Velocity and Position Sensors: LVT and LVDT Characterization, Parameter Identification

Lucas Simmonds & Charlie Nitschelm

Contents

[Objectives 3](#_Toc23332518)

[Executive Summary 3](#_Toc23332519)

[Linear Velocity Transducer 4](#_Toc23332520)

[Linear Variable Differential Transformer (LVDT) 8](#_Toc23332521)

[2.1 LVDT Characteristics 8](#_Toc23332522)

[2.2 LVDT System Calibration 10](#_Toc23332523)

[2.3 LVDT Frequency Response 13](#_Toc23332524)

[Conclusions 15](#_Toc23332525)

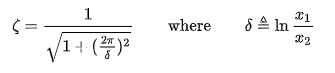
[Appendix 16](#_Toc23332526)

# Objectives

A Linear Velocity Transducer (LVT) and Linear Variable Differential Transformer (LVDT) were used to investigate the properties of a mass-spring-damper system by recording position and velocity respectively. The LVT measures voltage that corresponds to the velocity of a permanent magnet moving through a coil. The output LVT voltage is used to describe the motion of the mass and determine the system gain. The LVDT output voltage is recorded in the form of a sine wave that’s amplitude is proportional to the location of an iron core between primary and secondary coils. The LVDT output voltage was analyzed using a demodulator and low pass filter in order to retrieve a constant voltage value that was used in the system parameter identification.

# Executive Summary

When a mass of known value was dropped from a known height, an LVT was used to measure the velocity of the weight as it free fell onto a piece of foam. The voltage produced from the LVT could then be converted to a velocity (in/sec) with a sensitivity rating. Given the curve, the log decrement method could be utilized to get a damping ratio of the system by the equation



Once the damping ratio was calculated, the natural frequency could be calculated using

Where the damped natural frequency was calculated from analyzing the peak to peak times on the figure of velocity vs. time. The spring constant was then solved using the known force of the weigh due to gravity, and calculating the amount the weight was compressed into the foam at steady state. This was done by using the position vs. time graph, picking out the steady state position at the end, and subtracting that value from the known falling distance. So, the final equation used to find the spring constant of the foam was

The final values are listed below and explained more thoroughly in the main report.

|  |  |  |
| --- | --- | --- |
| Spring Constant, K | Damping Ratio, | Damped Natural Frequency, |
| 2.59 | 0.0392 | 43.41 |

The second study was using an LVDT to measure position, its characteristics, calibrating it, and its overall frequency response. Measuring the raw data from the LVDT and obtaining the sensitivities of the device measuring distance and its respective weight for each, a curve of position vs. time could be produced, enabling the calculation of the systems damped natural frequency. As from above, the log decrement method was again used to calculate the damping ratio of the system and its overall natural frequency.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Beam Spring Constant K (lbf/in) | Natural Frequency, | Damping Ratio, | Damped Natural Frequency, | Effective System Mass (lbm) |
| 0.125 | 161.98 | 0.0036 | 160.98 | 0.05 |

The effective mass was calculated using the fundamental equation relating the natural frequency and the spring constant by the equation

The frequency response of the LVDT was also analyzed, allowing the calculation of key features of the system. The break frequencies were estimated from plotting the theoretical bode plot using the given data from the test. Then, using the equation

Where R was given from knowing the circuit of the system, we could calculate the inductances Lp and L0. The system sensitivity, Ks, was calculated given the known value, and using that sensitivity, we could find the overall system gain with the equation

|  |  |  |  |
| --- | --- | --- | --- |
| Break frequencies [Hz] | Inductance Lp,L0 [H] | Theoretical Sensitivity [] | System Gain [] |
| 295 and 22070 | .220,3.61 | .0744 | 151.8 |

Linear Velocity Transducer

**a.) Plot of LVT output voltage vs. time curve**

A close up of a map

Description automatically generated

**b.) Describe motion of the mass**

Using the LVT Voltage vs. Time figure the mass is in free fall when the voltage is decreasing. It appears from the figure that every time the mass is in free fall it moves at the same rate. That is, the slope of the decreasing voltage is similar each time the mass free falls. This is because the slope of an LVT voltage vs. time curve represents the acceleration, and at free fall, the object has the same acceleration from Earth. From the figure it is shown that the initial impact is sudden, and there is not a lot of bouncing. When the mass bounces off the foam, it creates ripples in the troughs of the voltage data. As the mass continues to bounce, the foam overtakes earths pull force, creating the slope to turn positive, bringing it back above equilibrium, starting the free fall cycle again until the overall systems energy dampens and settles into its steady state.

