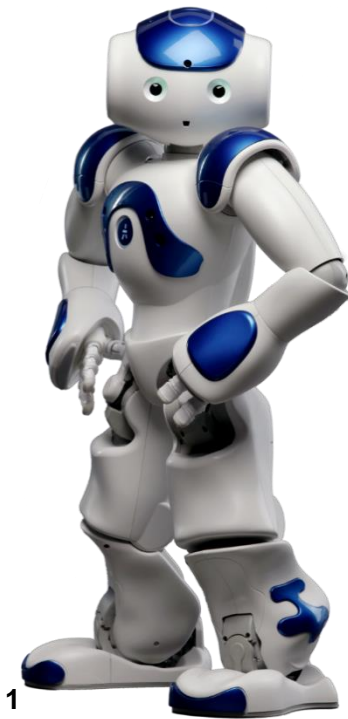


GE 320: Introduction to Control Systems

Laboratory Section Manual



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“Welcome to GE 320.....”

¹ www.softbankrobotics.com

1 Introduction

This section summarizes the course content and outlines the general procedure and reporting requirements.

1.1 Objectives of the Labs 1 through 5

- Gain a familiarity with standard laboratory instruments including the oscilloscope, multi-meter, DC power supply and myRIO.
- Learn HP VEE, MATLAB, and LabVIEW – the PC software we use in the lab.
- Gain working experience with DC motors, the direct measurement of their physical properties for use in deriving a transfer function, and the indirect measurement of the motor transfer function using frequency response methods.
- Design and implement the control for a DC servo motor.

1.2 General Lab requirements

- It is important to complete the pre-lab exercises BEFORE the lab as they are designed to present information required to understand the lab experiments.
- Each lab is weighted equally in calculating the final grade. Your pre-lab is considered as a prerequisite for you to be given a lab grade. **No pre-lab = 20% off lab grade.**
- All submitted lab reports should be typed. If pre-lab or post-lab questions contain equations, they can be neatly handwritten.
- **It is the student's responsibility to contact their TA well in advance if he/she needs to miss a lab. Your TA will explain how to make up the lab.**

1.3 Lab report requirements

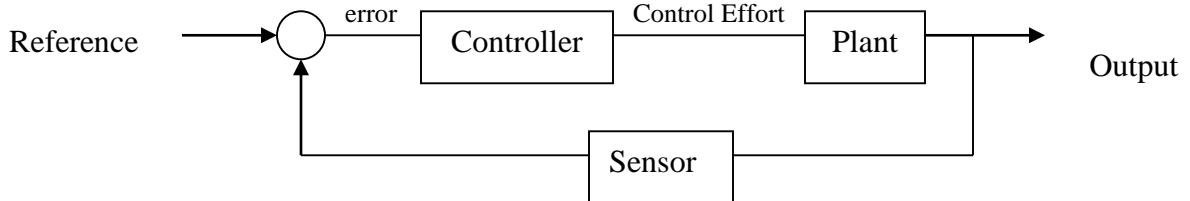
- A report on each completed lab session is to be completed and turned into your TA one week after your lab session, as instructed by TA.
- Laboratory reports, beyond common group data, are expected to be individual creations.
- The report should not include the problem statement, be succinctly written and should include the following:
 - **Introduction:** A brief statement of what was achieved in the lab. What was the 'essence' of the lab? (3 lines)
 - **Evaluation and Results:** Calculations should be explained and graphical results fully labeled. A typed copy of the data sheet should be appended.
 - **Discussion:** Compare experimental results to the expected ones. This is the **most important** part of the report. If something went wrong, explain how and

why. If a result seems unlikely – give reasons. Attempts to pass invalid data as correct will be heavily penalized.

