Project 2
Velocity Estimates

For this project, each team will investigate estimates of velocity of the end of the cantilever beam by using measurements of acceleration and position. Velocity can be estimated by taking the integral of the acceleration as a function of time or by taking the derivative of the position as a function of time. You will do both and compare the results.

In this project you will measure the acceleration of the beam using an accelerometer and the position of the end of the beam found using three different devices.

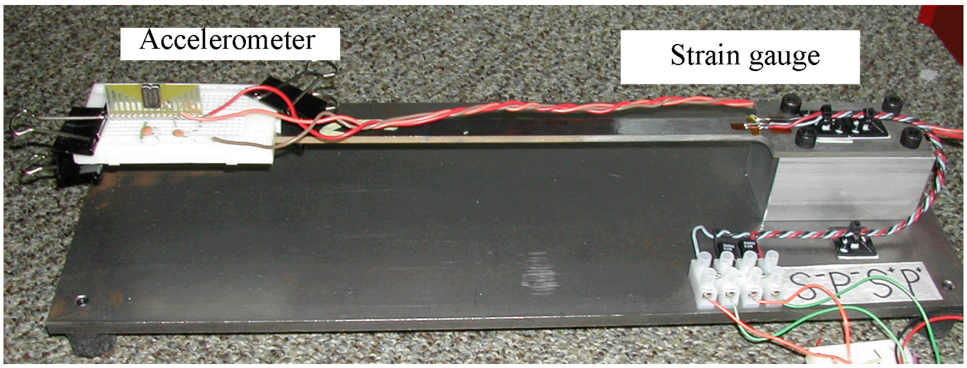


Figure 1.

When you connect each of these devices to the scope, you get a voltage signal. The strain gauge output is proportional to beam position. The accelerometer gives a signal proportional to the acceleration. We know that the unit of displacement is meters, m; the unit of velocity is m/s; and the units of acceleration is m/s^2. We also know that all of these signals are time dependant functions that look like decaying sinusoids. In this project, we will take data from both devices, calibrate them, convert them into velocity, and compare the results.

Part A of this handout discusses how to use the accelerometer chip (available from your instructor) to find the acceleration of the beam directly. Part B discusses methods of using measurements taken by the strain gauge (which is proportional to the displacement of the beam) and comparing it to the acceleration measurement of the beam. Part C discusses converting both signals to velocity and comparing the results. Part D discusses some ideas for extra credit. Appendix I contains a task list for the project. Please note that the handout for the project (Parts A-D) contains background information that you need, but the task list provides the order in which the tasks should be performed. Appendix II contains what your appendix for the project report should contain. Appendix III outlines the project report. For additional background information consult the links and spec sheets on the course links page: http://hibp.ecse.rpi.edu/~connor/education/EILinks.html#Proj2.

