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DEVELOPMENT OF A HARDWARE/SOFTWARE FILTERING SYSTEM FOR DISPLACEMENT/ACCELERATION RESPONSE OF A 2ND ORDER DYNAMIC SYSTEM

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Abstract

The numerical processing (integration/differentiation) of measured displacement and acceleration data can often be plagued with a variety of measurement problems. Drift, bias, offset, electrical noise and random effects can wreck havoc on the processing of data. In order to minimize these effects, a variety of different filtering schemes can be employed.

A student-designed measurement system that integrates the salient features of first order filtering systems is used to extend the student's knowledge on filtering. The students design hardware and software modules to provide filtering to minimize effects that distort the numerical integration/differentiation of the measured signals. Example signals are filtered using analog hardware filtering as well as MATLAB and Labview software tools with graphical user interface to assist in the fine tuning of the filter characteristics.

I. Introduction

Students do not always understand the need for basic STEM (Science, Technology, Engineering, Mathematics) material that is critical to the solution of engineering problems. While this is true in many of their engineering courses, this lack of "feeling comfortable" with the STEM material is seriously highlighted especially when physical measurements are made and interpretation of results is needed.

Students learn best with hands-on projects and problems with practical purpose [1]. Laboratory based, experimental problems are very good for demonstrating many aspects of engineering problem solving. Unfortunately, many laboratory environments are set up as “exercises” which typically have very clear, predetermined outcomes. This is done to reinforce lecture material that is presented in related courses [2]. The students are exposed to “canned” lab experiments and therefore, the laboratory becomes fairly well-defined and moderately deterministic. This forces the results to follow a fairly well-defined path. Experiments of this type are very good for demonstrating basic inherent skills that the students need to know.

However, this does not exploit the laboratory experience to its fullest. Engineering problems rarely follow a cookbook approach. Students must be afforded the experience of problems that require them to formulate solutions to problems with no specific straight-line structure to the solution – they must learn how to “think outside the box” [3]. Laboratory measurements pose the perfect opportunity for students to address “real problems” that do not follow a prescribed chapter in a text. They must bring to the problem all of their STEM skills to interrogate, decipher and analyze the phenomena observed in the laboratory measurement. Thus the laboratory environment becomes an excellent place for students to “think on their own” since there definitiely is “no answer at the back of the book”. While this is at times very frustrating to the students, they quickly learn that these are the problems they need to face as they transition from education to the workplace.

Experiments play a very critical role in validating analytical models and hypotheses. Students must feel comfortable in a laboratory environment and must not feel foreign to lab equipment, instrumentation, etc. Students must also feel comfortable formulating solutions to real engineering problems using all of the STEM tools available to them. The STEM must become an integral part of their learning process throughout their entire educational and professional careers – the students must, in essence, “live the material” every day and in every course.

In the Mechanical Engineering Department at UMASS Lowell, the laboratory courses are taught in a two semester sequence. The first semester concentrates mainly on basic measurement tools (oscilloscopes, multimeters, digital data acquisition, etc), measuring devices (flow meters, manometers, pressure transducers/gages, pitot tubes, strain gages, thermocouples, accelerometers, LVDTs, etc) and methods for data collection/reduction (regression analysis, curvefitting, numerical processing). The first semester has many different labs which, in general, are intended to get the students exposed to the overall mechanical measurement world. However, there are a few labs which are intended to force the students to work through several difficult issues. The second semester is split into two halves. The first half continues the more structured lab environment but introduces more complicated labs and concepts including fourier domain processing techniques with FFT analyzers. The second half of the semester concentrates on the student development of a measurement system given only vague specification of the overall measurement requirements or problem to be addressed. The student must formulate a measurement system to achieve the require goals. This paper addresses one of the student projects during the second semester laboratory sequence.