- **Reflection:** Please include a reflection of at least 100 words about the experiment. This can include answers to the following questions: What aspects of this laboratory assignment met or did not meet your expectations? How did this assignment surprise, excite, or frustrate you? What lessons did you learn from this assignment? What questions do you still have?
Note: this section is not graded and does not count toward the two-page limit.
- Each submission *must* have your name, your TA's name and section as well as the experiment date and time.
- The reports will be graded considering:
 - Overall appearance of the report. Are all the sections present? Technical correctness? Are results and discrepancies identified and explained? Is the test data attached?
 - If the report is LONGER than 2 PAGES, then the report WON'T BE GRADED and a final grade of ZERO will be given.
 - Points will be divided as follows:
 - Prelab: 20 points
 - Introduction: 5 points
 - Results: 25 points
 - Discussion and post lab questions: 45 points
 - General Format, spelling, and grammar: 5 points

1.4 Introduction to Control Systems

Nowadays, more machines are controlled without any human assistance. This is not an easy task; therefore many theories have been proposed in order to achieve this goal. One of the most reliable theories is Feedback Control. The basic idea behind Feedback Control is to design and construct a piece of equipment capable of forcing the system to behave the way one wants it to. This piece of equipment is called a controller (or compensator). Depending on the system one intends to control, the controller will vary from a gearbox, to an analog circuit, to a digital computer. Controllers for the most part, use sensors to measure the actual behavior of the system (output), and compare it to the desired behavior (reference). Using this information, controllers react accordingly to manipulate the system in such a way the system behaves as desired.



Controllers are built from mechanical and electrical building blocks. Mechanical controllers are usually implemented with shafts, gears, pulleys, lever arms etc. Electrical controllers, on the other hand, are subdivided into digital and analog controllers. Digital controllers are implemented with computers and digital circuitry, while analog controllers are implemented with summers, integrators and differentiators. One of the objectives of this lab is to teach the student how to implement these summers, integrators and differentiators in LabVIEW. The student will be introduced to two basic sensors: the potentiometer and the tachometer. These sensors can be used to determine a DC-motor's position and speed.

1.5 Equipment Introduction

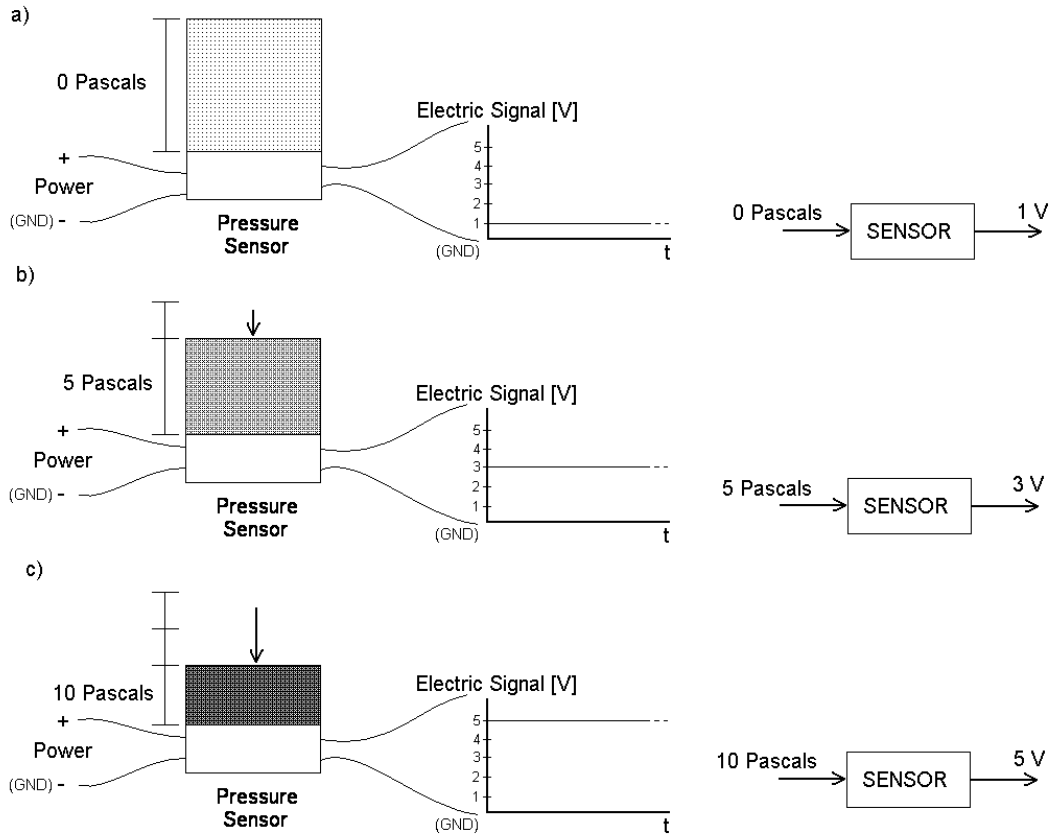
This introduction section to the lab is intended to give you a feel for some of the instruments you will be using in the next few weeks. Let us start with identifying the equipment:

- Locate the following apparatus on your bench and refer to the equipment information sheet for a brief description:
 - National Instruments myRIO
 - Multimeter
 - Oscilloscope
 - HP power supply and the patch panel
 - Motor, potentiometer, tachometer and flywheel.

1.6 Measurable Events and Electric Signals

Any measurable event can be mapped to an electric signal. This mapping is usually done with sensors. Sensors are electronic devices, which measure a physical event and output a proportional electrical signal.

Mapping example:



The mathematical formula, which maps the input with the output in this example, looks like follows:

Sensor's Mathematical Model

$$A \text{ [Pascals]} \longrightarrow \left[\frac{2}{5} A + 1 \right] \longrightarrow B \text{ [V]}$$

SENSOR

Gain can be defined as the ratio of magnitude of output to the magnitude of input signal at steady state. In this lab section, we calculate the gains for potentiometer and tachometer.

1.7 National Instruments myRIO

The National Instruments myRIO is an embedded hardware device with built in data acquisition capability. The myRIO contains a dual-core ARM processor that is similar to what runs most cell phones and tablet computers. LabVIEW is the most common programming language used to program the myRIO. This semester you will use the myRIO to collect and plot data as well as implement the controller.

1.8 Control Systems Building Blocks

In GE 320, one of control systems you will learn is proportional, integral, and derivative (PID) control. In order to implement this type of control system in hardware or software, you need three building blocks: summer, differentiator, and integrator. Each of these have pre-built blocks in LabVIEW. Each block is shown in Figure 1 below.

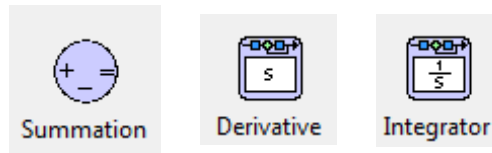


Figure 1 - LabVIEW Blocks

1.9 Electrical Sensors in the Lab

- Electrical sensors are devices, which convert physical phenomenon into electrical signals.
 - Rotational Potentiometers: Voltage varies as a function of rotational position (angle). (Figure 2).
 - Linear Potentiometers: Voltage varies as a function of translational position.
 - Tachometer: output a voltage depending how fast the tachometer's shaft is rotating (Figure 3).

