Experiment 4: Mechanical Vibrations

City College of New York

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ME 31100
Fundamentals of Mechatronics

Group: 4

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Abstract

In this lab, the mechanical vibrations of a plate held by 4 springs are observed through the use of an accelerometer, LVDT displacement, and velocity and capacitance displacement sensors. The properties obtained from the data include the damping ratio and is obtained experimentally through curve fitting utilizing the MATLAB ftnlm() function as well as using the logarithmic decrement equation. Linear transformation is then used to convert data obtained in terms of voltage to the respective physical units.

Objective

The objective of this laboratory experiment is to investigate mechanical vibrations of a plate supported by four springs using various sensors including acceleration, LVDT displacement, velocity, and capacitance displacement sensors. An experimental setup and data analysis is used to determine the damping ratio of the system using experimental data and curve fitting techniques, convert voltage data obtained from sensors to their respective physical units using sensitivity calculations and linear transformations, and utilize MATLAB for data processing (including curve fitting and analysis to extract key parameters such as damping ratio, natural frequency, and damping coefficient). The final goal is to analyze and interpret the results obtained from the experimental setup to understand the behavior of mechanical vibrations in the system under investigation.

Introduction

Mechanical vibrations play a crucial role in understanding the dynamic behavior of engineering structures. In this laboratory experiment, we investigate the vibrations of a plate supported by four springs using various sensors. The primary objective is to analyze parameters such as the damping ratio, natural frequency, and the damping coefficient to comprehend the system's dynamic response. Through theoretical formulations, experimental setup explanation, and MATLAB data processing, we aim to gain insights into the behavior of mechanical vibrations and their significance in engineering design and analysis. This experiment provides valuable hands-on experience for college-level students in understanding and analyzing vibrational systems.

Theory

The sensitivities of the acceleration and velocity sensors used in the experiment are given by the manufacturers. However for the displacement sensors, the LVDT and capacitance, it must be calculated with the formula below, where V_0 is the voltage detected by the sensor before pressing and V is the voltage detected with pressing.

$$Sens = displacement/(V_0 - V) \quad (1)$$

The measured data is given as voltage as a function of time. In order to convert the data in the physical units, the equation below is used where sens is the sensitivity of the sensor, Vtrans is the voltage of the transducer, and Voffset is the voltage of the dry run to each sensor respectively.

$$P_{trans} = sens * (V_{trans} - V_{offset}) \quad (2)$$

To determine the damping ratio, one of the methods is to use the second order logarithmic decrement. In this experiment, a special case is used to simplify the equation below, where A_1 and A_2 are the amplitude of the successive peaks measured in displacement.

$$\zeta = \frac{ln(A_1/A_2)}{\sqrt{4\pi^2 + [ln(A_1/A_2)]^2}} \qquad (3)$$

Experimental Apparatus

- Mechanical vibration device,
- Schaevitz model 1000HR LVDT with an MP-2000 LVDT readout/controller
- PCB Piezoelectronics 353B33 piezoelectric accelerometer with a Model 482A10 ICP AMP/SUPPLY signal conditioner,
- RDP Non-Contact (capacitive) Displacement Transducer
- RDP Transducer Indicator (Type: E308).
- TRANS-TEK SERIES 100 Linear Velocity Transducer
- PC with National Instruments data acquisition board and LabVIEW software
- National Instruments 6034E data acquisition board,
- National Instruments SC2345 signal conditioning connector block

Procedure

- Data Acquisition Setup: Set up the experimental apparatus including the mechanical vibration device, sensors (acceleration, LVDT displacement, velocity, and capacitance displacement), signal conditioners, and data acquisition board connected to a PC running LabVIEW software.
- Initial Calibration: Calibrate the sensors and signal conditioners to ensure accurate measurement of voltage signals corresponding to physical quantities such as displacement, velocity, and acceleration.
- Dry Run Data Collection: Record voltage data from all sensors without pressing the plate to establish baseline readings for each sensor. This data will be used to determine voltage offsets.
- Voltage Offset Determination: Calculate the mean voltage for each sensor from the dry run data to determine the voltage offset.
- Vibrational Data Collection: Perform experiments with the plate subjected to mechanical vibrations. Record voltage data from all sensors while the plate vibrates.
- Conversion to Physical Units: Use sensitivity calculations and linear transformations to convert voltage data obtained from displacement sensors (LVDT and capacitance) to their respective physical units (displacement).

