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NUMERICAL EVALUATION OF DISPLACEMENT AND ACCELERATION FOR A MASS, SPRING, DASHPOT SYSTEM

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Abstract

A laboratory project requires measurements for the displacement and acceleration of a simple mass-spring-dashpot system. Students acquire digital data using an LVDT, accelerometer and other transducers to obtain this displacement and acceleration data. The data acquisition system and transducers are intentionally selected such that the majority of possible errors exist in the data (drift, bias, offset, quantization, etc). This data is integrated and differentiated to compare displacement measurements to acceleration and acceleration measurements to displacement through numerical processing of the measured data via spreadsheet calculations. Students struggle with this "less than perfect" data to emphasize the importance of good measurements.

In order to firmly instill these concepts, this laboratory exercise is revisited later in the semester to re-measure the mass-spring-dashpot system with improved instrumentation and better understanding of the problems that need to be addressed. The students are better equipped to revisit this laboratory at the end of the semester after having been exposed to a wide variety of different measurement problems.

In addition to a detailed evaluation of the data, each student is required to write a final report addressing all aspects of the test and analysis of the data. The report must address the data with summary, conclusions and, most importantly, recommendations for future improvement of the test/analysis process. The project is discussed in this paper and the overall project is described.

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. Material taught in pre-requisite courses contain critical knowledge and skill sets necessary for upper level courses. Unfortunately, as students learn STEM material in subsequent courses, they do not see the practical need for this material in future courses. Therefore, students naturally tend to hit the "reset button" after each and every course since there is no apparent reason to want to actively retain this required information.

This is not only from one course to another but also within a given semester, where students often inquire if material from previous tests will be included in subsequent tests. Again, unfortunately, the manner in which courses are taught naturally tends to reinforce this incorrect student notion. Material taught in a particular chapter of the text contains problems at the end of the chapter which relate to problems where the solution can be found within the confines of that chapter. Further, the problems are posed with just the sufficient amount of information, properly posed and stated, to solve that particular problem.

The mission for all instructors is to educate their students in the most efficient manner possible. Teaching techniques should challenge, educate and promote innovative thinking from students. The lecture-based format of teaching which predominates in engineering education may not be the most effective manner to achieve these goals [1,2]. Constructivist learning theory asserts that knowledge is not simply transmitted from teacher to student, but is actively constructed by the mind of the learner through experiences. [3,4].

Students learn best with hands-on projects and problems with practical purpose [5]. 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 [6]. 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. Many professors are comfortable with this approach since the outcomes of the laboratory experiment are known and can be assessed and evaluated with very clear guidelines.

However, this does not exploit the laboratory experience to its fullest. Students get the impression that the experimental environment is very similar to the classroom environment where homework problems and tests have very explicit answers given the problem statement. Unfortunately most, if not all, engineering problems do not follow this 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" [7].

The laboratory environment is an excellent opportunity to force the students to "think on their own". Real-world laboratory exercises and experimental approaches clearly show that there is not always an "answer at the back of the book". While students, at times, become frustrated by this, they learn that they need to employ many of their STEM skills in order to solve even the simplest of problems. Industry advisors have clearly identified the need for students to be exposed to a real-world laboratory environment where modern instrumentation and computers interface in performing data acquisition and data reduction [9, 10, 11].

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.

Real engineering problems are rarely solved by "looking up answers at the back of the book". Yet many engineering courses are taught this way and students feel that they can push the "reset button" after each class since they do not see the integration of all the material until late in their undergraduate career through their capstone experience. This is too late for them to realize the importance of earlier course material.

In laboratory courses, students are expected to understand/comprehend all of their pre-requisite STEM material. Laboratory courses generally have some review material to summarize some of the basic underlying theory and methodology. The laboratory course can then concentrate on various measurement techniques.

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 lab projects from the first semester sequence. The particular laboratory project is useful in that it is one of the few projects that require the students to integrate a majority of all the material discussed during the entire semester. This particular laboratory exercise is discussed in the following sections.

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 is described herein. The simple MCK system is shown in Figure 1.