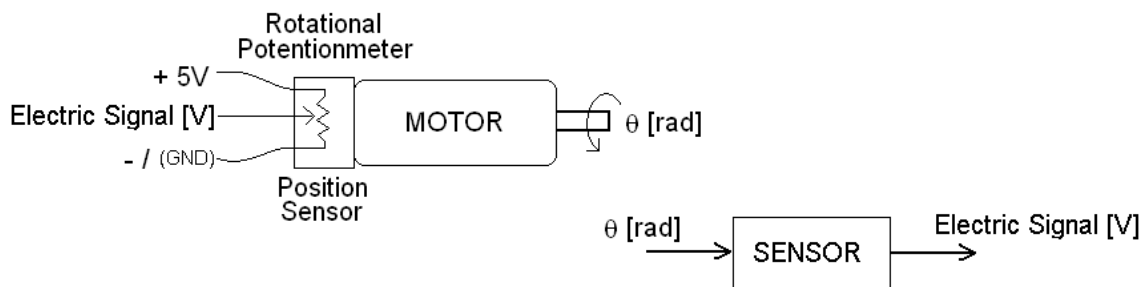


Figure 2 - Diagram of rotational potentiometer

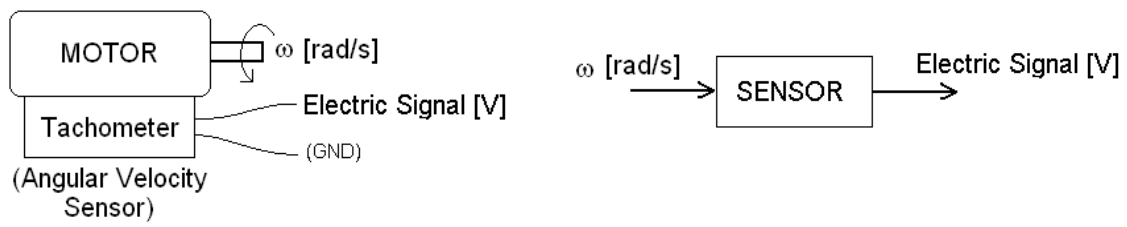


Figure 3 - Diagram of a Tachometer

2 Lab 1: Tachometer, Potentiometer, Motor Dead Zone

2.1 Introduction

In this lab, you will learn about two basic sensors: the potentiometer and the tachometer. These sensors can be used to determine a DC-motor's position and speed, respectively. Finally, you will be introduced to the DC-motor's dead zone and how to deal with it.

2.2 Pre Lab

1. With your own words, how would you define and describe a sensor.
2. What does "sensor calibration" mean?
3. What is a potentiometer?
 - a. Find at least 2 different kinds of potentiometers and explain how they work.
 - b. The potentiometer in the lab has 340 degrees of electrical travel and 5V will be applied across it. What is the potentiometer's gain in V/rad
 - c. What do you expect the output voltage from a circular potentiometer (spinning at constant angular velocity) to look like?
 - d. Could a potentiometer be a sensor? Why?
4. What is a Tachometer?
 - a. What are the units of input and output of a tachometer?
 - b. If the period of one revolution of a motor is 0.03sec and the output of an attached tachometer is 6V, what is the tachometer gain in V-s/radian?
 - c. Could a tachometer be a sensor? Why?
5. Describe Faraday's Law in your own words. How does this account for torque being produced in a DC motor?
6. Make sure to read the equipment information documented at http://coecsl.ece.illinois.edu/ge320/ge320_EquipManual.pdf

2.3 Objectives

By the end of this lab, you will be able to:

- Understand the physical reason for dead zone in a DC motor.
- Identify the motor parameters sensed by the tachometer and potentiometer.
- Explain the relationship in time between the tachometer and potentiometer outputs.