One of the earlier laboratory exercises addresses the measurement of a second order mass, spring, dashpot system with the use of an LVDT (linear variable differential transformer) and an accelerometer to measure displacement and acceleration, respectively. Unfortunately, both signals are contaminated with noise, drift, bias and other uncontrollable factors which cause significant difficulty in processing the data. The students are required to integrate and differentiate the signals. Due to contamination of the signals, the resulting processed data has many irregularities that cause the students difficulty [4].

In order to alleviate this problem, the students are required to design both a hardware and software filtering system to properly treat the contaminated data observed during the earlier lab. Simple RC filtering circuits are designed to filter the drift, bias, offset and other effects observed on the signal. The raw signal is also processed using software filters designed in both Lablab/Simulink and Labview using the same RC filtering circuits designed.

II Numerical Evaluation of a Simple Single DOF MCK System

While most of the projects in the Mechanical Engineering Laboratory course involve specific, well-contained technical issues, there is one laboratory exercise which involves the majority of the topics addressed during the course of the semester. The numerical evaluation of a simple single degree of freedom (DOF) mass-spring-dashpot (MCK) system using acceleration and displacement measurements requires calibration, digital data acquisition and numerical processing of the data to compare the acceleration to the displacement data and compare the displacement to the measured acceleration data. The project involves multiple transducers, calibration, digital data acquisition, data cleansing, and numerical processing of the data. The specific lab addresses the displacement and acceleration response of a simple single DOF system using a noisy LVDT measuring device, a poorly selected accelerometer with drift, bias, sensitivity issues and a digital data acquisition system with poor accuracy which lacks sufficient features to adequately perform a decent measurement. The worst possible situation is used for the measurement (students can not appreciate the need for a "good" measurement system if they have never been exposed to a "poor" measurement system). The laboratory measurement exercise poses many problems. The simple MCK system is shown in Figure 1.

The intent of the second semester laboratory project is to design a hardware and software filtering system to minimize the contamination of the measured signals. The students have already been exposed to the significant distortion that results when the raw data is processed numerically using integration and differentiation techniques. It is very clear to the students that the data must be cleansed prior to any numerical processing. The following sections describe the approaches taken to filter the raw data from both a hardware and software approach.

