 Motor-Generator (two tests to provide data)

What happens if you connect two motors, nose-to-nose, using one as a generator?



1. Designate motor A as the motor connected to a power supply and motor B as the motor not connected to a power supply. If necessary, use the adaptor provided to connect the shafts of motors A and B .
2. Run motor A and measure its V_A , i_A and ω_A (convert to $\frac{\text{rad}}{\text{sec}}$). While A runs, use a voltmeter to measure the generated voltage across the terminals of motor B . Repeat this experiment for a few different V_A (3 power-supply voltages should suffice). How does the generated voltage V_B compare with its value calculated via the previously estimated value of k ?
3. Repeat the experiment (use the same voltages as in step 2) except put a known power resistor across the terminals of motor B . This means that the “generator” side does work because current flows through both motor B ’s R_B and the power resistor. Again record motor A ’s V_A , i_A and ω_A and the voltage V_B across motor B ’s power resistor. Calculate motor B ’s current i_B .

Result:

$$i_B =$$

4. Explain what is going on in the double motor/generator circuit (pictured above).

2.2 Motor-Winch

One way to measure a motor’s mechanical output power is to connect its output shaft to a winch that lifts a weight at a measured speed (recall Assignment 1). At the winch station you will find a motor connected to a 40:8 speed reducing gear train and a winch. The winch “drum” has a radius of ≈ 8 mm (approximate,

because what we really want is the effective radius associated with the centerline of the string). The weight has a mass of 63 grams. Using a meter stick and stopwatch (smart-phone), estimate the speed of raising the weight.

1. Run three tests with voltages from 1 to 6 Volts, run the motor/winch test and record V , i , ω (radians/second), and the weight's vertical velocity v_y .
2. If there were no losses, we could write: $P_{in} = V i = T_L \omega = m g v_y = P_{out}$. However, there are power losses in the motor and transmission. Using your recorded data, compare this system's P_{in} versus P_{out} for each of your three voltages. Although we do not know how much power is lost individually in the motor or gears or spinning axles, we will be able to estimate their breakdown after doing the motor plots discussed in the next section.

3 Motor plots

For this section, assume we have measured the following values (these values may not match your values):²

$$R = 39.0 \Omega \quad k = 0.11 \frac{\text{Nm}}{\text{amp}} = 0.11 \frac{\text{volts}}{\text{rad sec}} \quad T_f = 2.5 \times 10^{-3} \text{ Nm}$$

With these values we can produce plots of power, efficiency, torque, ..., as a function of current or speed for any voltage. Let us consider operating cases of (a) $V = 3.0$ volts and (b) $V = 6.0$ volts.

For the following questions, use MATLAB®, Python, or a spreadsheet (Hint: See sample data below).

1. To make subsequent calculations easier, first compute i_{nl} , i_{stall} and ω_{nl} (rad/sec) for $V = 3.0$ volts and $V = 6.0$ volts.
2. Plot motor **output** power (Watts or Nm/s) versus ω (radians/second) from 0 to ω_{nl} for both the 3 volt and 6 volt cases (ideally, put two curves on the same plot).
3. What is the peak output power for each case?
4. Plot motor efficiency versus ω from 0 to ω_{nl} in radians/second for both the 3 volt and 6 volt cases (ideally, put two curves on the same plot).
5. What is the peak efficiency for each voltage – and at what speed (radians/second) does it occur?

For a given voltage V , we know that current is going to vary between a maximum i_s and a minimum, i_{nl} , where i_s and i_{nl} are computed using equations (1) and (2) and the given values of R , k and T_f .

- Make a column array in MATLAB® or Python (or in a spreadsheet) with a list of 10 or more currents spanning from i_s down to i_{nl} .
- Make a column array of ω in rad/sec for each corresponding value of i .
- Make a column array of $P_{in} = V i$ for each value of i .
- Make a column array of $P_{out} = T_L \omega$ for each ω .
- Make a column array of efficiency $= P_{out}/P_{in}$

If using Matlab, each column corresponds to another vector made by doing some operations on the "i" vector.

In the table below, zeros have been put in where we know the result should be zero.

If it's not exactly zero due to numerical roundoff, you can force it to zero. If it's not real close, you have an error.

current (amps)	omega (rad/s)	Power In	TL (Nm)	Power Out	Efficiency	Omega rpm
i	= (V-iR)/k	= V*I	= k*i - Tf	= TL * omega	= Pout/Pin	rpm=omega*30/pi
i_stall	0	...	...	0	0	0
0.9*i_stall	...	...	...	...	...	...
0.8*i_stall	...	...	...	...	...	...
etc.	...	...	...	...	...	...
etc.	...	...	...	...	...	...
i_nl	omega_nl	...	0	0	0	...

Example of setting up calculations for plots

²To see the equivalence for k , consider power: $P = V i = (k \omega) i = (k i) \omega = T \omega$