2.4 Reference

Section 2.8, Sensors in *Feedback Control Systems*

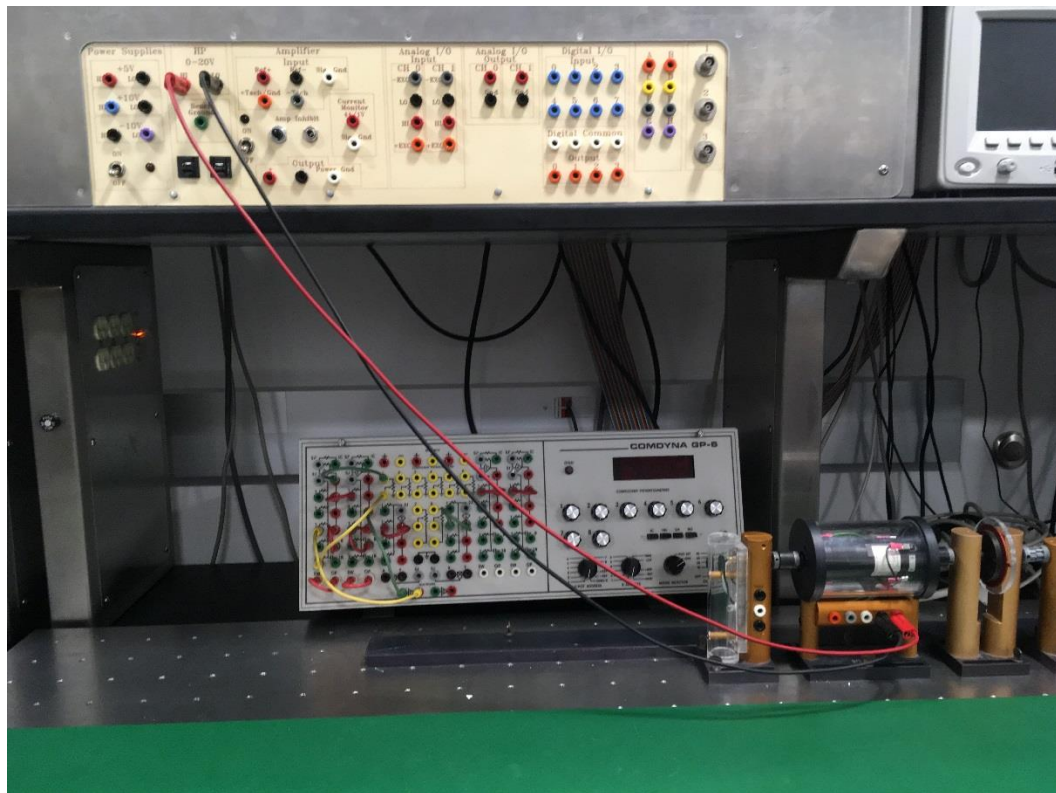
2.5 Calibration and Dead Zone

This section of the lab focuses on taking measurements to establish the dead zone of the motor, calibrate the potentiometer and the tachometer.

2.5.1 Motor Dead Zone Estimation

The motor requires a certain amount of power before it can rotate freely. We will find this value by varying the amount of current and voltage we apply to the motor.

- In HP VEE, open the file: “[n:/labs/ge320/exp1/deadzone.vxe](#)”
- Connect the HP variable power supply to the motor, from the patch panel.

