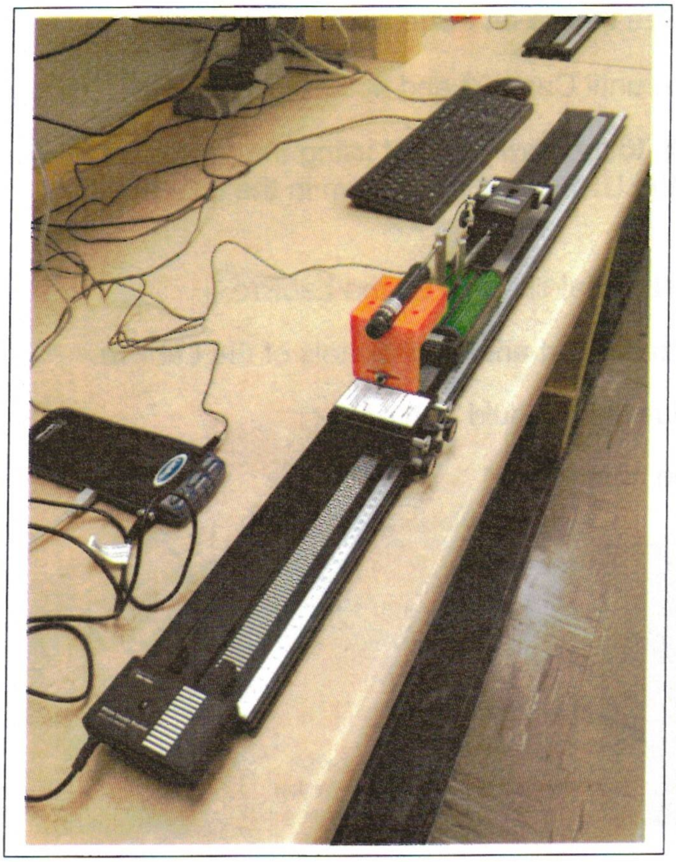
MAE 3724 Systems Analysis

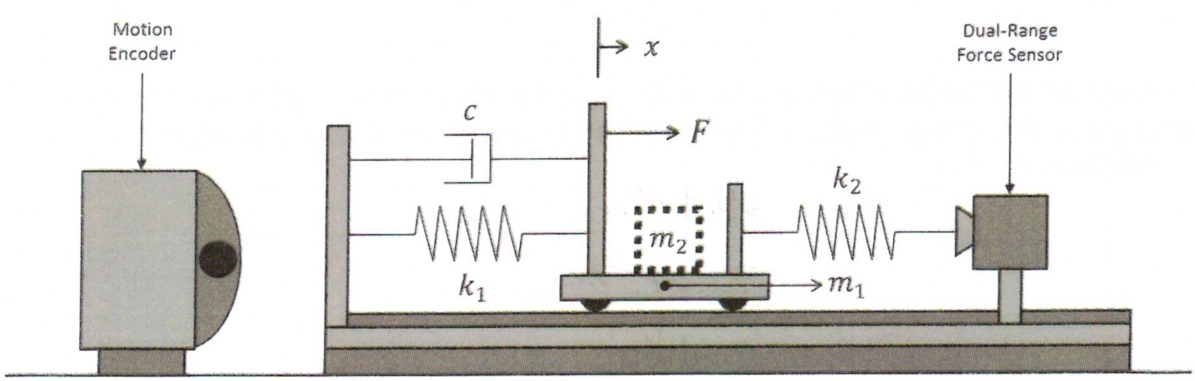
Laboratory Experiment 1
Free Response of a Second-Order Mechanical System



Objectives of the Experiment:

To have a hands-on experience. To see a real dynamic system in the laboratory and to compare the dynamic behavior of the system to that predicted from dynamic modeling and analysis. To become familiar with measurement methods and techniques for determining the experimental behavior of a dynamic system and for estimating values of parameters that are difficult to determine from first principles modeling.