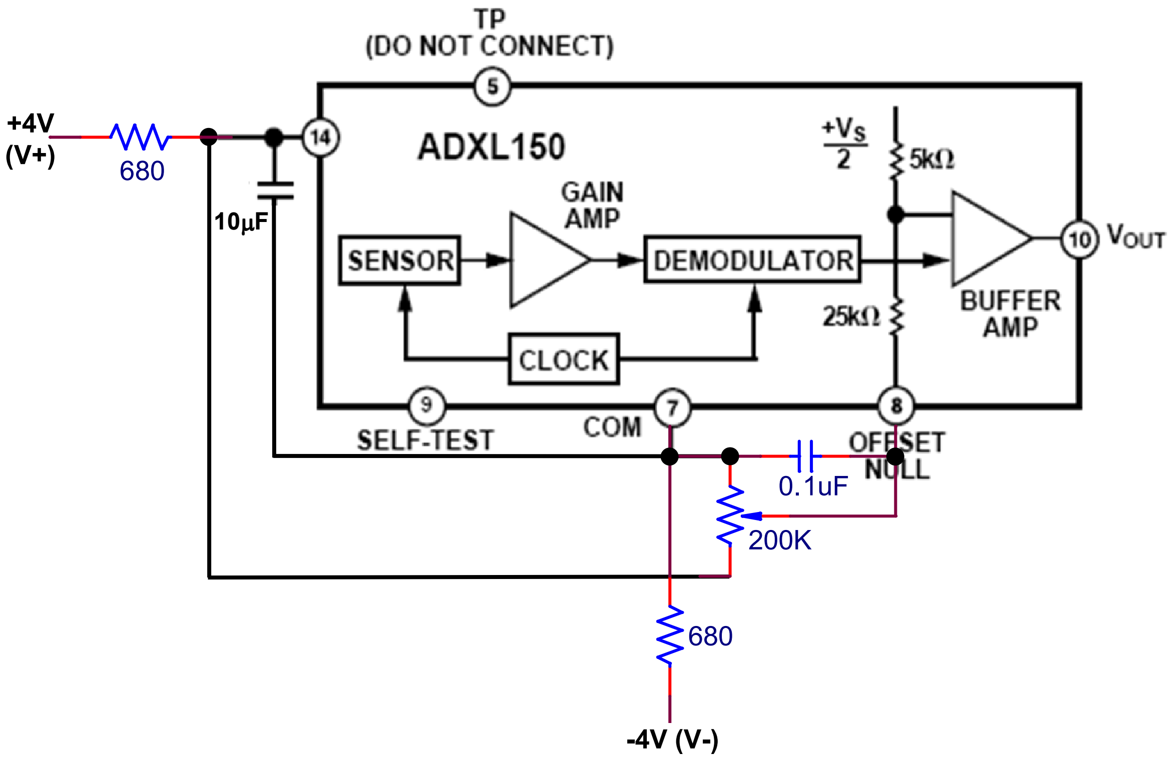
Note: Many groups end up taking their data more than once for this experiment. It is a good idea simply to practice the first time. Get your circuits working. Take practice calibration measurements. Make sure you are absolutely sure you know all the data you need to take. Then, when you are ready, all the data can be taken in about 15 minutes under the same conditions. As in Experiment 5, write down the number of the beam taken on the first day and use the same one throughout the project for more consistent results.

Part A - Building an AD Accelerometer circuit

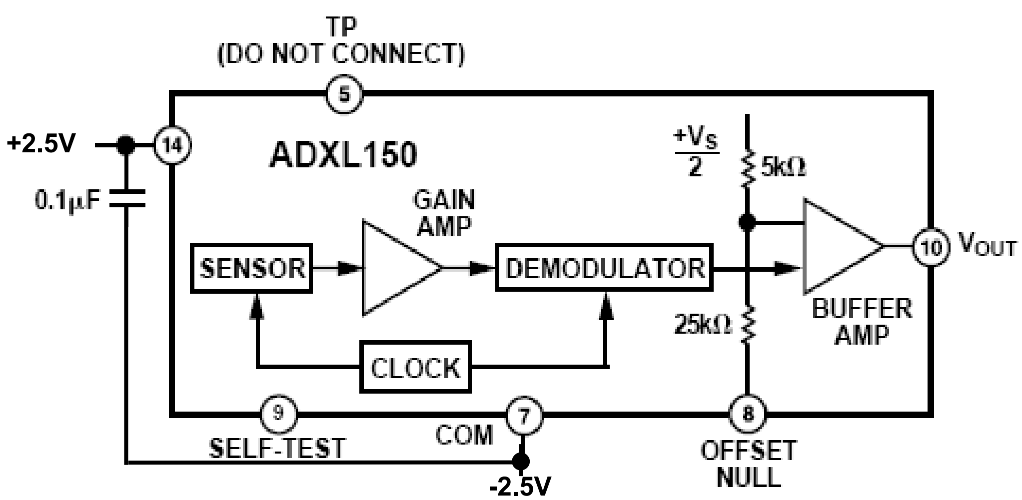
This section discusses how to build and calibrate an accelerometer circuit that you can use to find the acceleration of the cantilever beam directly.

The Circuit

The following circuit can be used to create a signal proportional to the acceleration of the beam using a commercial accelerometer. The IOBoards have built-in voltage supplies labeled V+ and V- to power the accelerometer.



a) Accelerometer configuration for RED2 IOBoard. (May use a 100K pot instead of the 200K pot.)



b) Accelerometer configuration with ±2.5V supplies.

Figure 2.

Note: The accelerometer chip is powered by +2.5V and -2.5V from the IOBoard. The RED2 IOBoards only have ±4V available. To use the higher voltage supplies, two 680Ω voltage reducing resistors must be wired in series with the accelerometer. Wiring this wrong will destroy the chip. Be very careful and be sure that you have it wired correctly before applying power! Adjust the 100k potentiometer so that the Vout is zero.