**c.) Describe physical significance of the first three zero crossings of the LVT output voltage and the first minimum and maximum voltage points.**

The first minimum and maximum voltage points represent the points where the mass meets the foam and where it reaches the maximum height when bouncing off the foam, respectively. This is because as the mass falls towards the foam it gains velocity until it meets the foam after some time so that it offers a larger spring force then the force of gravity. Then it begins to slow down until it stops at the first zero crossing. Then it is bounced upwards and gains velocity until it reaches a maximum velocity and then begins to slow down once the force of the foam becomes less than its weight. The first three zero crossings represent the times where the mass has either meet the foam and fully depressed the foam or the mass has reached its maximum height after being bounced off the foam, i.e. having zero velocity with respect to the system.

**d.) According to your free response curve, at approximately what time does the mass stop bouncing off the foam and remain in contact with the foam?**

According to the free response curve, the mass stops bouncing at approximately 1.181s. This can be seen in the figure below.

A close up of a map

Description automatically generated

**e.) From the initial slope of the curve, given that the acceleration due to gravity is 386 in/s2, determine the sensitivity of the LVT, , volts/(in/sec).**

From the initial slope of the curve the sensitivity was calculated to be -0.116 .

**f.) Using the LVT output, and its sensitivity, make a plot of the core velocity (in/sec) and position (in) vs. time**

The figure below shows a plot of the core velocity vs. time

A close up of a map

Description automatically generated

The figure below shows a plot of the core position vs. time

A close up of text on a white background

Description automatically generated

**g.) Determine the following parameters for the foam-mass system: i.) damping ratio ii.) damped natural frequency iii.) spring constant k**

The spring constant, damping ratio and damped natural frequency can be found in the table below.

|  |  |  |
| --- | --- | --- |
| Spring Constant, K | Damping Ratio, | Damped Natural Frequency, |
| 2.59 | 0.0392 | 43.41 |

**h.) What is the average force of impact on the foam when the shaft just hits the foam for the first time?**

The average force of impact on the foam when the shaft just hits the foam for the first time is .06 lbf. This calculation stems from finding the position where the start of the foam surface occurs, finding that velocity of the mass, and use the damper coefficient of the foam to calculate the initial force as there is no spring force at x=0 into the foam.

# Linear Variable Differential Transformer (LVDT)

## 2.1 LVDT Characteristics

**a.) Plot and describe the output of coil 1 and coil 2 as the displacement of the core varies**

Inside the LVDT is an iron core that passes through 2 coils. The coils are winded in opposite directions, i.e. one is winded clock-wise and one is winded counter clock-wise. The position of the iron core is directly proportional to the output amplitude of each coil. When the magnetic core passes through one coil it causes the output signal amplitude of that coil to increase while the other decreases. This can be seen below in the figure. When the core is in a neutral position the output amplitudes of both signals are equal. However, when the core moves above the neutral position the output amplitude of coil 2 increases and the output amplitude of coil 1 decreases.

**A picture containing text, map

Description automatically generated**

**b.) Plot and describe your observations of the output voltage after amplitude demodulation, but not before the filter.**

The output signal of the demodulation circuit can be seen below. The demodulation signal takes both output signals from the two coils and then sums them. The figure below shows the output signal when the iron core is lifted above the null. The demodulation circuit sums both signals together.

**A close up of a logo

Description automatically generated**

**c.) Plot and describe your observations of the output signal with the filter.**

The low pass filter attenuates high frequencies from the demodulator output. This effect can be seen in the figure below. The output signal from the low pass filter is the average of the demodulator signal.

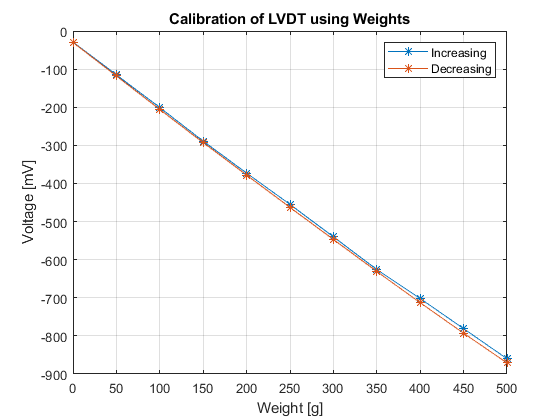
A close up of text on a white background

Description automatically generated

## 2.2 LVDT System Calibration

**a.) Plot LVDT output voltage vs. weight. Plot LVDT output voltage vs. displacement. Comment on the linearity of the curves and the range of linearity of the LVDT.**

The figure below shows the LVDT calibration using weights.