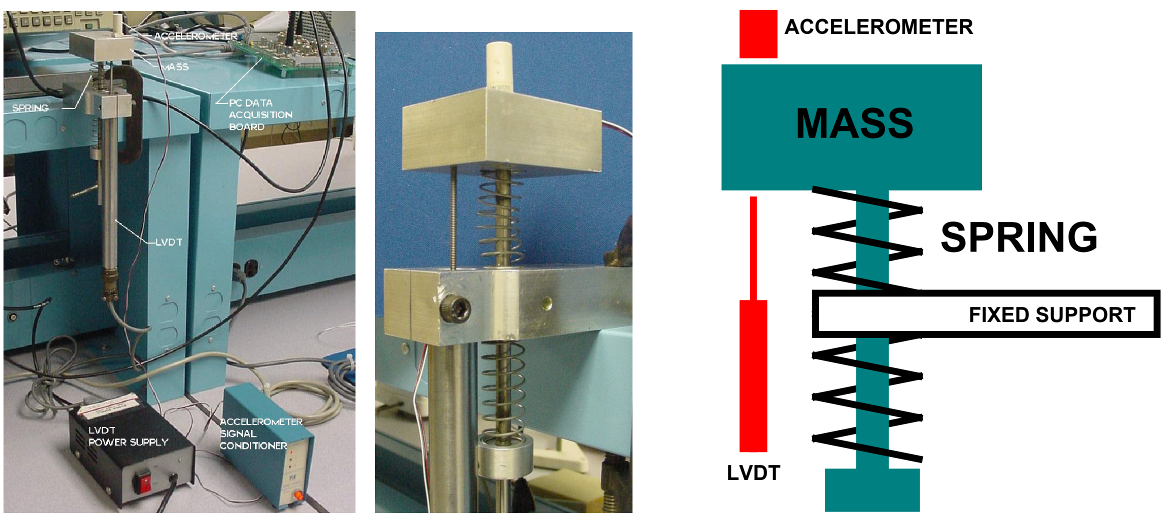

Figure 1 – Photo of MCK System along with Schematic of Configuration

The system is to be measured using an LVDT for displacement and using an accelerometer for acceleration. (The devices must first be calibrated to determine the overall sensitivities and then digitally recorded using a PC digital data acquisition system.) Once the data is collected, the acceleration data is to be integrated for comparison to the displacement measured data AND the displacement data is to be differentiated for comparison to the measured acceleration. While the project seems fairly innocent, there are many technical hurdles to overcome. Each of these are briefly described along with the resulting technical issues that must be addressed. It is important to note that none of these “issues” are identified to the students. They must address each of the challenges as they appear in the data collection and processing. As the students struggle with the data, they clearly learn that the processing of data is not as easy as they have been led to believe in previous courses where all of the data is deterministic and very well behaved. It is at this point that they must start to utilize all of the STEM materials and understanding of the problems in order to address this situation. They must also start to “think outside the box”.

II.1 Digital Data Acquisition Considerations

The PC digital data acquisition system is prehistoric compared to modern day acquisition systems but is retained for the student’s first exposure to digital processing so they can fully appreciate and understand all the issues important to the specification of a good data acquisition system. The acquisition board is a fixed 10 volt range, 12 bit ADC with no extra features such as AC coupling. The students immediately learn that the measurements of the low level acceleration (with relatively poor resolution accelerometer for the intended frequency range of interest) suffers dramatically from quantization errors. Of course, this is not immediately perceived by the students until the data processing occurs and they struggle with the processing of the data. The acquisition system has no AC coupling feature important to the collection of good data from the accelerometer. The students also struggle with this problem (discussed separately). A typical measurement with significant quantization error is shown in Figure 2.

