Executive Summary

In part 1, the parameters of the linear velocity transducer (LVT) were investigated and calculated. It was discovered that the LVT’s output (velocity) had a linear slope (acceleration) during the first 3 cycles, suggesting the mass went through free fall 3 times before it remained on the foam. The velocity profile and integrated displacement profile together showed the mass had maximum displacement and zero velocity at the lowest positions in the cycle; the mass also had maximum velocity and zero displacement when the mass reached the damped starting heights and upon impact with the foam. The sensitivity of the LVT was found by linearly fitting the free fall to find the slopes and compare to the expected gravitation acceleration and it was found to be 0.1224 V / (in/s). The following system parameters were calculated from the results: the damping ratio was found to be 0.113, the damped natural frequency to be 77.3 rad/s, the undamped natural frequency was found to be 77.8 rad/s, the spring constant was found to be 2.588 lbf/(in), and the damping coefficient was found to be 0.09 lbf/(ft/s). The spring constant and damping coefficient are found from the second order response portion of the output. The average damping force was found to be proportional to the velocity upon impact with the foam with the highest average damping force to be 0.223 lbf at 29.6 ft/s. The values are negative indicating the mass was falling downwards.

In part 2, the parameters of the linear variable differential transformer (LVDT) were investigated and calculated. It was discovered that for this E500 series Measurement Specialties LVDT, coil 1 generated more voltage when the beam is deflected downwards and coil 2 generated more voltage when the beam is deflected upwards. The total amount of voltage generated between the two coils seemed to remain constant as the voltage output seemed to be the same when the beam is not deflected. After the low-pass filter filtered out the noise in the signals, it was clear that the LVDT generated a positive voltage when the beam was deflected upwards, a negative voltage when the beam was deflected downwards, and, as expected, generated approximately zero volts when the beam was not deflected. The low-pass filter RC circuit had a break frequency of 213 rad/s suggesting the noise in the system had frequencies above the 213 rad/s. Furthermore, the LVDT’s responses to controlled loads and controlled deflections were measured. The results showed the output voltage and the input conditions had a highly linear correlation with coefficient of determination, R2, values of 0.9991 and 1.0 respectively for loads and deflections. This linearity is expected to hold true when the input signal frequency is within the bandwidth of the LVDT and the low-pass filter. Relating the loads to the deflections directly yielded the spring constant of the system to be 166.5 lbf/in. The same process also yielded the sensitivity of the LVDT to deflection to be 2.96 V/in. The damping ratio of the system was found to be .005, the natural frequency was found to be 191.5 rad/s, and the effective mass of the system was calculated to be 0.0045 g. Since the low-pass filter had a break frequency of around 200 rad/s, it would just barely not affect the output of the LVDT which was operating at 192 rad/s. Finally, the LVDT’s break frequencies were found to be 308 Hz and 47.5 kHz. Since the beam’s frequency was much lower than the LVDT’s operational bandwidth, the output was modulated by a carrier frequency at 2.5 kHz in order to be inside the flat region.

Jesse’s Conclusion:

The LVT outputs and the integrated results told the complete story of the mass’s movement. The first three zero crossings of the mass on the velocity profile were when the mass reached the minimum positions (maximum potential energy and zero kinetic energy), when the mass reached the damped starting height (maximum gravitational potential energy and zero kinetic energy), as well as when the mass reached the damped minimum position again. The zero crossings on the positive slopes corresponded to decreasing heights and indicated the loss of energy during motion from air friction and impact with the foam due to damping. After only three cycles, the mass lost too much energy to bounce off the foam and began its second order frequency response inside the foam until it lost almost all of its initial potential energy to reach steady state. The outputs were reasonable and matched the expectations well.

The LVDT outputs showed the LVDT’s coil 1 is closer to the magnetic core than coil 2 when the beam is deflected downwards and vice versa. The overall total voltage output between the two coils remained constant as the null position showed two coils output the same velocity and the deflected positions showed the two coils change amplitude by approximately the same amount. The natural frequency of the beam was at 191 rad/s, which was much lower than the bandwidth of the LVDT (between 1937 rad/s and 297,357 rad/s). This was why the outputs were initially modulated by a carrier signal at 2.5 kHz. The outputs were then demodulated and filtered to produce a steady signal showing the LVDT would generate positive output when the beam was deflected upwards and negative when it was deflected downwards. The low-pass filter filtered out the 2.5 kHz high frequency signals and returned the 191 rad/s low frequency signal of the beam. However, when the core is moving, it could generate higher or lower frequencies due to transient responses and lead to additional noise in the outputs.