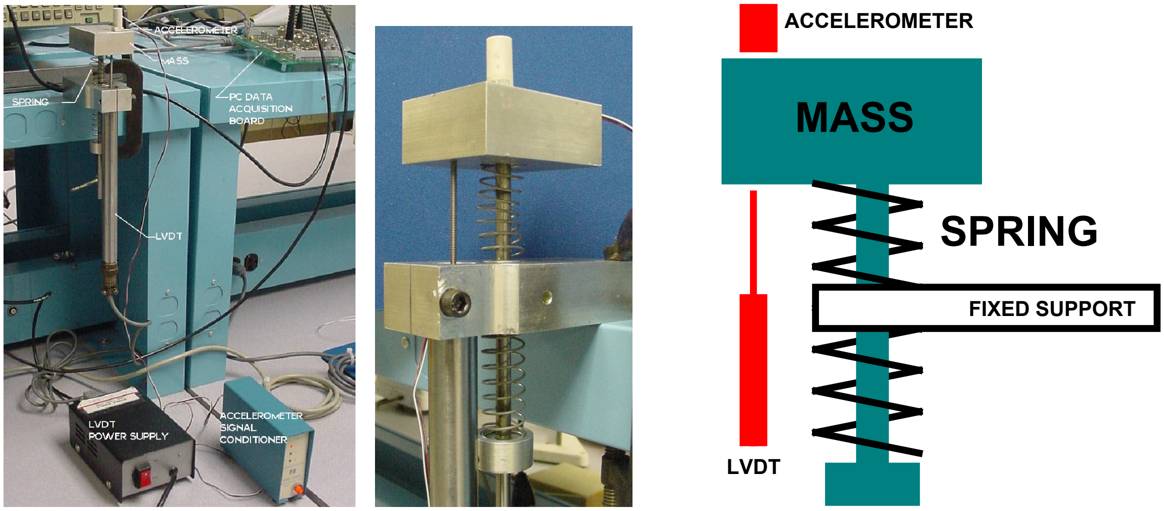


Figure 1 – Photo of MCK System along with Schematic of Configuration

II.1 Original Raw Data Integration and Differentiation

In order to understand the need for filtering of the signals, the raw data of the accelerometer and LVDT are integrated and differentiated, respectively so that each of the signals can be compared to each other. The displacement data obtained from the LVDT and the integrated accelerometer data is shown in Figure 2. The acceleration data obtained for the accelerometer and from the differentiated LVDT is shown in Figure 3.

From these two figures, it is very clear that there is significant data contamination issues that need to be addressed. In fact, many students make attempts to rectify the problem to improve the situation. In general, some improvements can be made but the solution to the problem is beyond the abilities of the students at that point in the first laboratory sequence. But, general improvements can be seen that forces the students to rethink their approach and helps to define their stategy better.

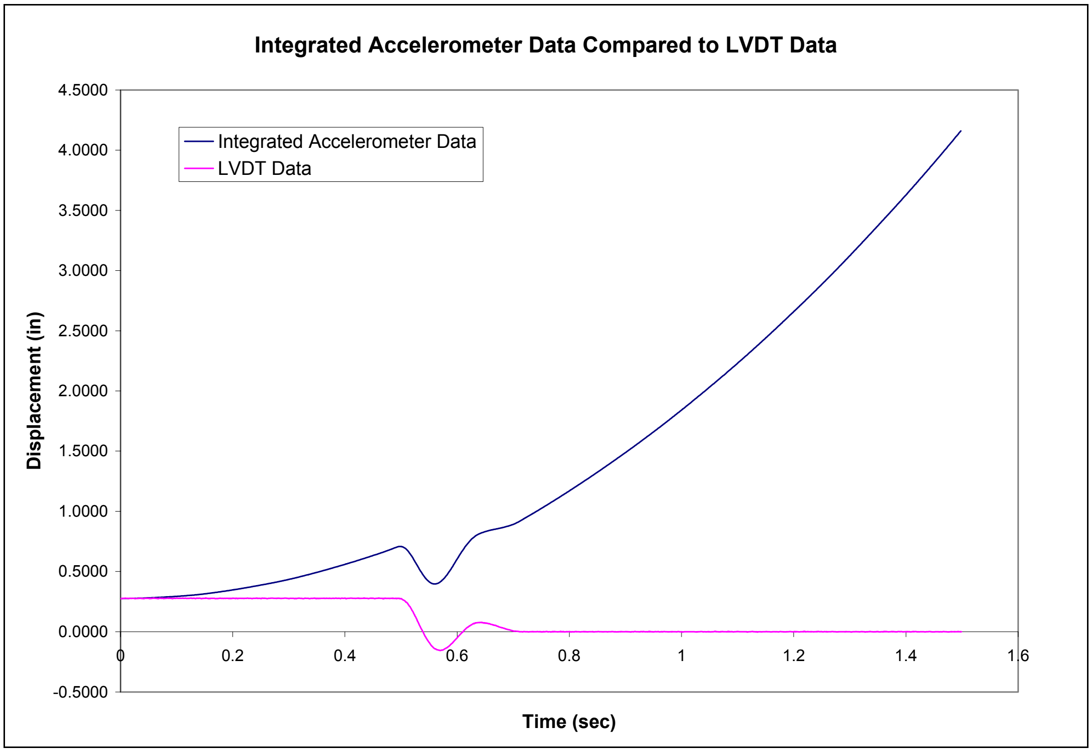


Figure 2 – Displacement Comparison between Integrated Accelerometer Data and LVDT Data