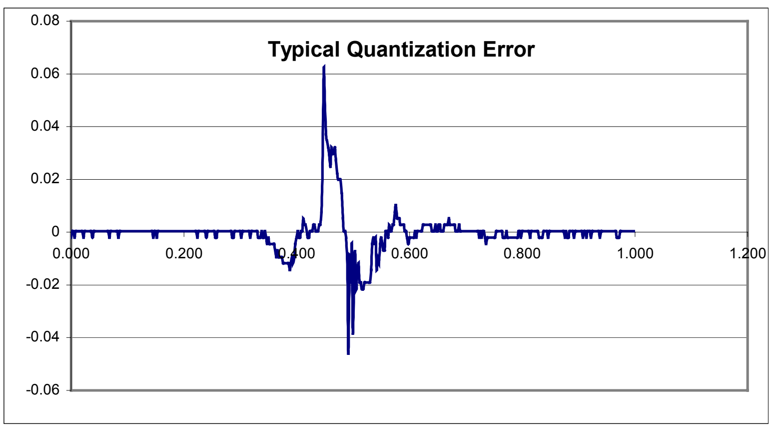

Figure 2 – Typical Quantization Error in Accelerometer Measurement

II.2 LVDT Measurement

The LVDT calibration is fairly straightforward and students easily collect data and perform regression analyses to determine the LVDT sensitivity and linear range of operation. The dynamic data collected by the LVDT is plagued by noise issues. However, the signal strength of the LVDT measuring the response of the single DOF system masks this noise problem. The time data collected barely shows any problems relative to any noise on the measured displacement. This does not become an issue until the data is further processed (discussed separately). A typical LVDT measurement with noise is shown in Figure 3.

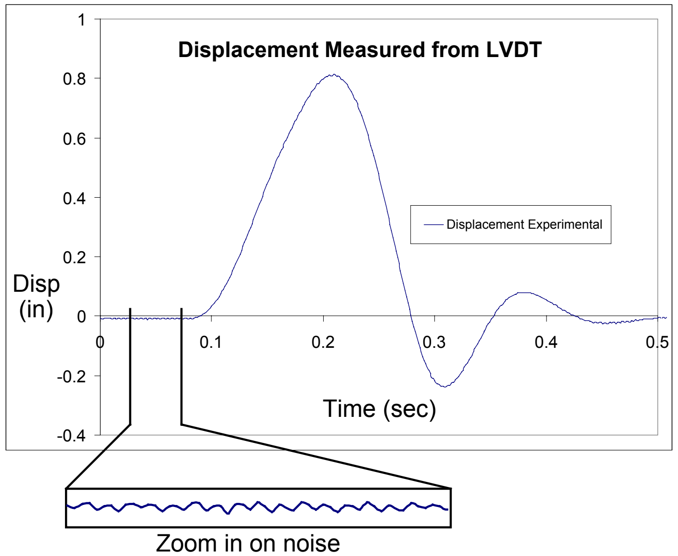

Figure 3 – Typical LVDT Measurement with Noise

II.3 Accelerometer Measurements

The accelerometer signal is generally very low and is extremely sensitive to quantization errors. In addition, there is drift and bias errors that can be seen in the accelerometer measured signal. The signal should be acquired with a better suited accelerometer with improved frequency resolution and better sensitivity. In addition, an improved data acquisition board with more bits of resolution and features such as AC coupling are required to collect better data for the measurement of the acceleration of this system. However, in this first stage, the students are required to use the existing measurement system to process the data. A typical accelerometer measurement is shown in Figure 4.

