Lab 2a
Dynamic Response of a Mass-Spring System with Damping

OBJECTIVES

Warning: though the experiment has educational objectives (to study the dynamic characteristics, etc.), these should not be included in your report.

- To calibrate displacement and acceleration sensors.
- To measure displacement and acceleration of the system.
- To study the dynamic characteristics of a spring-mass-damper system.
- To perform uncertainty analysis of the measurement, including bias and precision errors for spring constant, natural frequency of the system

EQUIPMENT

Name	*Model*	*S/N*
Linear Potentiometer		
Vernier Accelerometer		
Power Supply		
Digital Multimeter		
Mass-Spring set		
DAQ NI USB-6009		
Vernier LabQuest DAQ		
Computer		

The dynamic response measurement workstation consists of a mass-spring system, one position sensor (linear potentiometer) and one acceleration sensor (Vernier accelerometer), with data acquisition system (DAQ NI USB-6009 and LabView 2013 software). In this experiment, you will calibrate the linear potentiometer and the accelerometer. You will then measure the dynamic response of the single degree of freedom (1 DOF) system with the calibrated sensors.
Note: This lab was designed to be completed in 2 lab sessions. Data processing may take 1 or 2 more sessions. Data processing should be performed as data is taken, to guarantee good results.

REQUIRED READING

Read reference [1] for principles of displacement and acceleration measurement, and reference [2] for theory of dynamic systems. Read reference [2] for an introduction to frequency analysis.

PRELAB QUESTIONS (10% of the total grade of the lab, 2% each)

a) Describe the principles used to measure displacement with linear potentiometer.
b) Describe the principles used to measure acceleration with accelerometer.
c) Describe how you could obtain spring constant of a given spring.
d) What is Coulomb damping?
e) Describe how to determine the frictional force of the Coulomb damping.

PROCEDURE

1. Write detailed explanation of how the different components of the experiment work. Be sure to include information about:
    - How to mount the sensors to the mass.
    - How to connect output of the sensors to the DAQ, i.e. which wires are the output of the sensor, which channel of the DAQ the wires should connect to.
    - What is sensitivity of the accelerometer?
2. LabView program (Lab 2a LabView) will be used to control the measurement of this experiment with the DAQ. You should be able to find the device NI USB-6229 in the Measurement & Automation of LabView in the Devices and Interfaces.

    Figure 1 in Appendix.A shows the front panel of the program. By pressing "Ctrl + e" you can switch between the front panel and the block diagram when open. *Note that the data saved in the specified file will be overwritten if the file name is not changed for each run of the program*. Explore the program to understand its functionalities before conducting the experiment. Note that you should click the "stop" in the front panel to stop the program instead of "abort execution" in the menu bar.

    Copy the program VI to the place of your preference such that you can play around with it without modifying the original. Use the copy for the whole experiment.

Calibration of position sensor

You will use micrometer, test stand, Digital Multimeter (DMM) to calibrate the displacement sensor (linear potentiometer). In your logbook, draw a diagram to explain how to connect the linear potentiometer to DMM, DAQ and power supply.

3. Check the operation range of the linear potentiometer. Do this with the potentiometer not mounted with mass and spring in the test stand.
    i. Measure the input resistance of the potentiometer (red and black wires). How well does this compare to the value marked on the barrel of the potentiometer?
    ii. Measure the output resistance of the potentiometer at its maximum and minimum ranges (white and black wires). When connected to the power supply, will the potentiometer output range from 0 to the maximum voltage?
4. Determine the calibration range. Mount the mass and spring to the test stand with the potentiometer attached (refer to Figure 2 in Appendix.A for the set up). Determine the range of the potentiometer that will traverse during the operation of the system, by displacing the system to the maximum and minimum positions that you anticipate during experiment, and measure the output resistances at these positions. Note the displacements and resistances in your logbook.

5. Power the bridge circuit (see voltage divider circuit discussion in your text [1]) of the potentiometer (red and black wires) with 5 V DC. Connect the sensor output (white and black wires) to the DMM and the DAQ. Take voltage measurements at five different settings to cover a displacement range that you determined at step 4. Record the readings of both the DMM and the DAQ. Repeat five times for increasing displacement (or, low to high voltage) and repeat five times for decreasing displacement (or, high to low voltage) to check for hysteresis. Establish a spreadsheet and calculate the average voltage for each displacement.

6. Use the data measured by the DAQ, plot the averaged voltage output versus displacement, and obtain a linear correlation between the averaged voltage output versus displacement, using a least squares technique (linear equation: $y = ax + b$). You will use this correlation to convert voltage to displacement.

