

Prelab	Participation	Lab
√+ √ √- 0	√+ √ √- 0	√+ √ √- 0

Name: \_\_\_\_\_

# 1 Lab: Motor Spin Down Test

Each laboratory experiment consists of a PreLab, Inlab, and Postlab.

- The PreLab is to be done individually **before** coming to lab. The PreLab is checked for completion by your TA **immediately upon your arrival** at your lab section.
- The InLab is held in Building 520, room 145 (d'Arbeloff lab). Experiments are done in small groups during your regularly scheduled lab section.
- The Postlab is due at the same time as the homework. Submit the PostLab (lab handout and graphs) **separately** from the homework.

## 1.1 PreLab: Motor spin-down (analytical and Working Model)

1. Do the following two homework problems (from the book):  
System identification for a 1<sup>st</sup>-order dynamic system (Coulomb friction).  
System identification for a 1<sup>st</sup>-order dynamic system (viscous damping).
2. Download/install Working Model (demo version) from:  
<http://www.stanford.edu/class/me161>  
Download/try the Working Model tutorial **WMTutorial.pdf** (from the website).  
Become comfortable with Working Model as you will use it in several labs.
3. Download the following Working Model (.wm2d) simulations.  
Get these files from: [www.MotionGenesis.com](http://www.MotionGenesis.com) ⇒ [Textbooks](#) ⇒ [Resources](#)  

<a href="#">MotorSpinDownTest.wm2d</a>	<a href="#">MotorSpinDownTestGuess.wm2d</a>
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4. Run the Working Model simulations.  
Record results on the Working Model PreLab (.pdf on [www.MotionGenesis.com](http://www.MotionGenesis.com)).  
Show your lab-section TA your completed pre-lab at the start of lab.

## 1.2 Experiment: Motor spin down

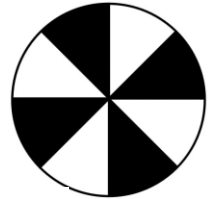
This section acquaints you with lab hardware and real motors. By measuring the angular speed of a freely spinning motor you will be able to determine numerical values for the viscous damping and/or Coulomb friction in the motor. Each lab station has the following equipment:

DC motor	Plastic or wooden rod	HEDS 9100 encoder
Timer (e.g. stopwatch)	Variable voltage supply	Motor driver/Arduino Interface board
Oscilloscope	Arduino UNO board	DS275 RS-232 Transceiver Chip

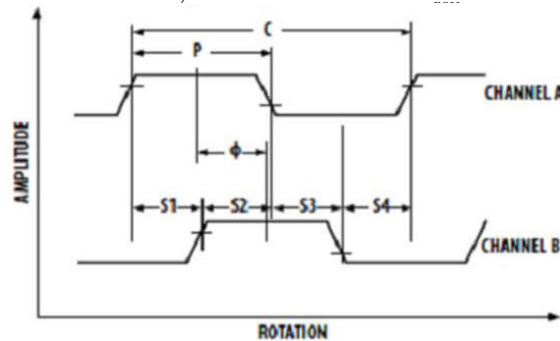
To measure and record the motor's angular speed, we use an encoder,<sup>1</sup> Arduino microprocessor, transceiver, and computer (described below – read for context, not for full comprehension).

- **Encoder:**

The optical quadrature **encoder** measures motor rotational speed by detecting alternating light and dark patterns on a disk. For example, the encoder on the right shows 8 transitions (from light to dark or vice-versa). A quadrature encoder can detect both angular speed **and** direction. Our encoder has 1000 transitions (500 black sections and 500 white sections) and counts 1000 tics.



Shown to the right is the output signal from the encoder to the Arduino microprocessor.



- **Computer:**

The computer connects to the Arduino microprocessor via a USB cable (Serial Communication). Computer bits (ones and zeros) are transferred between the computer and Arduino microprocessor. You will use the compiled Arduino-specific executable file (Lab1.ino) to communicate between the computer and motor.