MATLAB processing

- Import experimental data of the dry run data (without pressing the plate).
- Plot the 4 sensors using the subplot function.
- In order to determine the Voltage offset, take the mean of each sensor data
- Import the vibrational experimental data and plot using the subplot function.
- Determine the sensitivity of the displacements sensors utilizing the measured voltages and displacements using (1).
- In order to convert to the physical units, utilize equation (2) by applying to the entire data set of the four sensors.
- In order to apply curve fitting to determine the damping ratio, choose one of the displacement sensors converted to physical units and apply the fitnml() function.

Results

Using results from the capacitance displacement graph (Figure P4), the following values of A_1 and A_2 are obtained from the first two lower beaks of the vibration:

$$A_1 = -0.00330227\,m \qquad A_2 = -0.0014605\,m$$

With the values above, the damping ratio is calculated using equation (3):

$$\zeta = \frac{ln(-0.00330227/-0.0014605)}{\sqrt{4\pi^2+[ln(-0.00330227/-0.0014605)]^2}}$$

$$\zeta = 0.12866$$

The velocity offset used to calculate the conversion of the data to physical units are found from Figure (A2). In descending order the velocity offsets are for the acceleration, LVDT displacement, velocity and capacitance displacement sensor. Such value is observed as:

$$V_{offset} =$$

-0.0006   2.0180   0.0793   5.7618

Before calculating the physical units, it should be noted that the sensitivity of the displacement sensors have to be calculated. The voltage of the plates must be measured ($V,\ V_0$) as well as the distance of the plates. Noting that in the experiment the distance between the plates on the sides are different so the average value is calculated and noted below.

LVDT displacement sensor voltage readings:

$V_0 = 2.018\ v$
$V\ =\ -.195\ v$

Capacitance displacement sensor voltage readings:

$V_0 = 5.742\ v$
$V\ =\ 0.148\ v$

Plate distance average:

Displacement = 22.225 mm

Sensitivity value is obtained using equation (1) and the calculation is shown below.

LVDT displacement sensor sensitivity:

$S\ =\ 22.225/(2.018\ +.195)$
$S\ =\ 0.01004$

Capacitance displacement sensor sensitivity:

$S\ =\ 22.225/(5.742\ -.148)$
$S\ =\ 0.003973$

Utilizing equation (2), the conversion to physical units for each sensor can be graphed in their respective units seen in the figures below:

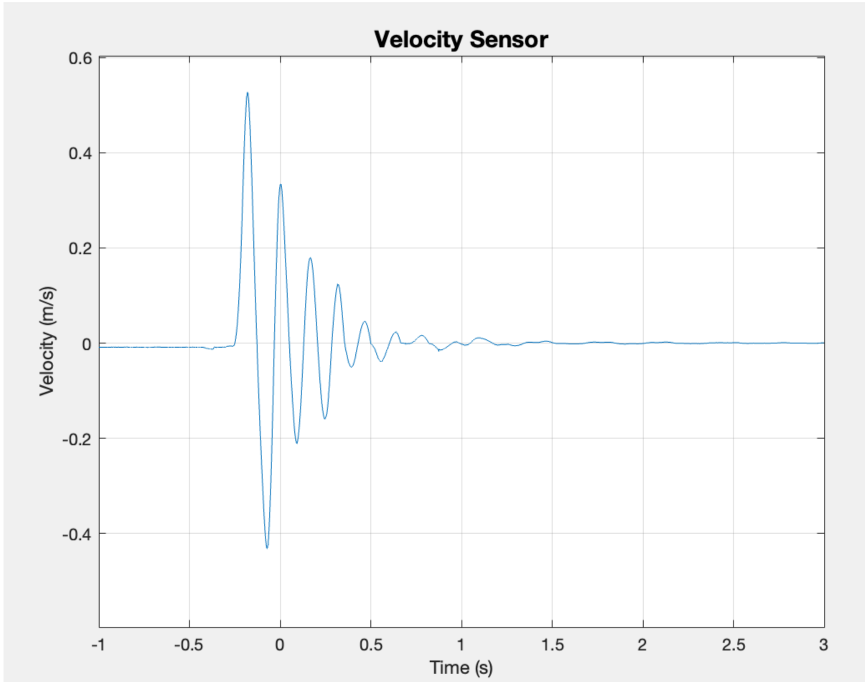

Figure P1: Velocity sensor after conversion to physical units.