The accelerometer is surface mounted and, thus, cannot be plugged into a protoboard. It also needs to be oriented vertically in order to record the acceleration of the beam. Therefore, we have mounted the chip on what is called a surfboard. You will have to be careful that you connect things correctly, since the surfboard has 16 pins and the accelerometer has only 14. (We do not use the two in the center). The pin numbering is given in the figure below.

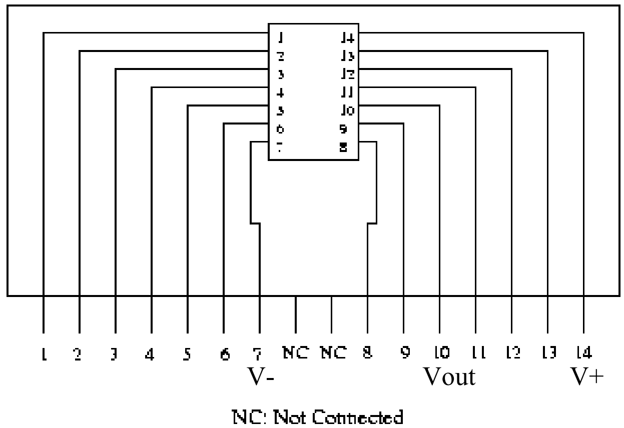
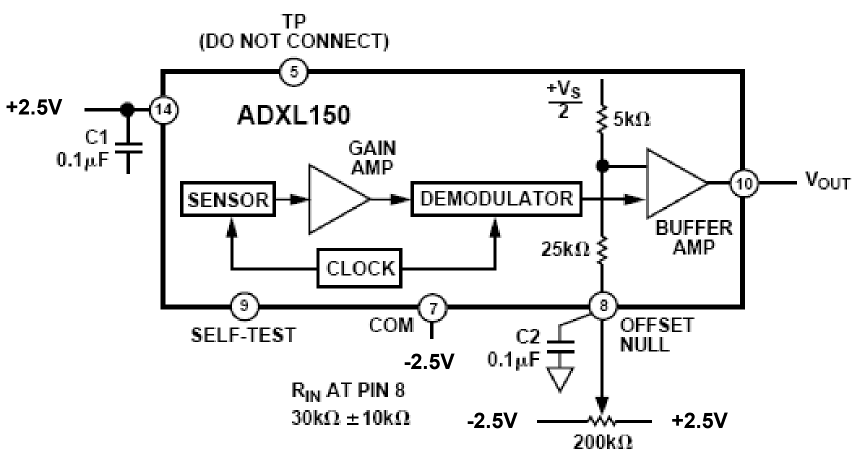


Figure 3.

You only need 3 connections between the IOBoard and the accelerometer, +V, -V and Vout. These are pins 14, 7 and 10 respectively. Wires from these pins should be long, and should run down the beam. This will reduce the effects the wires have on the motion. The output of the accelerometer is sufficient to be recorded directly with the IOBoard. Be very careful with the accelerometer. It is mechanically robust, but the surfboard is not. Also it is electrically sensitive. If you apply the wrong voltages, you may damage it. (Circuit components cannot be repaired). *Please have a TA or instructor check your circuit before applying power.* Mount your small protoboard to the end of the beam and test to see if your circuit is working. The accelerometer signal should have only a small dc offset. **The circuit below is optional when using ±2.5V supplies as in Fig. 2b.** It is one method to reduce the dc offset. When using 680Ω voltage reducing resistors, the offset may be around 100mV due to the small difference in the 680Ω resistor values. Fig. 2a. includes the offset nulling trim potentiometer circuit. This should be wired right on the small protoboard with the accelerometer chip and mounted on the beam for optimum performance. Start with the 100k pot close to its center point and adjust it slowly until the quiescent Vout signal is zeroed. This can also null out the constant 9.8m/s^2 acceleration offset voltage due to gravity. Either a 100k or 200k potentiometer may be used for this offset null feature. The smaller the offset the better the integrator will work later in Part C.



Offset Nulling the ADXL150/ADXL250 Using a Trim Potentiometer

Figure 4.

Important Note: This experiment does not work unless all your measurements are taken when the 'effective mass' at the end of the beam is the same. You may recall from experiment 5 that adding additional mass to the end of the beam slows down the frequency. This means that you need to have the accelerometer mounted to the beam when you take all your measurements or else your frequencies (and data) will be off. The wires attached to the accelerometer circuit also contribute to the effective mass at the end of the beam. Heavy connectors tend to add extra weight and make the damping excessive. Supporting the wires by hand (every time you take data) can help alleviate this problem. A better method is to take long wires (cut from the spool at the front of class) and use them to make connections to the accelerometer. Make sure these wires can move freely to minimize their influence on the data.