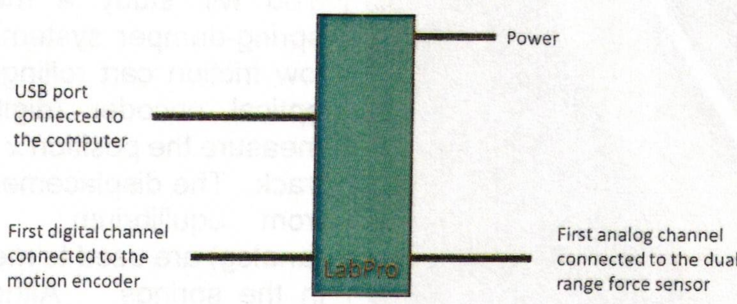
You will study a mechanical mass-spring-damper system, consisting of a low friction cart rolling on a track. An optical encoder (digital) is used to measure the position x of the cart on the track. The displacement x is measured from equilibrium. Force sensors (analog) are used to measure the forces in the springs. Although the cart is termed "low friction," damping still occurs during the movement of the cart on the track. All of this equipment is manufactured by Vernier. In Cases 3 and 4, you will add dampers manufactured by Airpot.



(*Note: In this experiment, you will be determining the <u>free response</u>, therefore* $F = 0$.)

Setup:

- Thoroughly clean the tracks the cart rolls on. Even small dust can cause increased friction. The tracks can be cleaned using the tissues provided.
- Place the cart on the track. Attach one end of spring k_2 to the dual range force sensor and the other end to the cart. Attached one end of spring k_1 to the cart and the other end to the fixed support. (See Figure on Page 1)
- Leave the Airpot damper disconnected until Cases 3 and 4.
- Plug the LabPro (blue-green device) in to the power outlet using the power cable, and connect it to the computer using the USB cable (as shown in the schematic below).
- Connect the motion encoder to the first digital channel on the LabPro.
- Connect the dual range force sensor to the first analog channels of the LabPro.
- Press the power button on the cart (blue light should turn on).
- Launch the Logger Pro program on the computer.**



** All of the equipment and software used in this experiment are made by Vernier. However, we are using an old version (still perfectly good) of the interface device, LabPro, and an up-to-date version of the software, Logger Pro.

The values for the respective masses and spring constants will be provided for the track assembly you are using. Record them here, so that you can easily reference them for your calculations later.

$k_1 =$ 65.4 N/m

$k_2 =$ 70.07 N/m

$m_1 =$ 0.61 Kg

$m_2 =$ 0.51 Kg

Procedures:

- On the menu bar in Logger Pro, under "Experiment", go to "Setup sensor" and choose "LabPro 1." In the new window, go to the digital channels "DIG/Sonic 1" and select the first channel. Under "Choose sensor," select "Linear position sensor." Then click on the channel again and click the "Zero" button. On the same window, go to the analog channels "CH1"; select the first channel. Under "Choose sensor," select "Force" and then select "Dual Range Force." Select the first channel again and click the "Zero" button. **The sensors have to be zeroed each time you make a measurement.**

- On Logger Pro, under "Experiment", go to "Data Collection." Change the "Duration" to 20 seconds and the "Sampling Rate" to 25 samples/second. Then click "Done."

Case 1 Experiment *(without the additional mass)*

1) With the additional mass (m_2) OFF the cart, click the "Collect" button (green button on Logger Pro), then push the cart 3 cm to the right, and then release the cart, wait until you see the data is being collected before you release. (Because we are using an old version of the LabPro interface and a new version of the LoggerPro software, the measurement of position in Logger Pro is scaled down. An actual 3cm displacement would show as 1.2 mm in Logger Pro.)

2) From Logger Pro copy the data for time and position into an Excel spreadsheet, name this sheet 'Case 1.' Copy the sinusoidal range of the data to Case 1 in the Excel sheet. Include at least 5 to 10 cycles (oscillations). Plot the data using Excel or MATLAB and determine the number of peaks, and the height of the first and last peak.

3) Interpret the force plots on Logger Pro. What do they tell you? **Have the Lab Assistant verify your answer.**

Case 2 Experiment *(with the additional mass m_2)*

4) Repeat procedures 1-2 (in Case 1) with the additional mass (m_2) ON the cart. Save your data on a new sheet named 'Case 2' in the same Excel spreadsheet. You will need these data for the Final Report.

Case 3 Experiment *(without the additional mass m_2, with the Airpot damper attached)*

5) Take the additional mass OFF the cart. Attach the Airpot Damper. Move the cart 3 cm to the left and observe the motion. Adjust the screw on the damper so that the motion is ***slightly underdamped***. Repeat procedure 1 (in Case 1). Save your data on the spreadsheet under a new sheet named 'Case 3.' You will need these data for the Final Report.