Calibration of acceleration sensor

7. Record and note the Vernier accelerometer type and serial number.

8. Determine the zero-g voltage of the Vernier accelerometer. Expose the accelerometer to the Earth's gravitational field (i.e. do not apply any motion to the accelerometer) and connect its output to the DMM and DAQ. Record the readings of the voltage output of DMM and DAQ, note it as $V_{0\text{-g, DMM, Vernier}}$ and $V_{0\text{-g, DAQ, Vernier}}$. This will be the only calibration point for the Vernier accelerometers. Therefore, only this bias error will be considered for any uncertainty analysis.

Dynamic response measurement of spring-mass system

9. Determine the spring constant k using the equipment available to you in the lab. You will determine the spring constant k in [N/m] by measuring the displacement at various loading conditions. Best results are obtained using the linear potentiometer and loading the spring appropriately. Perform the measurement in such a way that you will be able to estimate the precision (accuracy and repeatability) of your measurements. For example, using three loads from the masses available, load the spring and measure the deflections from the DAQ output. Also, record the readings using a DMM for comparison.

10. Set up the dynamic response system as shown in Figure 2 of Appendix A. Mount the linear potentiometer and Vernier accelerometer to the mass-spring set such that the motion of the system can be measured accurately. Power the sensor with the appropriate excitation from power supply (linear potentiometer: 5 V DC). Connect the output signal of the sensors to the appropriate channels of the DAQ. Check the VI block diagram for the correct channel and device settings. Note connection information in your logbook.

11. Set the system into motion by displacing the system a known distance (initial displacement) and suddenly releasing. Record the data with the VI for analysis. Repeat the experiment with different initial displacements.

12. Use three mass loadings and repeat step 11 for the experiment.

Analysis

For calibration of position sensor:

13. Compare data from DMM and DAQ; discuss precision of the calibration measurements over the displacement range.
14. Discuss whether the data exhibits any hysteresis and discuss uncertainty of the linear fit. Uncertainty in the linear fit is discussed in Section 4.6 of the textbook.

For dynamic response measurement:

15. Read reference [3] for data reduction.
16. Discuss your observations of the measurements, including displacement and acceleration. Make one example plot of acceleration versus position using data from a particular mass loading. Comment on the position-acceleration relationship.
17. Based on an appropriate physical model, discuss the "apparent" damping of the system, e.g., Coulomb versus viscous damping. See pages 53-58 of reference [2] on the course website for the theoretical background. Assuming that the system is Coulomb damped, determine the frictional force for each loading.
18. For each loading and initial displacement, determine the measured natural frequency from the acquired data using DFT analysis (software to be downloaded from Lab 1a section of Laboratories page). Be sure to read reference [2] to understand the frequency analysis. If you need help, the TA or instructor will demo this in lab for you. Compare this natural frequency with the theoretical value (from spring constant and mass) and with the value obtained from the time history of the position data. Discuss your results and findings.
19. Determine and discuss uncertainties of your measurement. This includes all the necessary elemental error and propagation error for spring constant k, mass m, frictional force F_d (from step 17), natural frequency ω_n.

REFERENCES

[1] Figliola, R. S. and Beasley, D. E., *Theory and Design for Mechanical Measurements*, Fifth Ed., Wiley, 2011, pp504-506, pp509-515.

[2] L.D Chen, “Experimental Engineering Lecture Notes”, http://www.engineering.uiowa.edu/~expeng/lecture_notes/LD_Chen_Notes.pdf (1996), pp53-58.

[3] “Notes on Data Reduction for Lab 2a”, http://www.engineering.uiowa.edu/~expeng/laboratories/lab_references/Lab2a_data_reduction.pdf

[4] Li, Yuwei, “Introduction to Frequency Analysis for Experimental Engineering”, http://user.engineering.uiowa.edu/~expeng/laboratories/lab_resources/Frequency_Analysis_w_DFT_GUI.pdf