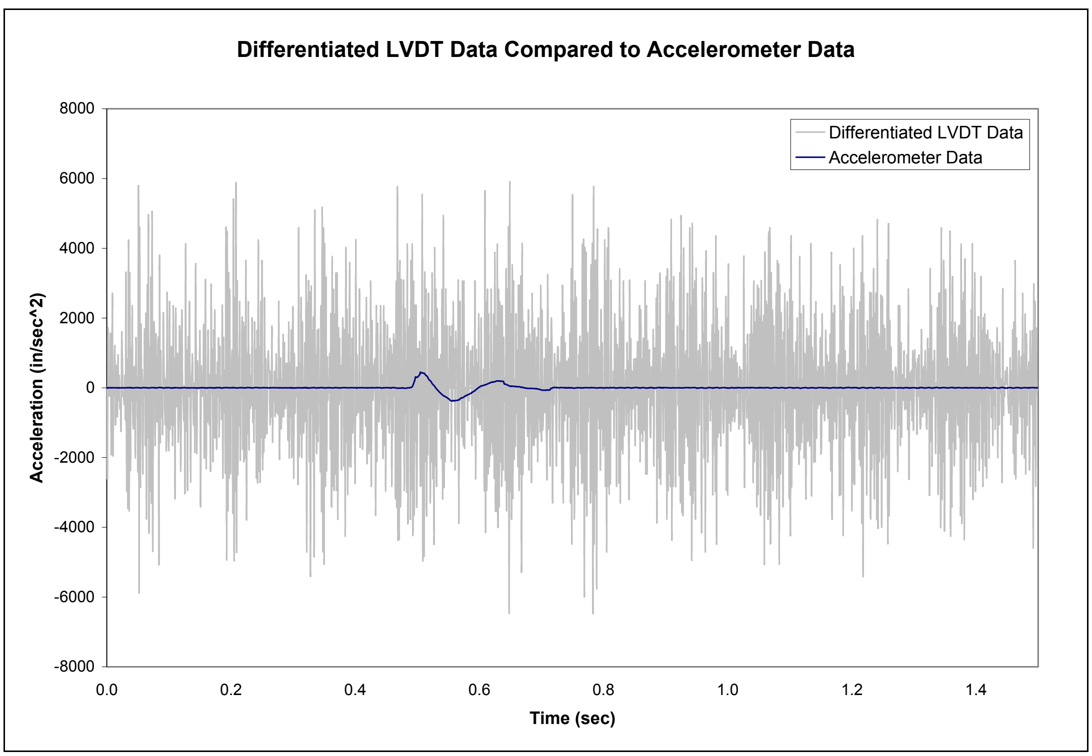
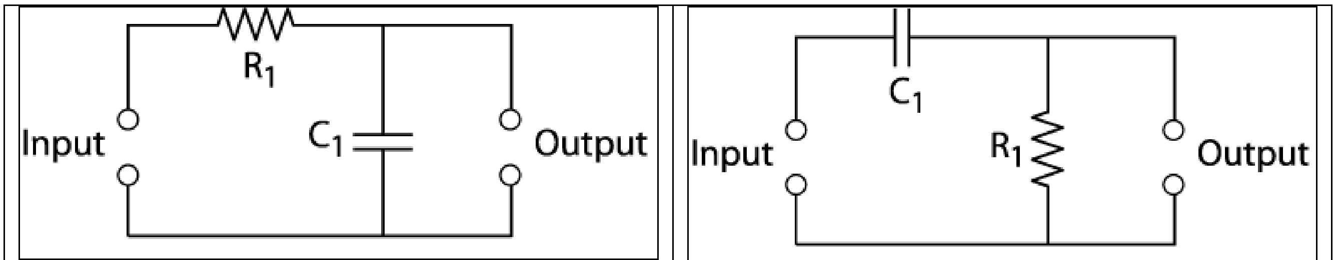


Figure 3 – Acceleration Comparison of Differentiated LVDT Data and Accelerometer Data

II.2 Hardware Filtering

An RC circuit is designed to address the issues pertaining to DC offset, bias error and higher frequency noise. Knowing the natural frequescy of the system to be measured and the desired frequency range of interest, the students start to design both a high pass and low pass filter. Design parameters such as signal attenuation and phase shift are important considerations in order to select appropriate cutoff frequencies. The simple low pass and high pass filter schematics are shown in Figure 4 and the hardware circuits are shown in Figure 5. These were used for actual filtering during data collection.