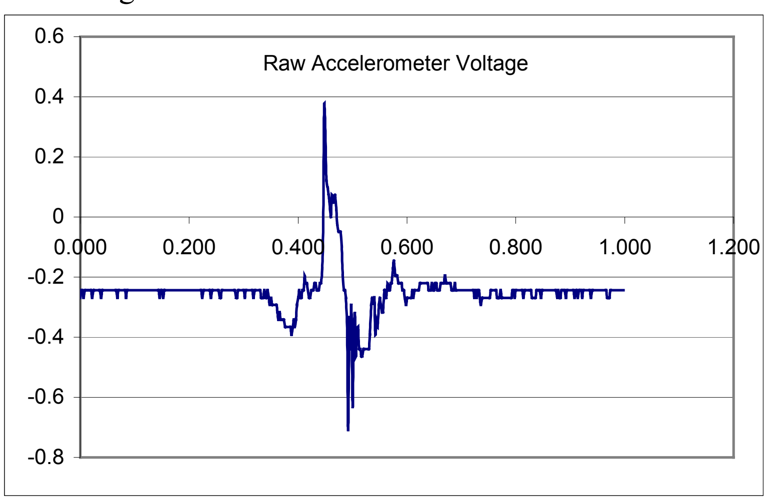

Figure 4 – Typical Accelerometer Measurement

II.4 Differentiation of LVDT Signal

The LVDT signal is plagued by noise which is amplified by differentiation. Students do not immediately recognize that this is the problem. Many times the problems are blamed on the numerical differentiation without really identifying the source of the errors However, since a numerical methods course often highlights the fact that the numerical techniques are sensitive to the time step used to process the data, students often, all to quickly, blame the problem on this. In addition, students may also point to the digital data acquisition sampling process as being insufficient. However, occasionally an assessment of the signal will indicate that there is actually 60 cycle noise – which should actually be the first item checked. An assessment of the noise on the LVDT signal after just one integration reveals that the signal riding on top of the desired signal of velocity is actually 60 cycle noise.

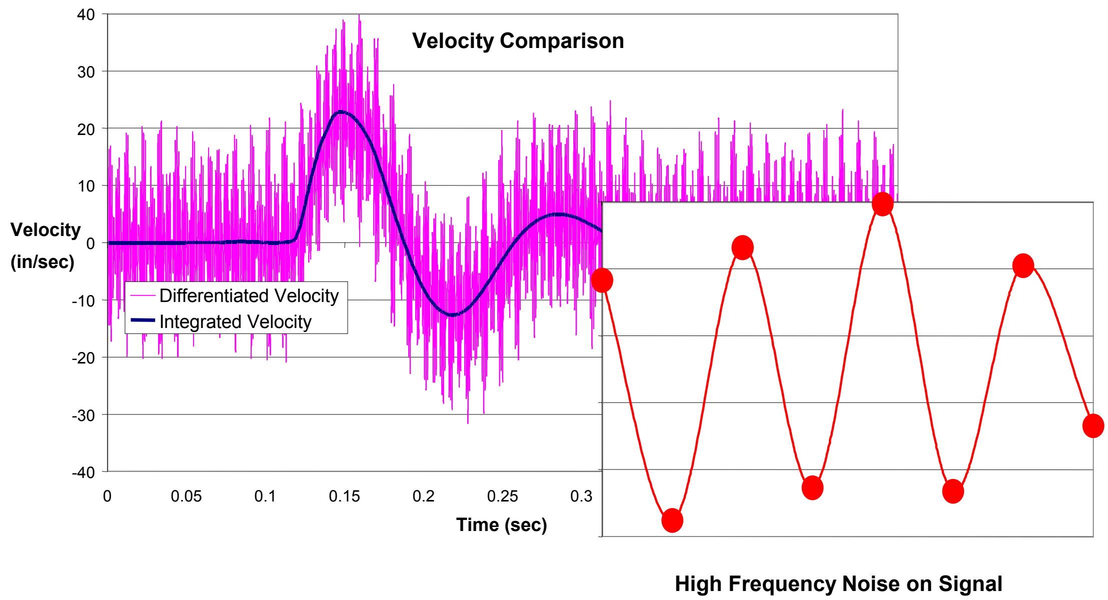

Figure 5 – Typical Differentiation of LVDT Measurement Contaminated with Noise

II.6 Integration of the Accelerometer Signal

The accelerometer signal is also plagued by DC offset, drift, and quantization errors. Upon their first attempt on integration of the data, students quickly realize that they do not know the initial conditions for the numerical integration. In numerical methods courses, they are always provided with this critical piece of information. The students become frustrated when they realize that somehow they need to determine the initial conditions, otherwise their numerical processing will suffer. Of course, some students start to realize that the velocity initial condition is sometimes available through differentiation of their displacement signals. And some realize that with certain excitation conditions, the initial conditions can be obtained from the manner in which the system is excited.

Another issue that quickly surfaces, is that the lack of AC coupling on the accelerometer measurement which causes drift and bias as a result of the accelerometer normal operation and related signal conditioning. Integration of their accelerometer measurements with no initial processing of the raw measured data results in trends that at first appear very strange to the student. Again, with head scratching, the students realize that some of the underlying basic STEM material contain all the answers as to why this signal, at times, appears distorted. A typical set of different integrations (one for acceleration to velocity and one for acceleration to displacement for two different data sets) is shown in Figure 6 illustrating typical results initially obtained by some of the students.