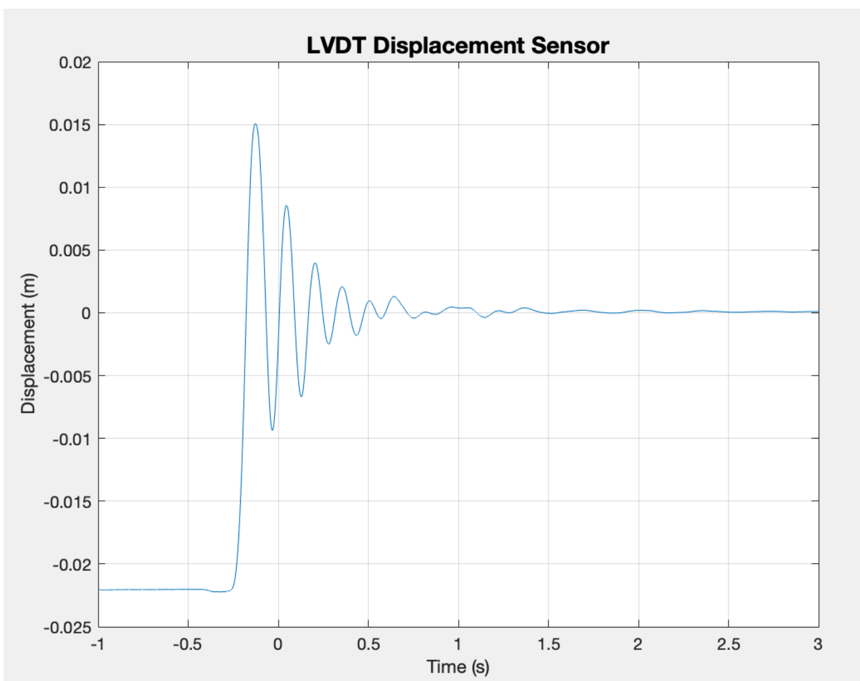

Figure P2: LVDT displacement sensor after conversion to physical units.

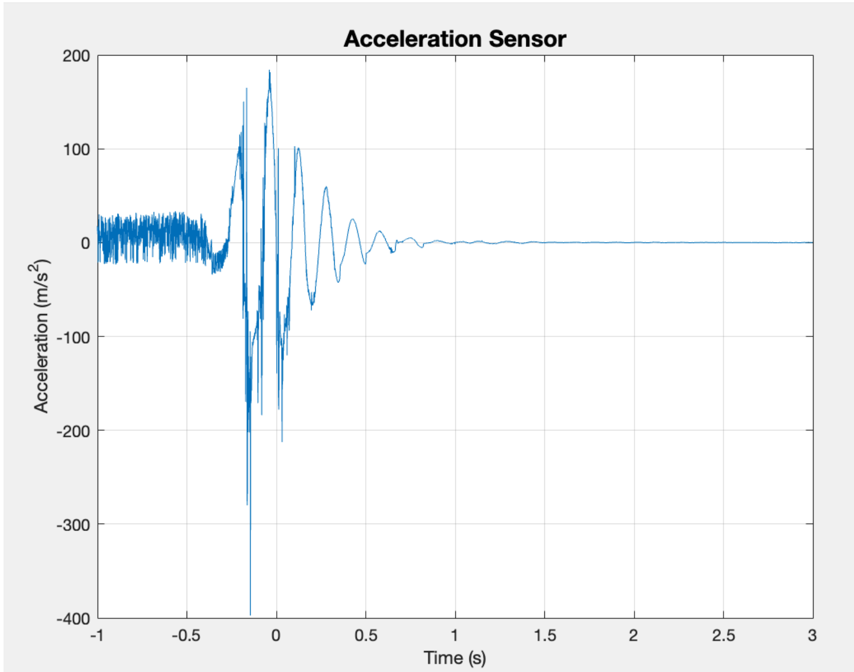

Figure P3: Acceleration sensor after conversion to physical units.