Build this circuit and record a voltage trace. Save the trace as a file. You will use MATLAB to plat the data, see section 5 of this document on plotting data in MATLAB.

Calibration

The signal you get from the accelerometer circuit is not acceleration in m/s^2. It is a voltage proportional to the actual acceleration. The data sheet for the ADXL150 accelerometer states the sensitivity of the output is 38mV/g where g is the acceleration due to gravity, 9.8m/s^2. Thus, we get:

$$a_b[t] = V_a[t]\frac{9.8}{0.038} \qquad (equ\ 1).$$

Using this scale factor, you can calculate $a_b[t]$ in m/s^2.

Part B – Calibrating the Strain Gauge

This section discusses the calibration of the strain gauge and a simple comparison between the strain gauge and the accelerometer.

Circuit

In experiment 5 you built the diff amp circuit required a bridge to measure the output from the strain gauge. Hopefully this circuit is still intact. Reconnect the circuit below.

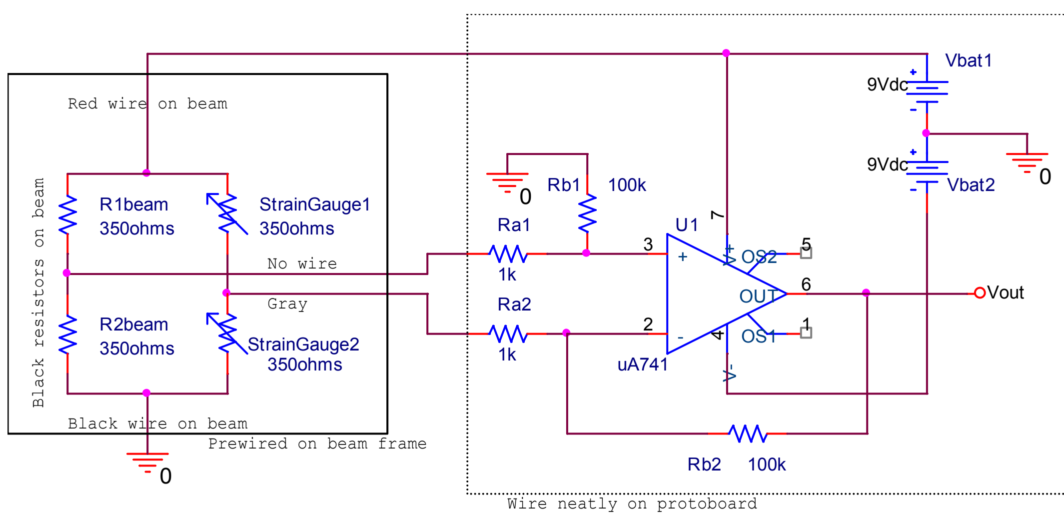


Figure 5.

Remember that you may use either the uA741 op-amp pictured above or the LF351.

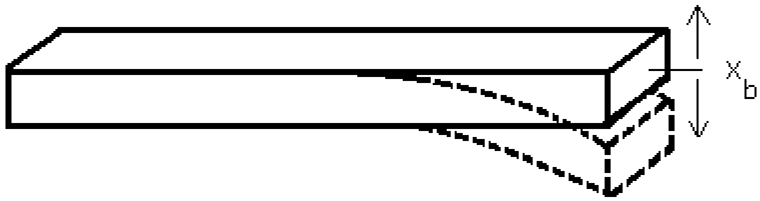


Figure 6.

Calibrate the strain gauge:
Use a ruler and measure the output voltage vs. the displacement of the beam. Take 5 measurements. For example, measure Vout with the beam displaced by -1cm, -0.5cm, 0, 0.5cm and 1cm. You may pick different positions, but don't bend the beam too far or it will be permanently bent. This will void any measurements made before the bending. Plot Vout vs. position using Excel or MATLAB and fit a line to the data. The slope of the line gives the sensitivity of the strain gauge circuit, call this constant k1. The point where x = 0 is arbitrary, so equation 2 can be used to find position of the beam as a function of time. V_{sg} is Vout of the strain gauge circuit, k1 is the constant for the calibration of the strain gauge circuit and x_b is the position of the end of the beam.

$$x_b[t] = V_{sg}[t]\frac{1}{k1} \qquad (equ\ 2)$$

Comparing the strain gauge and the accelerometer signals
Connect ADC1 of the IOBoard to the accelerometer. Connect ADC2 to the output of the strain gauge circuit. Record both for one plunk of the beam. Save this data to a file.