(a) (b)

Figure 4 – (a) Low-pass (RC) filter circuit diagram and (b) high-pass (CR) filter circuit diagram

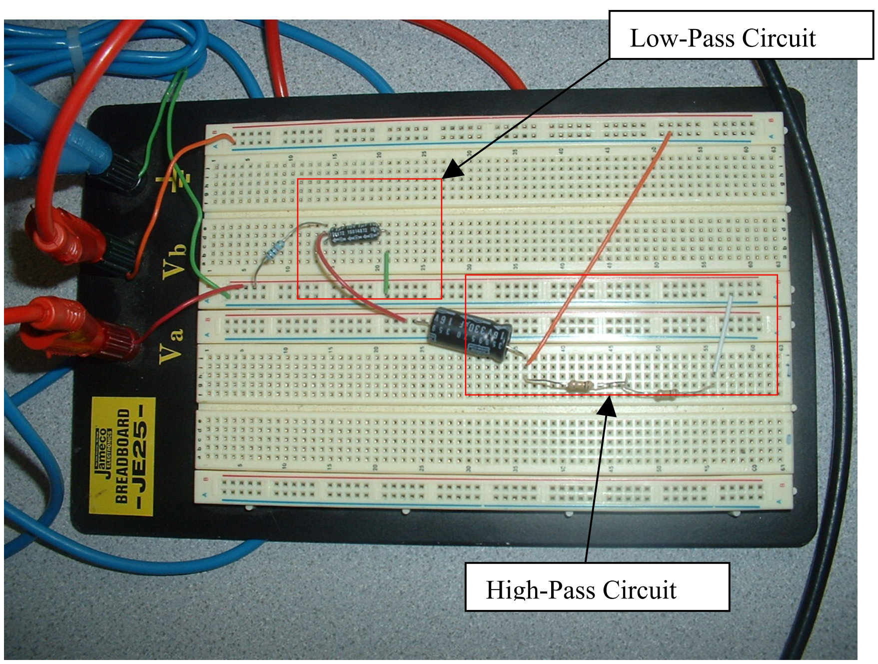


Figure 5 – Hardware Circuit for a Band-Pass Filter

II.3 Analytical Filtering with Simulink and Labview

In addition to hardware filtering, software filtering was performed on the raw data collected. This was performed by developing the companion RC and CR circuits in both Simulink and LabVIEW. In addition, a band pass filter was also simulated by putting the low pass and high pass filters in series as was also done in the hardware configuration. A typical block diagram showing the low pass filter is shown in Figure 6. In addition, another block diagram of the low pass, high pass and band pass filters are shown in Figure 7. As was done with the hardware configuration, appropriate cutoff frequencies were selected to minimize the amplitude attenuation and phase shift.