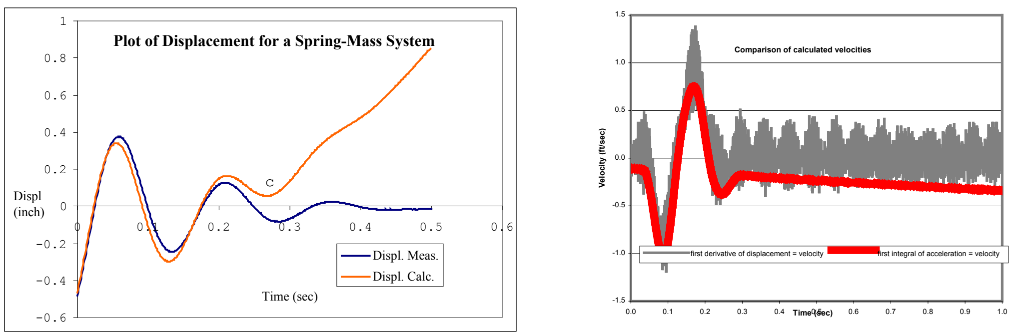

Figure 6 – Typical Integration of Accelerometer Measurement with Bias and Drift Issues

II.7 Summary of Initial Measurement Acquisition / Processing

The students struggle with many different aspects of poorly collected data. This specific laboratory experiment addresses many issues of transducer selection, digital data acquisition issues, and numerical processing of poorly collected data. The students learn that the real-world is not as nice as the more deterministic “textbook” problems that they have seen in previous studies. The students struggle with this data to help emphasize the importance of good measurements and proper laboratory measurement/processing techniques.

Once this laboratory has been completed (typically by mid semester) they are assigned a final project in which better instrumentation and signal conditioning are made available along with an improved data acquisition system. However, not all of the problems are removed but many of the more serious hurdles have been tamed. The final project for the semester requires the students to re-address the measurement system but with improved instrumentation/measuring devices and a better overall understanding of the problems at hand. The final lab helps the students to revisit the measurement system and correct all of their errors and misconceptions from the previous effort. This final laboratory requires a formal report writeup with all aspects of signal processing, measurement issues, numerical processing addressed in the report. The final report also requires the students to not just make summary and conclusion remarks, but to also make firm recommendations as to how to further improve the overall laboratory measurement system. This further illustrates that the students fully comprehend the problem and can adequately address the situation at hand.

II.5 Misc Processing Illustrating Student Ownership of Problem

The students often still have issues that need to be addressed. The purpose at this point of the laboratory and report writeup is for the students to clearly identify that they command the STEM material necessary to solve the problem and can really address the overall situation with confidence and conviction. A typical set of measurements are shown in Figure 7 for one student's final processed data. Several issues still remain in the data but the overall evaluation and assessment are generally much improved.