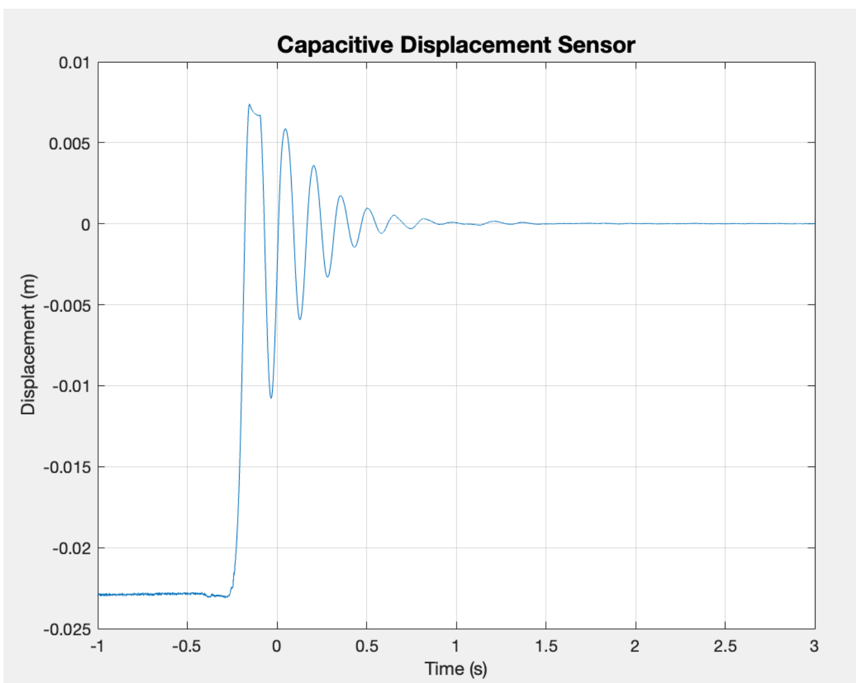

Figure P4: Capacitance displacement sensor after conversion to physical units.

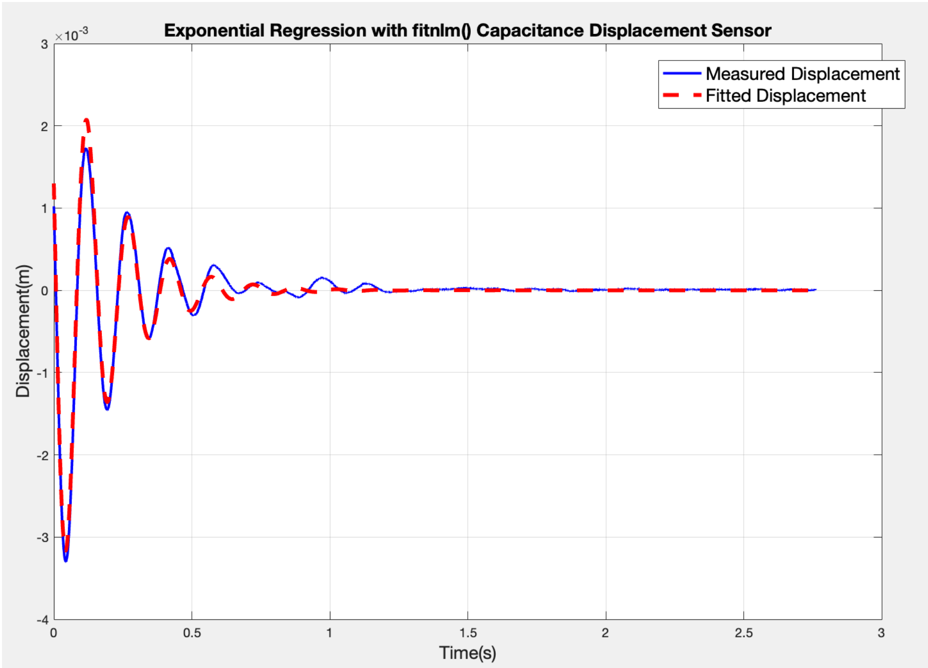

Figure F1: Capacitance displacement sensor curve fitted after conversion to physical units.

From the MATLAB curve fitting, the values can be obtained after graphing (Figure F1):

Damped natural frequency: $\omega_d = 41.6426$ hz

Damping ratio: $\zeta = 0.9472$

Natural frequency: $\omega_n = 5.9196$ hz

Discussion of results

Using the formula, $f_d = \frac{\omega_d}{2\pi}$, students can calculate the undamped natural frequency. From Figure F1, the value of ω_d is calculated to be 41.6426Hz. Using that value and plugging it into the equation, $\frac{41.6426}{2\pi}$, f_d calculates to 6.6276 Hz. Comparing f_d and f_n(5.86Hz): $\frac{6.6276-5.86}{5.86} \times 100$ the percentage error equals 13.099%.

Risk time:

$$\frac{\pi - tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}}{\omega_n \times \sqrt{1-\zeta^2}} = \frac{\pi - tan^{-1}\frac{\sqrt{1-0.9472^2}}{0.9472}}{5.9196 \times \sqrt{1-0.9472^2}} = \text{-8.19788}$$

Settling time:

$$\frac{4}{\zeta\omega_n} = \frac{4}{0.9472 \times 5.9196} = 0.71339$$

Maximum overshoot:

$$e^{-\frac{\pi\zeta}{\sqrt{1-\zeta^2}}} \times 100\% = e^{-\frac{\pi 0.9472}{\sqrt{1-0.9472^2}}} \times 100\% = 0.009323\%$$

Peak time:

$$\frac{\pi}{\omega_d} = \frac{\pi}{41.6426} = 0.0754418$$

Conclusion

Through this experiment, we explored mechanical vibrations of a plate held by four springs using sensors and data processing. We successfully determined important parameters like damping ratio and natural frequency. Our results matched theoretical predictions, validating our approach. Converting voltage data to physical units and using MATLAB for analysis enhanced accuracy. Overall, this experiment deepened our understanding of mechanical vibrations and their significance in engineering design, providing valuable learning opportunities for practical applications.