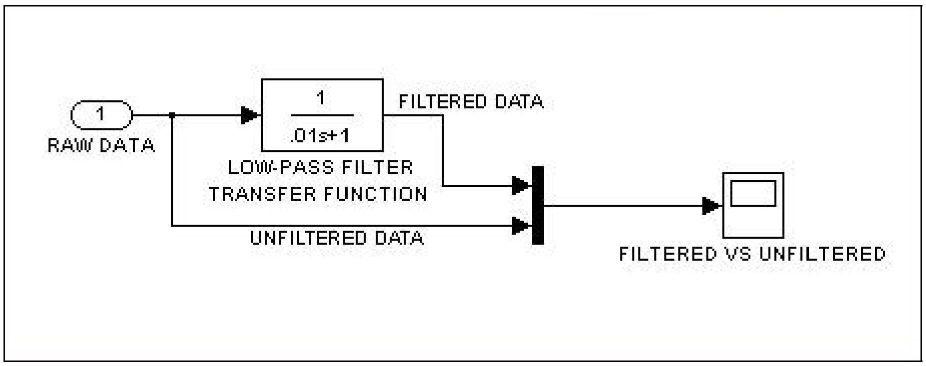


Figure 6 – SIMULINK RC Filter Using Transfer Function

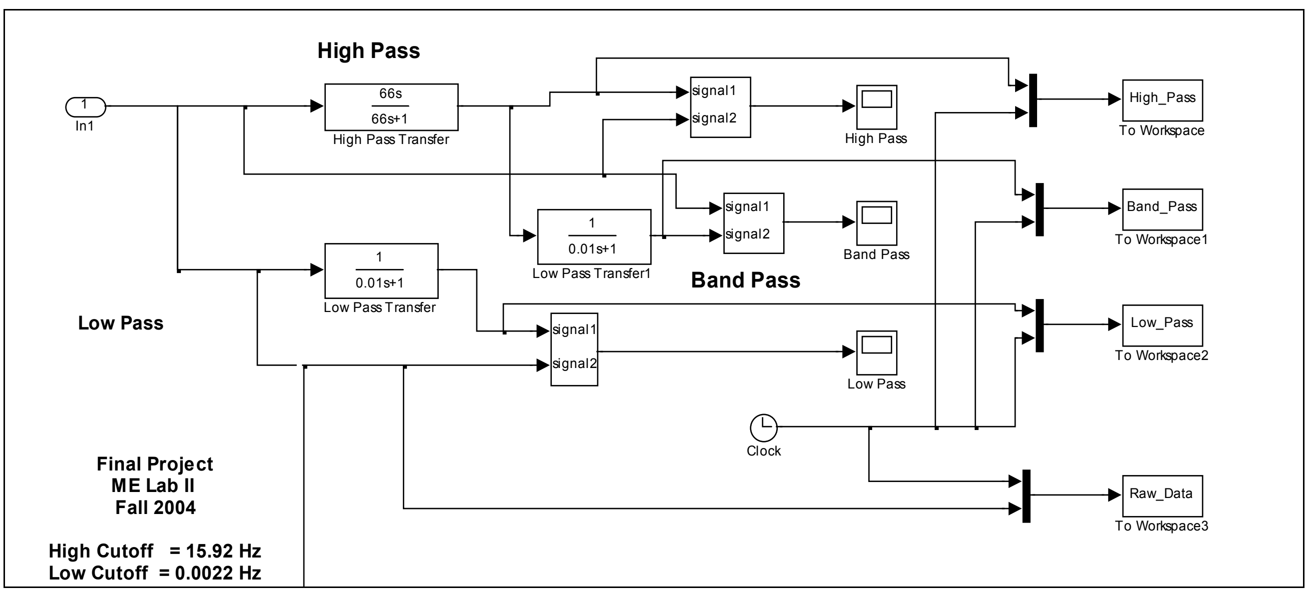


Figure 7 – SIMULINK Low Pass, High Pass and Band Pass Filters

II.4 Differentiation of the Displacement Signal

The LVDT signal is plagued by DC offset, drift, and noise as seen earlier. Using the hardware and software filtering techniques described above, the LVDT signal was cleansed. This signal was then differentiated to obtain an acceleration signal and compared to the accelerometer signal. This is shown in Figure 8. Since differentiation will always amplify any noise on the signal, any remaining noise will be amplified. This is seen on the data in Figure 8. While the data still has some noise, a significant improvement is seen over the unfiltered data. Additional filtering could be explored but the goal is to show the students that filtering may be a necessary part of the data processing.