Case 4 Experiment *(without the additional mass m_2, with the Airpot damper attached and knob twisted)*

6) With the additional mass OFF the cart and the Airpot Damper still attached, turn the knob on the damper approximately two full turns in the counterclockwise direction from the position in Case 3 (opening the bleed orifice more). Repeat procedures 1 and 2 (in Case 1). Save your data on the spreadsheet under a new sheet named 'Case 4.' You will need these data for the Final Report.

Before you leave the laboratory, check to make sure data for all four cases have been saved. These data will be needed for the plots required in the Final Report.

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Spring 2019

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FINAL REPORT: (Each individual needs to submit a Final Report)

SHOW ALL YOUR WORK ON THIS AND THE FOLLOWING PAGES. Scan these pages and all requested plots and upload them into the Brightspace Dropbox for Lab 1

Case 1

1) *[2 pts]* Select a first peak, last peak, and number of peaks from the Excel data or MATLAB plot. Use the Logarithmic decrement method to estimate the damping ratio (ζ_1).

Note that at the end of the data, the value of the peaks may be in error due to the resolution of the sensor. It is OK cut off the data before the values become too small in order to avoid this issue, but make sure to still include about 10-15 peaks.

$x_1(1.8) = 0.9737$
$x_{n+1}(7.92) = 0.5077$
$n = 13$

$$\delta = \frac{1}{n} \ln\left(\frac{B_1}{B_{n+1}}\right) = 0.0434141$$

$$\zeta_1 = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} = 0.0069094$$

2) *[1 pt.]* Using Eq. 2.5.15 from the textbook, determine the damping coefficient (c_1).

$$c_1 = 2\zeta\sqrt{mk} = 0.12561$$

3) *[2 pts]* Using Equations 2.5.8 and 2.5.17 from the textbook, calculate the undamped (ω_{n1}) and damped (ω_{d1}) natural frequencies for this case.

$$\omega_{n1} = \sqrt{\frac{k}{m}} = 14.902$$

$$\omega_{d1} = \omega_{n1}\sqrt{1-\zeta^2} = 14.902$$

Case 2

4) *[2 pts]* Find the damping ratio for this case (ζ_2).

$X_1(5.32) = 1.227$

$X_{n+1}(14.2) = 0.50799$

$n=14$

$\delta = 0.06299$

$\zeta_2 = 0.010024$

5) *[1 pt.]* Determine the damping coefficient for this case (c_2).

$c_2 = 0.2469$

6) *[2 pts]* Determine the undamped (ω_{n2}) and damped (ω_{d2}) natural frequencies for this case.

$\omega_{n2} = 10.99$

$\omega_{d2} = 10.99$

7) *[2 pts]* How did the damping ratio change after adding m_2? Is that change consistent to the results of the PreLab? If so, why? If not, why not?

The damping ratio increased with the added mass, which is consistent with the PreLab.

Case 3

8) *[1 pt.]* State your observations.

The addition of a dampener reduced the number of oscillations and decreased the amplitudes.

Case 4

9) *[2 pts]* Estimate the damping ratio for this case (ζ_4). *(Hint: Because of the extra damping, it may not be possible to include more that 4-5 peaks.)*

$X_1(4.92) = 0.76199$ $\delta = 0.448$

$X_5(6.72) = 0.1264$ $\zeta_4 = 0.071$

$n = 4$

10) *[1 pt.]* Determine the damping coefficient for this case (c_4)

$c_4 = 1.293$

11) *[2 pts]* Determine the undamped (ω_{n4}) and damped (ω_{d4}) natural frequencies for this case.

$\omega_{n4} = 14.902$

$\omega_{d4} = 14.864$

Final Plots

Complete the following parts using the data saved on your Excel Sheet.

12) *[1 pt.]* Using the plotting tool in Excel or MATLAB, plot the complete range of the displacement vs. time response for Cases 1, 2, 3 and 4 all on the same plot. *(Make sure to include a legend).* You need not plot the force vs. time plots, but can do so for your own benefit if you wish.

13) *[1 pt.]* What are your conclusions about the damping ratios estimated in Cases 1, 2 and 4?