The two signals should look similar even though one is proportional to acceleration and one is proportional to position. For the moment, ignore the fact that the oscillation is decaying with time, then:

$$x_b[t] \cong C_1 \sin \omega t \qquad (equ\ 3)$$

and therefore

$$v_b[t] \cong C_1\, \omega \cos \omega t \qquad (equ\ 4)$$

and

$$a_b[t] \cong -C_1\omega^2 \sin \omega t = -\omega^2 x_b[t] \qquad (equ\ 5)$$

The signal from the accelerometer should look the signal from the strain gauge with only a difference in magnitude. Determine ω from the data, and combine this with k1 (the strain gauge calibration constant) and the accelerometer constant and make a conclusion as to whether the two measurements are in agreement or if something is wrong. (Remember that ω is 2πf.)

Part C – Estimating the velocity

The velocity of the end of the beam is our desired quantity. The velocity can be found by taking the integral of the acceleration signal or by taking the derivative of the position signal. You will do both.

Build the circuits:
You built an integrator circuit in experiment 4. You now need to build another one to integrate the accelerometer signal. In experiment 4, a differentiator circuit was presented but not built. Now you will build one.

Integrator:

Build the circuit below, using the uA741 or LF351 op-amp. The power connections aren't shown; use +9V and -9V from the batteries. It is assumed that you are more than capable of adding these at this point.

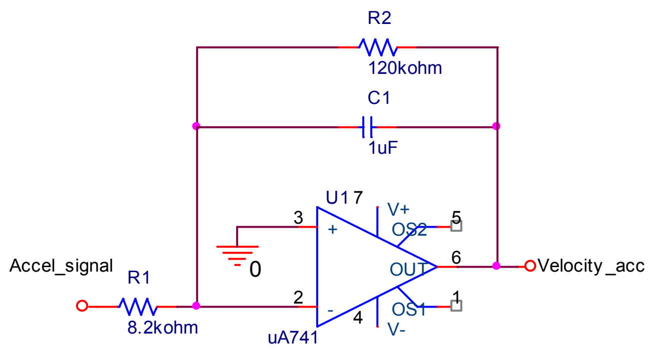


Figure 7.

The input is the signal from the accelerometer. Connect ADC1 to the input of this circuit. Connect ADC2 to the output. Record a good signal. Save it to a file. Return to the material for experiment 4 and determine the gain of this circuit at the frequency of the beam. State if the circuit functions as an integrator.

The values for R1, R2 and C1 were chosen for you. Comment on if these are appropriate. What is the corner frequency for this Miller Integrator? At the frequency of the beam oscillations, what is the relative magnitude of Velocity_acc vs. Accel_signal? Is this a good choice, why or why not?

Differentiator:

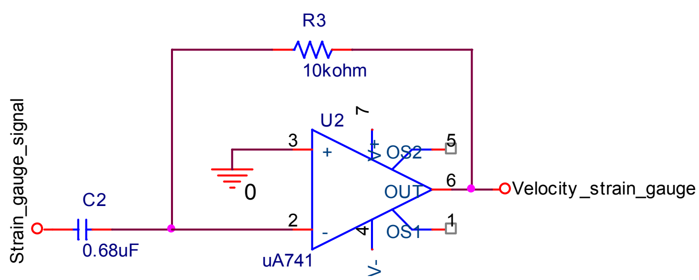


Figure 8.

Build the circuit above, again use the uA741 or LF351, and include power. Don't take apart the diff amp or the integrator, you need them all. The 0.68μF capacitor is labeled as 684, this 68×10^{4}pF or 0.68μF. The strain gauges should still be connected to the diff amp. The output of the diff amp is the input to this circuit.

Connect ADC1 to the input of this circuit. Connect ADC2 to the output. Record a good signal. Save it to a file. Return to the material for experiment 4 and determine the gain of this circuit at the frequency of the beam. State if the circuit functions as a differentiator. Note that it is very noisy. Why? The values or R3 and C2 are given to you. Based on the way that the circuit works and the frequency of the oscillation, were these good choices? Why or why not?