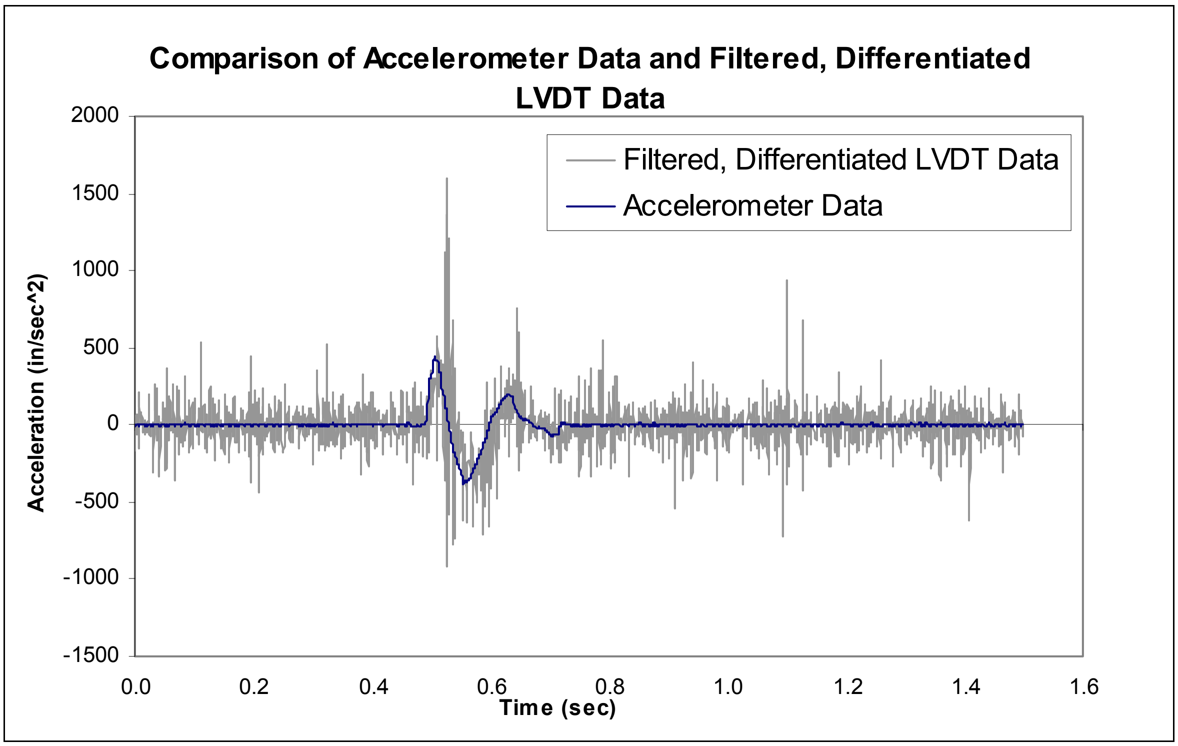


Figure 8 – Filtered LVDT Data Differentiated and Compared to Accelerometer Data

II.5 Integration of the Accelerometer Signal

The accelerometer signal is also plagued by DC offset, drift, and quantization errors as seen earlier. Using the hardware and software filtering techniques described above, the accelerometer signal was also cleansed. This signal was then integrated to obtain a displacement signal and compared to the LVDT signal. This is shown in Figure 9. While there is still some distortion on the data, improvements can be seen. Again, the intent is to clearly show that signal filtering may be an important consideration when processing data.