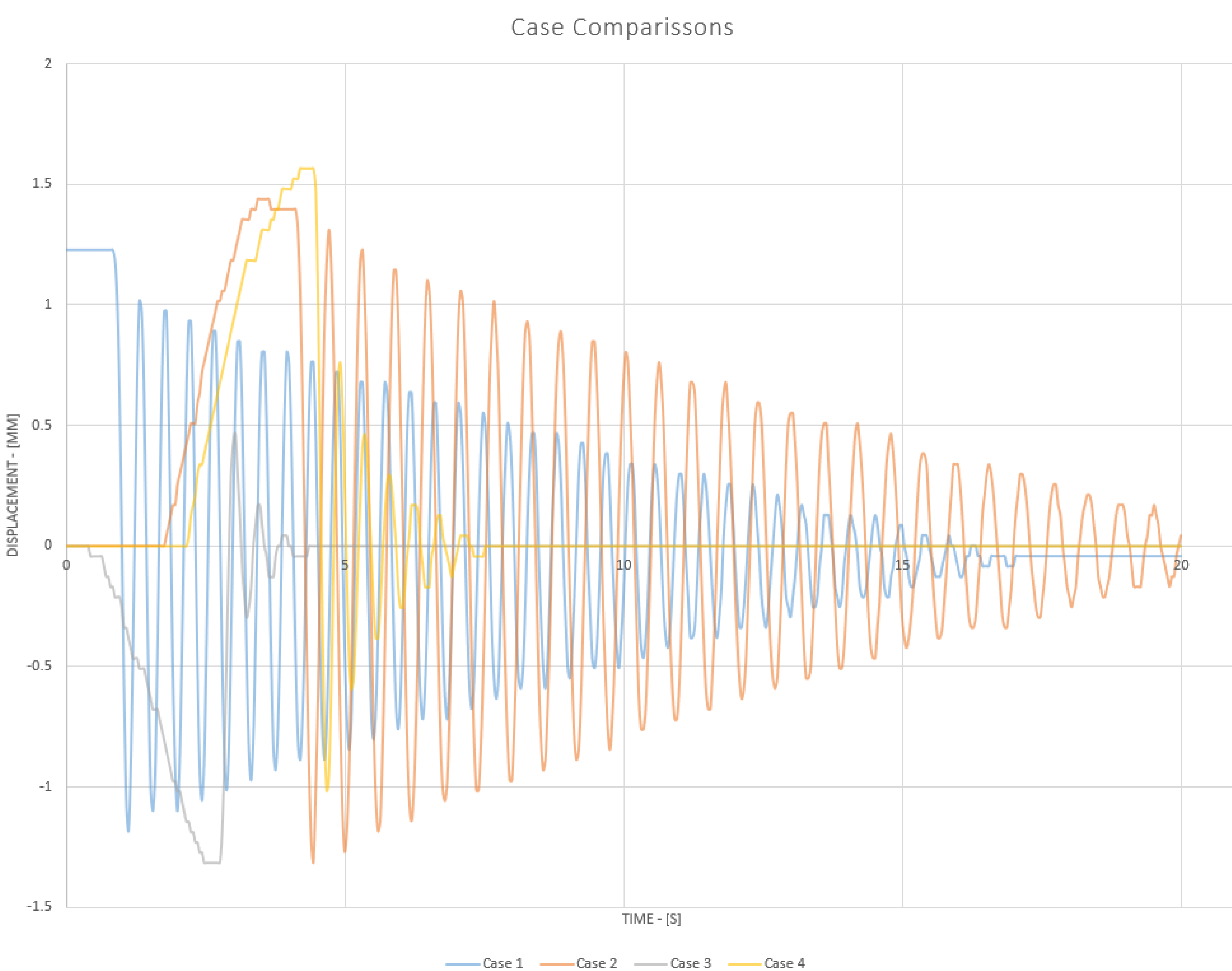
I conclude that the damponing ratios are consistent with what we have learned in class.

Final Evaluation (for feedback purposes only, will not affect grade)

1) What did you learn from this experiment?

2) What could we do to make the experience more beneficial?

3) Which parts of the instructions were confusing, if any? If so, explain?



Case Comparissons
DISPLACEMENT - [MM]
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
5
10
15
20
TIME - [S]
Case 1
Case 2
Case 3
Case 4