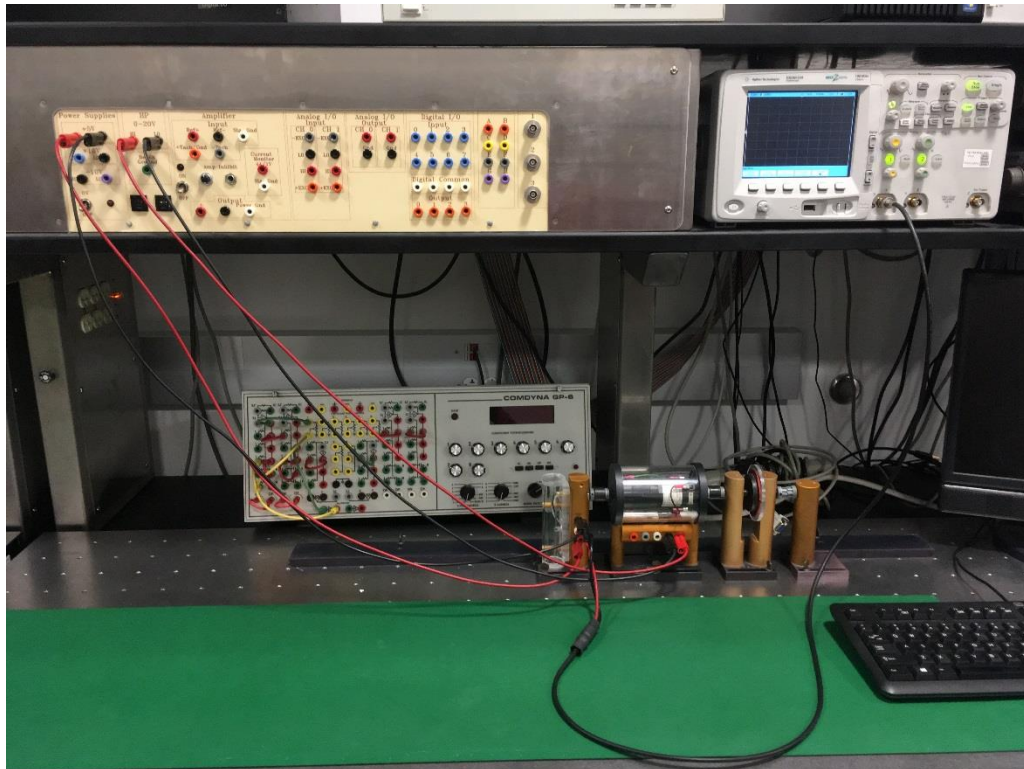


- Turn the HP power supply on.
- Click the “Reset” button and set the “output enable” to “off”. This controls the HP power supply that is output on the patch panel, which you must now connect to the motor. Where is the HP power supply?
- Set the maximum current to 2 amps and turn “output enable” on.
- Gradually increase the voltage from 0 in 0.2 V increments. At each step, look at the motor and check for smooth, continuous unimpeded rotation. Show this to your TA and record the voltage and current values on the data sheet.
- Turn off the output enable.
- This is the motor dead zone in Volts and was measured with a limited current of 2 amps. We now consider the dead zone measured in amps:
- Set the voltage to 5 times the voltage dead zone value.
- Set the current to 0 and increase it in steps of 0.05 amps. (Turn the power on first!) Continue until the motor rotates in a smooth, continuous and unimpeded fashion. Record these values.

2.5.2 Calibration of Potentiometer

As you discovered in the prelab, the potentiometer is a variable resistor (usually carbon deposited) or variable voltage divider. The “slider” of the potentiometer has a friction contact to the potentiometer’s base resistor. Movement of the slider allows for a variance in the resistance from the slider to the end points of the potentiometer. Some sensors due to their construction and properties have non-linear output. So, we will be examining the linearity of the potentiometer output.

- Open the file: “[n:/labs/ge320/exp1/pot cali.vxe](#)”.
- Connect the potentiometer to the motor; the shaft of the motor has to be attached to the potentiometer. Use the 5V power supply from the patch panel to power the potentiometer. Scope the output from the pot. Refer to the equipment manual for help if needed.



- Click the “reset” button on the power supply and then check that the “output Enable” switch is off. Set the voltage to 5 volts and the current to 2 amps. Set the trigger level on the scope to 2.4 V. Finally update the parameters of the real scope by clicking the Send New Scope Parameters button. You are now ready – SHOW THE TA. **Note:** While using the VEE Pro software to control the oscilloscope you should not use the actual knobs of the oscilloscope. VEE Pro does not realize that you have changed a setting and will return your data incorrectly scaled.
- Turn the output enable switch on and the motor should begin to spin. Turn the 5V

power supply to the potentiometer on and the waveform representing the output from the potentiometer should appear on the scope.