The figure below shows the LVDT calibration using a micrometer to displace the LVDT core.

A screenshot of a cell phone

Description automatically generated

From these two figures there is linear relationship for weight and output voltage of the LVDT for a range of 0 to 500 grams. From the second figure there is a linear relationship between voltage and distance for a range of 0 to 0.3 inches. This is consistent on what was expected from the LVDT device.

**b.) Determine the beam spring constant k**

The beam spring constant was determined to be 0.125 .

**c.) Determine the LVDT system sensitivity in V/in.**

The system sensitivity was calculated to be .

**d.) Find the damping ratio, the damped natural frequency, and the undamped natural frequency of the first mode of vibration.**

|  |  |  |
| --- | --- | --- |
| Natural Frequency, | Damping Ratio, | Damped Natural Frequency, |
| 161.98 | 0.0036 | 161.98 |

**e.) Find the effective mass of the system.**

The effective mass of the system was calculated to be .05 lbm

**f.) Bode plot of first order filter and how does it affect the LVDT output for the given system**

**A close up of a map

Description automatically generated**

From the bode plot, this is a low pass filter, enabling smaller frequencies to be along the flat band, but dropping off once it hits the break frequency. This does have an overall effect on the output of the system as it begins to not pick up the higher frequency signals during data collection. As the weights were all measured by steady state, those frequencies are very small, so a low pass filter is preferred to ensure the data being read is under the appropriate band/flat magnitude region.

## LVDT Frequency Response

**a.) Use the experimental Bode plot to find the two break frequencies.**

The first break frequency is approximately 295 Hz and the second break frequency are approximately 22.07 kHz.

A close up of a map

Description automatically generated

**b.) Using the break frequencies from a) and the transfer function, find the inductances Lp and L0. What is the bandwidth of the LVDT based on your experimental Bode plot.**

The inductance of inductor Lp was calculated to be 220 mH and the inductance of inductor L0 was calculated to be 3.61 H.

**c.) For the flat portion of the Bode plot, what is the theoretical sensitivity of the LVDT? Using this expression and your experimental Bode plot, if x= 0.1 in find the gain term Km.**

The theoretical sensitivity Ks is equal to 0.0744 and the gain term Km is equal to 151.8.

**d.) Use MATLAB to make a theoretical Bode plot using the transfer function derived from the homework problem, and the values of Lp, L0, and Km found in parts b.) and c.). Assume x = 0.1in**

**A close up of a map

Description automatically generated**

**e.) Compare the experimental and theoretical frequency responses.**

The theoretical bode and experimental bode plots both show very similar bandwidths. The difference between the experimental bode plot and the theoretical bode plot is that at higher frequencies on the experimental bode plot there is some amplitude gain and the phase increases to 360 degrees. This is different from the theoretical bode plot where the gain decreases at higher frequencies and then phase shift falls to -90 degrees.

**f.) Filtering can cause problems in accuracy of the output signal when the core is moving. Why or why not?**

This statement is conditionally true. If measurements are being taken while in the bandwidth the measurements are accurate. If you are not operating within the bandwidth the system dynamics are harder to understand because the gain and phase shift change drastically at higher frequencies.

**g.) Discuss the effect of lowering the excitation frequency to the LVDT. Use the Bode plots to draw conclusions.**

The excitation frequency in this lab was set at 2.5kHz which falls within the two break frequencies of 295 Hz and 22.07 kHz. If the excitation frequency were lowered it would be crucial until it fell below the break frequency of 295 Hz. Under that frequency there is not a constant amplitude ratio relationship meaning that the values you are reading do not convert to data with a constant gain.

# Conclusions

Lucas Simmonds

Charlie Nitschelm

The two primary sensors used in this study was a Linear Velocity Transducer (LVT) and a Linear Variable Differential Transformer (LVDT). The LVT drop mass test enabled us to produce position and velocity vs. time figures of the system and analyze core characteristics of the system. It was found that with the data and knowing the geometry of the system before mass release, forces, time of significant events, and the spring and damping coefficients of the foam could be found analytically, enabling the concept of measuring certain system responses to calculate many others. The LVDT, measuring position, was calibrated and from that raw data, relationships for force given to the system and its voltage could be utilized to calculate, again, core system characteristics including the beam spring constant and the systems natural frequency. A frequency response was also produced allowing calculation on the system inductance, its apparent break frequencies and its clear ‘usable’ bandwidth range for collecting system data. Appendix