APPENDIX.A FIGURES

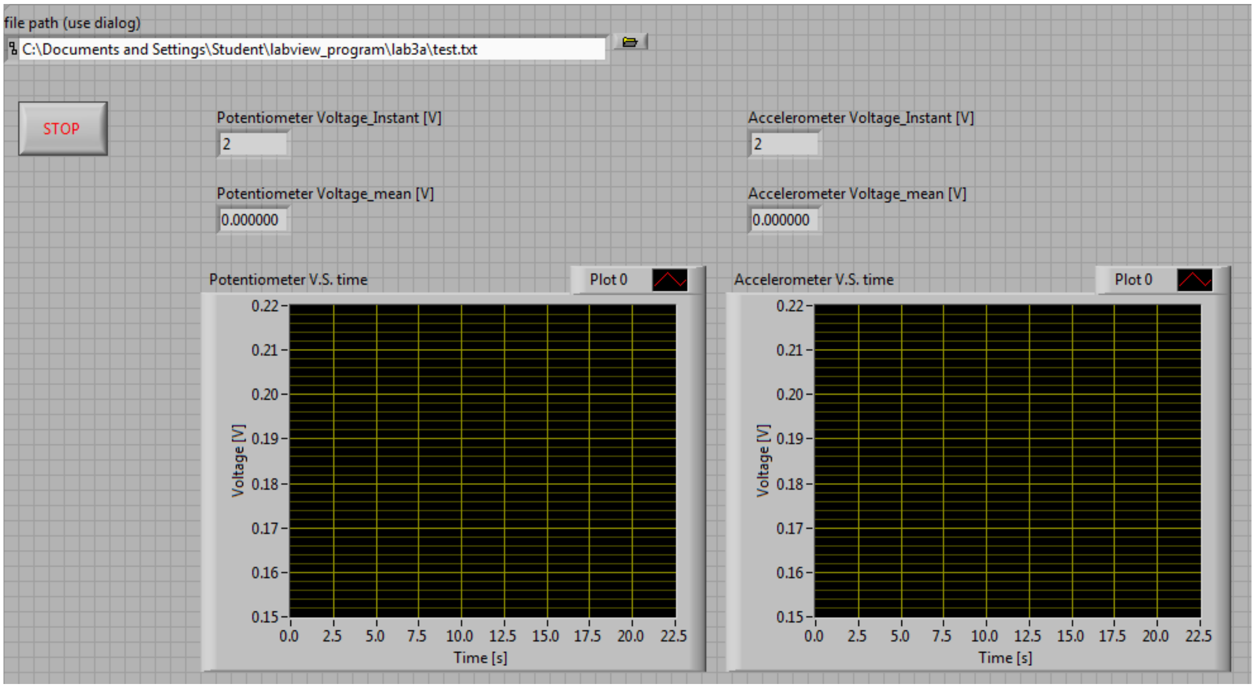

Figure 1: Screenshot of lab2a front panel

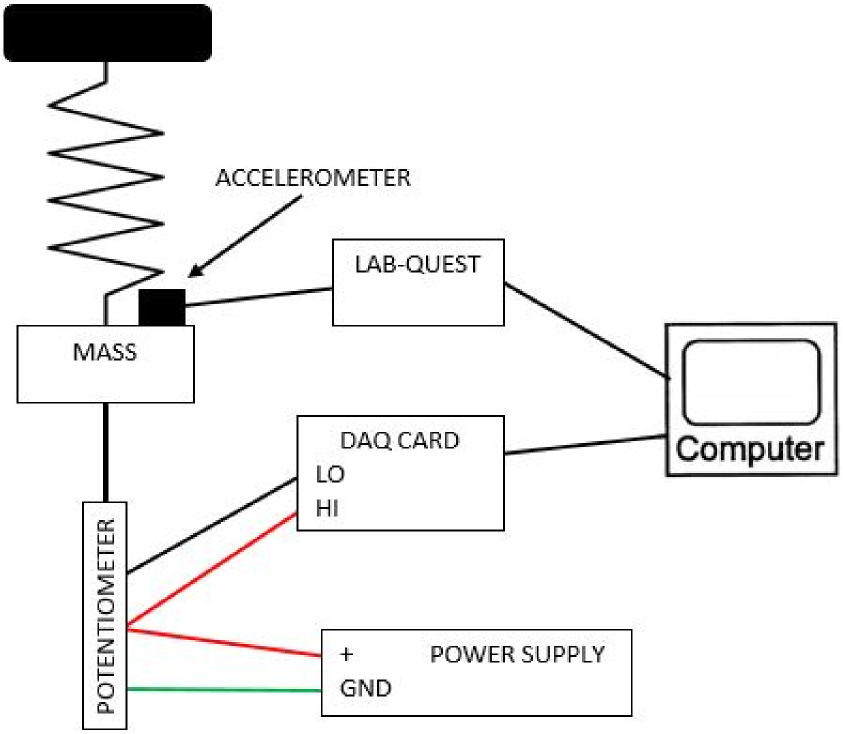

Figure 2: Vertically suspended spring-mass-damper system