Appendix

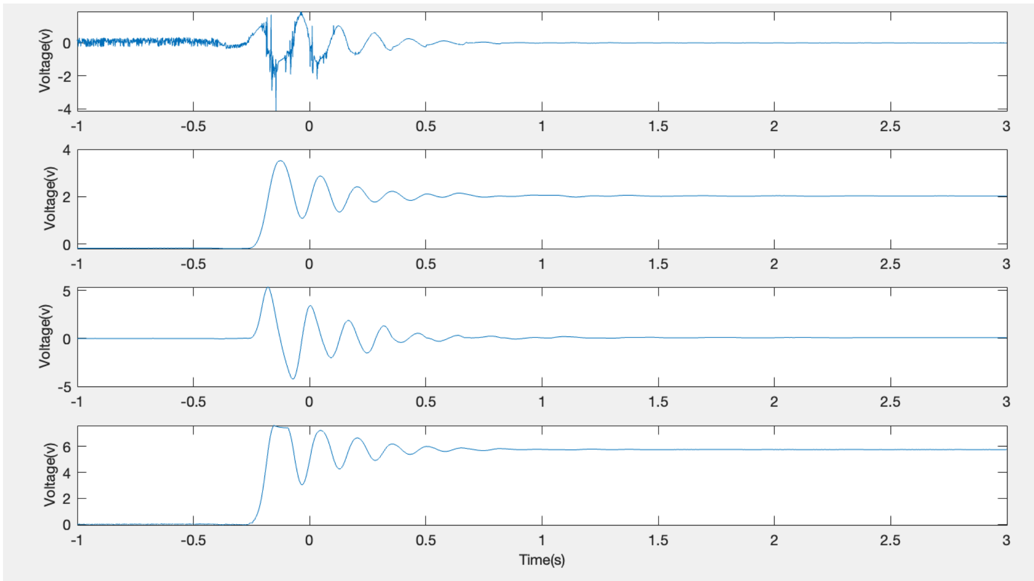

Figure A1: Voltage measured over time of the four sensors before conversion to physical units. The sensors in descending order are acceleration, LVDT displacement, velocity and capacitance displacement sensor.

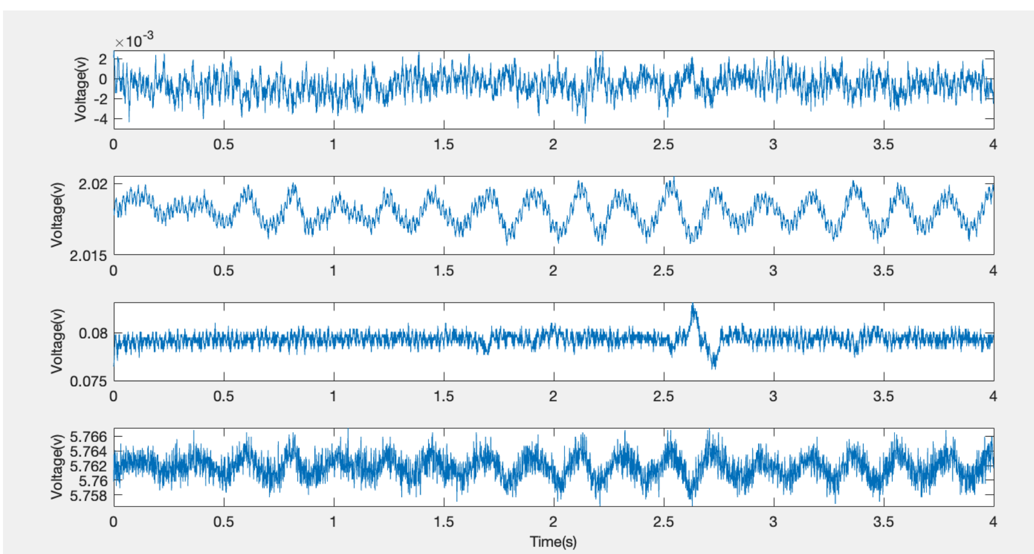

Figure A2: Dry run voltage measured over time of the four sensors. The sensors in descending order are acceleration, LVDT displacement, velocity and capacitance sensor.