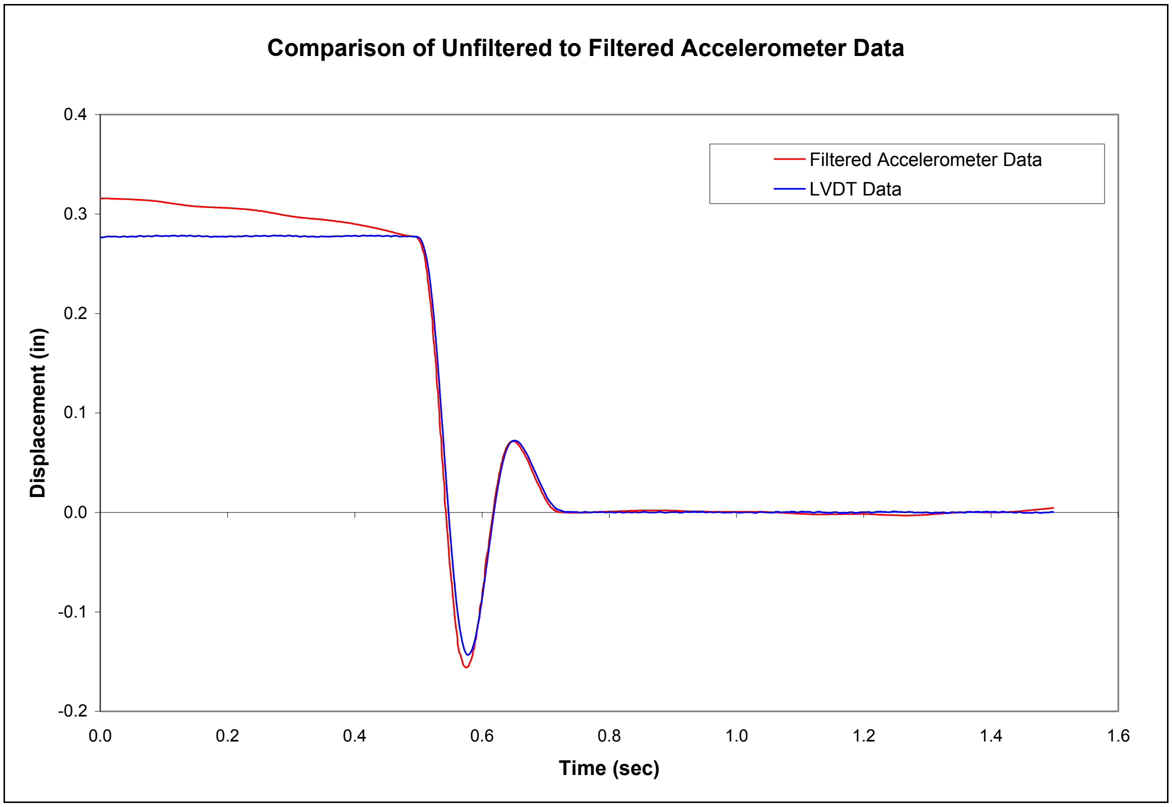


Figure 9 – Filtered Accelerometer Data Integrated and Compared to LVDT Data

III Observations

Mechanical engineering students often process data for comparisons of acceleration and displacement data. In a pristine analytical world, these signals are fairly easy to manipulate using standard numerical techniques. However, when collecting real data, many issues pertaining to the measured data must be addressed. The reality of measured data and common issues of drift, offset, bias and other random noise effects, distort the data. Numerical processing of this raw data will often yield very confusing results to the student.

However, once the typical measurement issues are identified, the students can filter the data with very simple hardware and software tools. This helps to reinforce the generic underlying principles of first order systems but applied in a very different situation than typically seen by most mechanical engineering students. The students take charge of identifying the problem and defining solutions which forces them to "think outside the box" and employ many of the their STEM skills in order to solve this problem.

IV Summary

A typical laboratory measurement system that is plagued with common measurement issues is used to illustrate the application of simple first order filtering schemes. The students employ basic first order theory to design appropriate hardware circuits and then also build those same circuits using Simulink and LabVIEW. While additional filtering will improve the situation further, the students gain first hand knowledge of the need for filtering in an environment which forces them to fully understand the theoretical aspects of the filters themselves. These filters are then both implemented in hardware and software configurations to show the application of these tools. The students gain significant benefit from having to develop each piece of this project.

V Acknowledgement

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