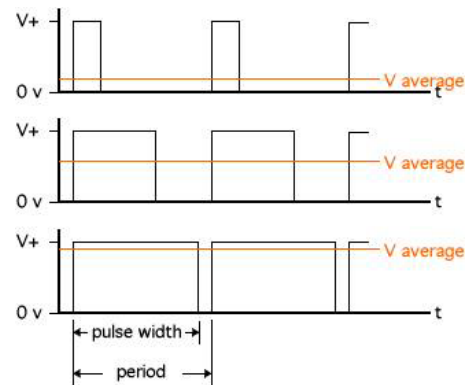
- **Arduino UNO microprocessor (the interface between the computer and motor):**

In this lab, the Arduino will use PWM (Pulse Width Modulation)<sup>2</sup> to vary the average voltage delivered to the motor.

The frequency of this PWM signal is 30 KHZ.

For questions involving the encoder, the Arduino receives the digital signal from the encoder and counts the transitions from “high” (5 Volts) to “low” (0 Volts) of the signal in 5 milliSecond intervals.

The on-screen data is in units of  $\frac{1 \text{ tic}}{5 \text{ milliSecond}}$ .



- **Motor driver/Arduino Interface Board:**

The motor driver circuit receives the PWM signal from the Arduino microprocessor and controls the voltage delivered to the motor via the 12 Volt wall adapter.

<sup>1</sup>Most motors do not come attached to a rotary encoder and assembled with an encoder, microprocessor, transceiver, and computer. It is still possible (without an encoder, etc.) to make rough estimates of the viscous damping or Coulomb friction in a motor.

<sup>2</sup>A PWM signal is on (designated by a “high-bit” 1) or off (designated by a “low-bit” 0) for different intervals.

### 1.2.1 Download/install Arduino software on your computer

- Go to [www.Arduino.cc](http://www.Arduino.cc) ⇒ Download
- Download/install the relevant Arduino software for your computer (e.g., Windows / Mac OSX).

### 1.2.2 Estimation without an Encoder

This section uses a timer (e.g. stop-watch) and variable power supply to estimate the shape of the spin-down angular speed for a DC motor with a rod (plastic or wooden) attached to the shaft.

- Ensure the motor is firmly clamped to the table. Attach the plastic rod to the motor shaft by **gently** tightening the set-screw (if your set-screw is broken, use tape and TA help).
- Ensure the wall power-adaptor is plugged into both the Arduino microprocessor and the wall (the power-adaptor reduces the 120 Volts from the PG&E to 12 Volts).
- Ensure the encoder is plugged into the Molex connector on the Arduino board, near the digital IO pins (i.e., ensure the encoder is plugged into the Arduino board).
- Ensure the USB cable connects the computer to the Arduino microprocessor.
- Double-click on the file Lab1/Lab1.ino (which should launch the Arduino software program).
- To upload the Lab1.ino program file to the Arduino Uno Microcontroller hardware, press the **Upload** button (top-left corner of the Arduino software window).
- When the Arduino graphics window appears on-screen, click the on-screen logo for the serial-monitor (top-right corner).
- To allow a voltage to be entered into the Arduino program Lab1.ino, type **1** (1 also instructs Lab1.ino to disregard data from the encoder). Next, enter a voltage between 1 and 5.
- Wait a few seconds for the motor to spin-up to full speed (you will see/hear “full speed”).
- Type **s** and press Enter (which effectively disconnects the power-source with 0 input voltage and no electrical current through the motor). The motor’s speed will slow down.
- Simultaneously to entering **s**, start timing (e.g., with a stop-watch).
- Stop timing when the motor stops spinning.

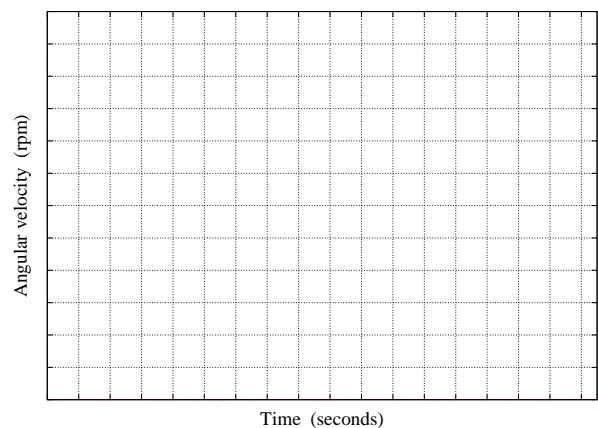
Graph the time-history of motor angular speed (below). **Label the scale on your axes!**

Note: The motor’s no-load speed is 5984 rpm at 24 volts and the no-load speed is **directly proportional** to the input voltage (assume the rod does not contribute a significant load).