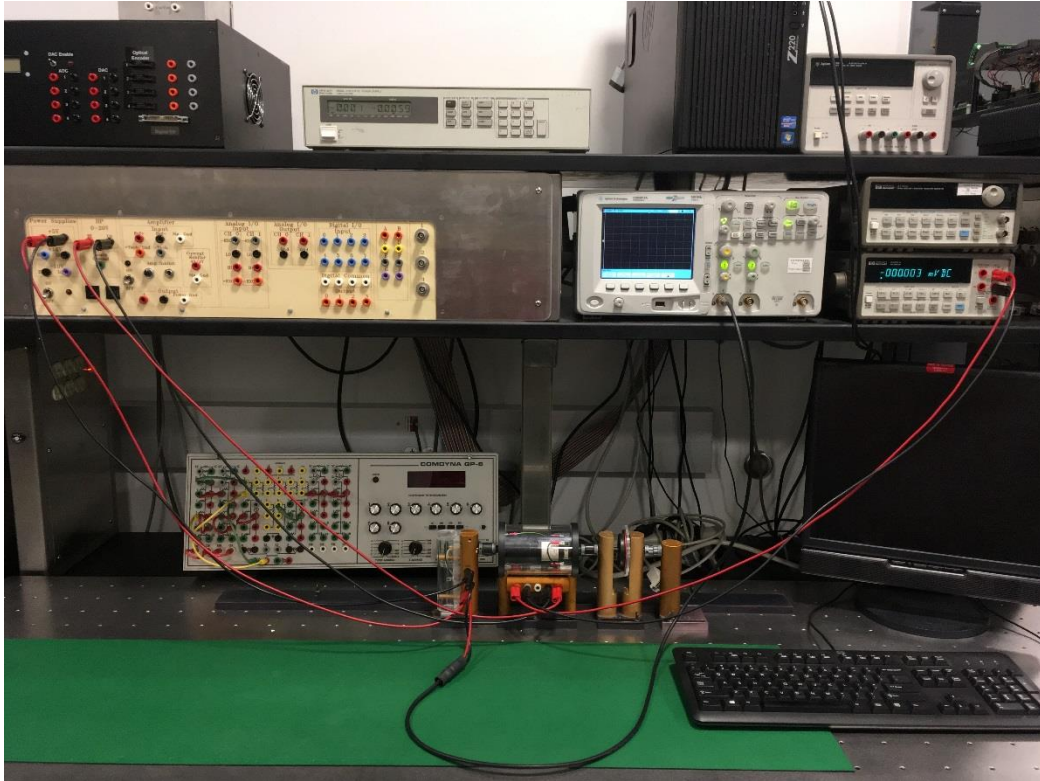
- Change the Time Base on the virtual scope to fit an entire period of the potentiometer's signal. **Note:** Don't forget to update the real scope's parameters by hitting the Send New Scope Parameters again.

Click **Collect Data from Scope** and a copy should appear on your screen. Sketch two wavelengths on the data sheet and turn off the power. How linear is the potentiometer? You should find it very linear so just record the potentiometer gain found in the prelab on your data sheet.

2.5.3 Calibration of Tachometer

As you discovered in the prelab, a tachometer produces a voltage directly proportional to the angular velocity of its shaft. In this lab we will measure the proportionality constant or gain in units of voltage / unit angular velocity.

- Leave the equipment as setup above but use the multimeter to measure the tachometer output. Open the file “n:/labs/ge320/exp1/tach_cal.vxe”



- Set the trigger level on the scope to 2.4 V.
- Reset the power supply window, turn the output off, and set the current to 2 amps. Set the voltage to 5 volts and then turn the power on. The motor will spin, and a waveform will appear on the oscilloscope.
- Record the output value from the tachometer and click Collect Data from Scope. Now, use the triangles to measure exactly one period. Record this value and compute the angular velocity. The ratio of the voltage to the angular velocity (in rad /sec) is the tachometer gain.
- Repeat the above step in 1V increments up to 9 V. Show the TA.

Disconnect all the wires, and put them back where you found them, log off the computer, turn off all the equipment, turn off the bench power supply, put your chair at the desk and go home.

2.6 Post Lab

Include the answers to the following questions in your lab report

1. What is the difference between the functionality of a tachometer and a motor?
2. What causes the motor to have a dead zone?
3. Why is it that when the voltage was set to five times the dead zone, but the current was limited, the motor did not have unimpeded, continuous rotation?
4. Based on this experiment, what do you think causes the motor to spin?
5. When you observe the potentiometer output, what is the shape of the output? Include a sketch of the potentiometer output.
6. Is the potentiometer linear? Why is there a small flat section at the bottom of the waveform? How does the motor speed affect the waveform?

2.7 Data Sheet

Motor Dead zone			
Voltage Dead Zone		Current Dead Zone	
Voltage		Voltage	
Current		Current	

Potentiometer Gain	
GAIN	(V/rad)

Tachometer Calibration				
Voltage	Period	Angular Velocity	Tachometer voltage	Tachometer Gain
5 V				
6 V				
7 V				
8 V				
9 V				
Average				(V*sec / rad)

**Include a sketch of the potentiometer output