Final data:
For one plunk, record the outputs of both the integration of the accelerometer and the differentiation of the strain gauge signal. Even though one is noisy, determine if they are in agreement. You will need to include all of the gain constants, which are: 1) the sensitivity of the accelerometer, 2) the gain of the integrator, 3) the sensitivity of the strain gauges with the diff amp, and 4) the gain of the differentiator.

Additional Questions
In the conclusion of your report, we want you to consider the following:

- Accelerometers are used extensively these days in cars. How would you use accelerometer signals in a car to enhance the driving experience? If there are so many accelerometers in present day cars, why is acceleration typically not displayed for the driver?
- If you had a portable accelerometer, what would you do with it?

- Details about the report conclusion are contained in Appendix III of this handout. You will need to include several MATLAB plots. See Appendix II of this handout for details.

Part D – Extra Credit

A small amount of extra credit will be offered to teams that do one of the following. Extra credit will only be offered for one topic. We will only read the 1st extra credit submission received in each report.

a) Nice tutorial on plotting from MATLAB
For this to count, you need to finish it 2 weeks before the Project 2 due date. That way it can be sent to the other teams before they finish their reports. This tutorial should be submitted as a separate item before the main body of the report. It needs to include examples of titles, legends, grids, axis control. These examples should be relevant to this experiment.

b) Clean up the Data
Some of the data is noisy. Find a way to process the data to keep the required information and reduce the noise. This can be either by using a filter circuit or by processing the data on your computer. You need to explain what you did, why you did it, how you did it, and show results.

The data sheet for the ADXL150/ADXL250 has some filter circuits that might be useful. The accelerometer signal may already be clean, so you might consider applying these circuits to the strain gauge circuit.

MATLAB is capable of processing the data.

c) Do the integration and differentiation using MATLAB
Create a software version of the two circuits and process the data traces. You need to give a complete description of what you did and why. And of course you need to show that the processing works. This might be easy if you know Simulink.

d)Other Extra Credit Ideas
If you have something else you would like to try for extra credit, ask your professor.

Part E – Plotting data in MATLAB

Start MATLAB

1) Importing data
    a. Click on File menu > Import Data
    b. Select the file with the data
    c. Note in the top right – "number of text header lines"
        i. This should be set to at least 1
        ii. Play with it if you have some extra info at the beginning of your data file
    d. The default name for the import data is: data
    e. If you had one channel of the IOBoard active, then you will have n by 2 matrix.
        i. The first column is the time of each data point
        ii. The second is the voltage recorded, channel 1
    f. If you had both channels active, then there is a third column that is data for channel 2.
2) Using the data – below are lines from a MATLAB session:

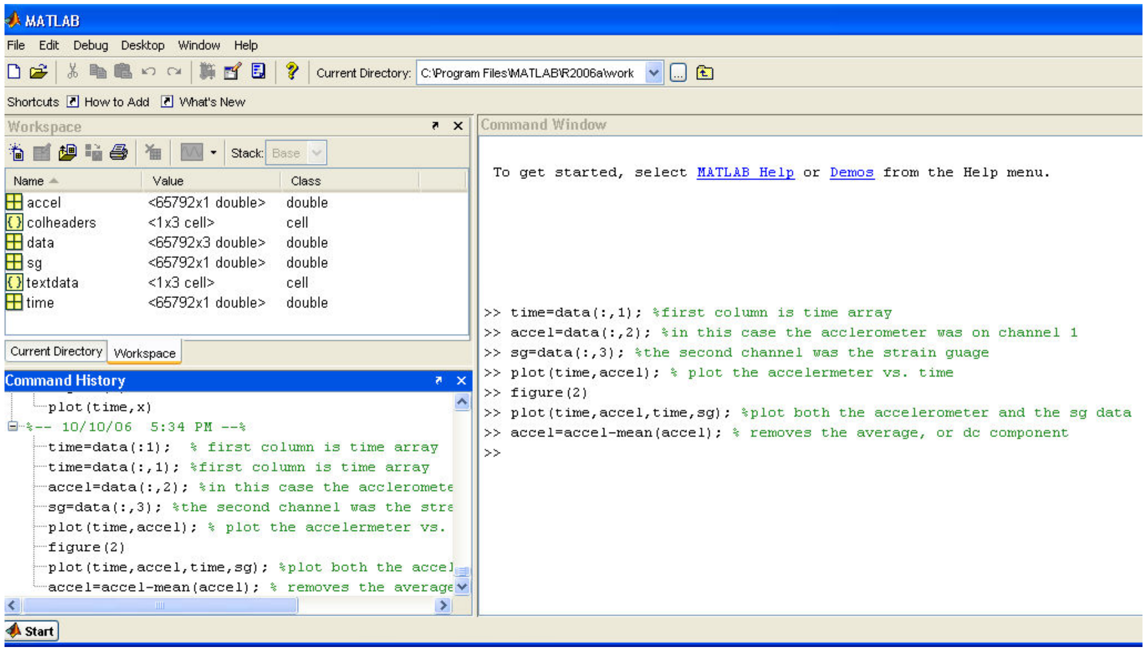


Figure 9.

3) You need to add annotation to the plots for them to be acceptable. Titles, legends, and appropriate axis settings are expected for the report.

Part F - Appendices

The following appendices summarize what you need to do, what the appendix of your report should contain, and what should be included in your report. Appendix I of this handout gives you a task list of things you need to do. Appendix II of this handout gives you a list of things to include in the appendix of your report. Appendix III of this handout summarizes the parts of the report. In general, every response plot of data generated in the studio should be signed and dated by a TA or instructor and included in the report.

Appendix I: Task List

A. Build the accelerometer circuit.
   1. Put the accelerometer on the small white board. Clamp it to the beam as near to the end as practical.
   2. Have your circuit checked by a staff member. This is important because the accelerometer chips are expensive and easily damaged if wired incorrectly.
   3. Test your circuit to make sure that it functions.
   4. Use MATLAB to plot the raw data vs. time. ***Have this signed.***
   5. Convert the raw data and plot acceleration vs. time by including the calibration constant given on page 3 of this project. This can be done outside of class and doesn't need a signature.

B.1 Reconnect your diff amp circuit to the strain gauge.
   1. Measure the output voltage while holding the beam at 5 positions. Plot the output vs. position using MATLAB or Excel. Find the slope. This is the calibration constant for the strain gauge.
   2. Take a data set just recording the output of the strain gauge circuit, (the strain gauge circuit includes the bridge and the diff amp.) Plot the raw data vs. time using MATLAB. ***Have this signed.***
   3. Convert the raw data to position and replot. No signature for this plot.

B.2 Record both the accelerometer signal and the strain gauge circuit signal at the same time.
1. Plot both on the same plot using MATLAB. This plot shouldn't include any calibration constants. ***Have this signed.***
2. Pick a point of the plots and analyze that point. Apply the calibration constants. Calculate the frequency of the oscillation to determine ω. Show the data points used for this calculation.
3. Determine if equation 5 on page 4 is satisfied. Discuss this.

C.1 Estimate the velocity from the acceleration.
1. Build the integrator circuit and connect the accelerator signal to the input.
2. Record the input and output for a plunk of the beam.
3. Plot the raw signals, both on one plot. ***Have this signed.***
4. Use the output of the integrator, equation of the integrator and the accelerometer gain constant to plot the velocity as a function of time in real units.

C.2 Estimate the velocity from the position.
1. Build the differentiator circuit and connect the strain gauge circuit output to the input of this circuit.
2. Record the input and output of the differentiator for a plunk of the beam.
3. Plot the raw signals, both on one plot. ***Have this signed.***
4. Use the output of the differentiator, equation of the differentiator, and the strain gauge gain constant to plot the velocity as a function of time in real units.

C.3 Data from both velocity measurements.
1. Record the output of the integrator and the differentiator at the same time for a plunk of the beam.
2. Plot both with all calibration constants included.

D. Analyze your data and the circuits.
1. Compare the velocity measurements by both methods.
2. Comment on the effectiveness of the integrator circuit.
   a. Are the components chosen reasonable. Are there better options?
   b. Did it work?
3. Comment on the effectiveness of the differentiator.
   a. Are the components chosen reasonable. Are there better options?
   b. Did it work?

E. Assemble the appendix (as described in Appendix II).

F. Write your group report (as described in Appendix III).

Appendix II: The Appendix of Your Report

General note: plots that are signed don't need to be nicely formatted. These can have hand notes to indicate what is being displayed. Processed plots, which include the calibration constants, must be professional in appearance.