Initial voltage (Volts)	Time to stop spin (seconds)	Time for graphing (seconds)	Initial angular speed (rpm)
1	$t_1 =$	$t_5 - t_1 =$	
2	$t_2 =$	$t_5 - t_2 =$	
3	$t_3 =$	$t_5 - t_3 =$	
4	$t_4 =$	$t_5 - t_4 =$	
5	$t_5 =$	$t_5 - t_5 = 0$	

Note: Initial angular speed is calculated from initial voltage and no-load speed info.

Note: The graph is formed from only the last two columns in the previous table.



How many data points do you need to determine if the motor’s speed decreases linearly or exponentially?   .

### 1.2.3 Estimation with an Encoder

lab1.ino displays a column of numbers to the computer screen. Each such number (herein called  $z$ ) is the number of tics (black/white transitions) sensed by the encoder in the previous 5 milliseconds. The following equation converts the value of  $z$  to the motor's angular speed in rpm.

Example: If lab.ino displays the number 20, the motor's average angular speed in the last 5 milliseconds was 240 rpm.

$$\text{Conversion factor: } \frac{z \text{ tic}}{5 \text{ ms}} * \frac{1000 \text{ ms}}{1 \text{ second}} * \frac{60 \text{ sec}}{1 \text{ minute}} * \frac{1 \text{ rev}}{1000 \text{ tics}} = 12 z \frac{\text{rev}}{\text{minute}} = 12 z \text{ rpm}$$

Collect two sets of data. The 1<sup>st</sup> set is without attaching the rod to the end of the motor. The 2<sup>nd</sup> set is with the rod attached. Ensure no wires or hands collide with the spinning rod!

To collect data using the computer setup:

- Return to the Arduino's program's main-menu by typing **r**.
- Enter **2** to start this spin-down test (the number **2** allows a voltage to be entered into the Arduino program Lab1.ino; waits until the motor reaches constant full speed; then effectively disconnects power – setting input voltage to 0 and preventing electrical current from flowing through the motor; then collects data from the encoder until the motor speed is 0).
- Select a motor voltage of 5 Volts. Select a time-step in microseconds of 5000.
- The Arduino will stop reporting data when the motor has stopped.
- Save the data into a file (e.g., into a folder on your desktop).
- Repeat this process to get the two sets of data described above.
- Plot the data file (e.g., using Microsoft Excel, MATLAB®, or PlotGenesis).  
Note: Before plotting, delete the menu (first couple of lines) at the top of the file.  
Think about converting the encoder data (counts) into rpm and what to use for the time scale.
- For each set of data, print out a graph of angular speed (rpm) vs. time (s) of the motor to hand in with your lab handout. Label the axes and title the graphs!
- Ensure the power to the board is off and the setup is neat for the next lab section.

### 1.2.4 Questions

For the condition **without** the rod:

- The motor's speed appears to decrease **linearly/exponentially** (circle one)
- It behaves like this because **Coulomb friction/viscous damping in the motor/air-resistance** (circle one) dominates the response
- Form an expression for the quantity that dominates the motor spin-down in terms of  $I_{\text{motor}}$  i.e., **either** the Coulomb friction constant **or** the time constant  $\tau$                      .

For the condition **with** the rod:<sup>3</sup>

- The motor's speed appears to decrease **linearly/exponentially** (circle one)
- It behaves like this because **Coulomb friction/viscous damping in the motor/air-resistance** (circle one) dominates the response
- Assuming  $I_{\text{motor}} \ll I_{\text{rod}}$ , determine the value of the quantity that dominates the motor spin-down, i.e., **either** the Coulomb friction constant **or** the time constant  $\tau$                      .

† **Challenge question:** Knowing that data from a motor that decays purely exponentially allows you to calculate the time constant  $\tau$ , what would you do to find numerical values for both the damping constant  $b$  and moment of inertia  $I$  in the motor's ODE:  $I\dot{\omega} + b\omega = 0$

<sup>3</sup>The rod's moment of inertia can be estimated as  $I_{\text{rod}} = \frac{1}{12} m L^2$