The following list of items must be included in the appendix of your report, numbered and ordered as listed. This will help make sure that everyone includes everything that is required. In your report you should refer to each appendix specifically as needed to help illustrate your descriptions and conclusions. If you would like, you can include a second copy of what is in the appendix in order to better illustrate what you are trying to say, however, this is not necessary and cannot be used as a replacement for the contents of the appendix.

Appendix A: Accelerometer
1. Plot of raw acceleration data vs. time, **signed**.
2. Plot of acceleration including calibration constant.

Appendix B: Strain and Accelerometer
1. Plot of strain gauge voltage vs. position. Indicate the slope of data.
2. Plot of raw position data vs. time, **signed**.

3. Plot of position vs. time, includes the calibration constant.
4. Plot of raw from accelerometer and strain gauge, **signed**.

Appendix C: Velocity
1. Plot of input and output of the integrator, **signed**.
2. Plot of velocity using the output of the integrator, scaled and labeled.
3. Plot of input and output of the differentiator, **signed**.
4. Plot of velocity using the output of the differentiator, scaled and labeled.
5. Plot of velocity from sensors on the same plunk, scaled and labeled.

Appendix D: References (Must be included.)
1. Names of websites referenced.
2. Title, author, etc. of any books used.
3. Any additional references.

Appendix E: Extra Credit
- Any additional materials you would like to include for extra credit.

Appendix III: Your Group Report (80 points)

General note: plots that are signed don't need to be nicely formatted. These can have hand notes to indicate what is being displayed. Processed plots, which include the calibration constants must be professional in appearance.

<u>Introduction (5 points)</u>
- State the purpose of the project.
- Also include at least 2 topics you studied in this course that helped you understand the project.

<u>Theory (20 points)</u>
- Describe the basic theory. What is the relationship between displacement, velocity, and acceleration? How does the accelerometer measure acceleration? How does the strain gauge measure strain?
- Describe how the circuits work. What are the basic elements of your strain gauge circuit, (bridge and diff amp). Describe the integrator and the differentiator circuits, are the component values reasonable for this task? How did you determine if they were reasonable or not? For what frequencies would the integrator be expected to act like an integrator? The same question for the differentiator. Given the frequency of the beam oscillation – what is the maximum input signal that can be applied to these circuits without causing the output to go into saturation?
- Describe the calibration process. What calibration constants are needed? Where do the constants come from (data sheets or experiment)?
- Describe the gain constants associated with the integrator and differentiator circuits. How are they determined? (Feel free to reference a previous experiment.)
- Use your own words and be sure to site any resources you used in appendix D.
- Demonstrate to the grader that you understand what is happening.

<u>Circuit operation (10 points)</u>
- Accelerometer circuit
  - Document the entire accelerometer circuit including the integrator (schematic).
  - Is the output of the integrator consistent with the measured acceleration and the component values used? Amplitude and phase?
  - Include references to relevant material in the appendix.
- Strain gauge circuits
  - Document the entire strain gauge circuit, including the bridge, diff amp and differentiator.
  - Is the output of the differentiator consistent with the measured strain and the circuit components used? Amplitude and phase?

Final Analysis and conclusions (11 points)

- Given the raw signals.
  - What was the peak acceleration of the beam?
  - What was the peak deflection?
  - If you assume the motion is a pure sin wave, are these traces consistent? Amplitude and phase? If not, speculate why not?
- Compare strain gauge and accelerometer measurement of velocity.
  - Is one better suited to determine the velocity? If so, why?
  - What is the peak velocity measured?
  - Do the calculated velocities have the same amplitudes and phases?
  - Explain.
- How could each measurement be improved? What are the errors associated with each measurement?
- State you conclusions on measurements of strain, acceleration and velocity, as they apply to the instrumented beam.
- Answer "additional questions" on page 6 of this document.
- Include references to relevant material in the appendix.
- Discuss any extra credit activities you did and why.

Personal Responsibilities (4 points)

- How were the tasks divided between group members?

Appendices (20 points)

- Many of the sections contain points for things included in the appendix.
- See Appendix II of this handout.

Extra Credit (0-5 points)

- Include any details that you would like to include about anything you tried above and beyond the basics of the project.

Your grade will also include a general assessment of project understanding and quality worth up to 10 points. You do not need to write a general assessment.

Total: 70 points for project report
+10 points general assessment
+20 points attendance
100 points

Attendance (20 possible points)
3 classes (20 points), 2 classes (10 points), 1 class (0 points)
Minus 5 for each late
No attendance at all = No grade for project