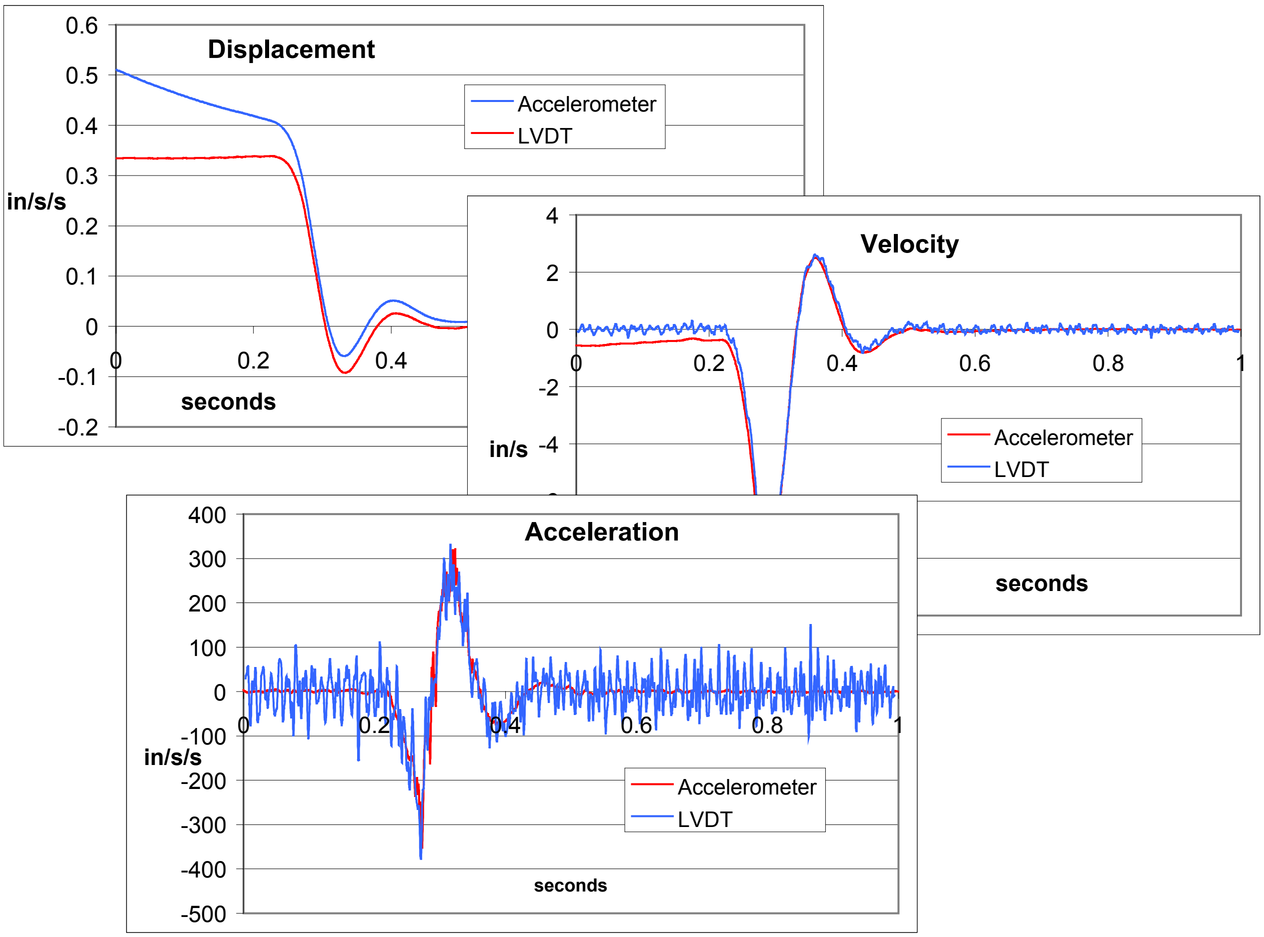

Figure 7 – Typical Displacement, Velocity, Acceleration Plots from the Reworked Lab

The students at times come up with very novel and innovative ways to process the data. Some of these have often surprised the professor clearly indicating that the students have taken complete ownership of the material . Figure 8 shows a velocity plot from integration of the acceleration signal which has bias errors. Rather than remove the bias, the data was integrated and then a straight line was fit through the data set to remove the linear velocity bias that results from the integration of a DC signal.

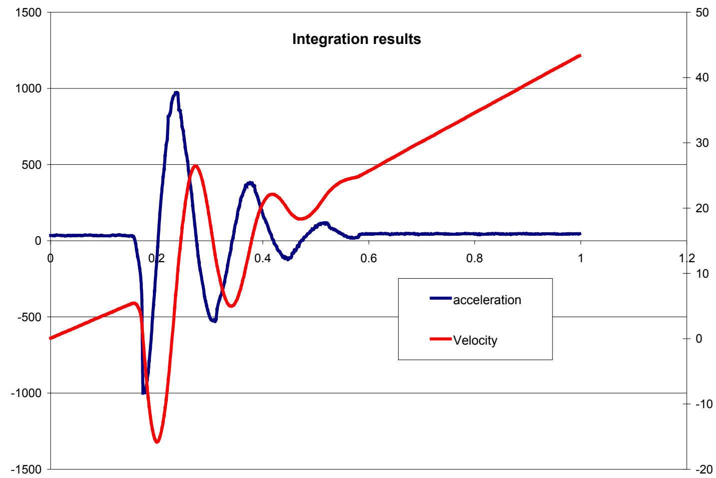

Figure 8 – Velocity Obtained from Accelerometer Integration with Bias Errors

And of course there are many times that the students produce very well behaved plots after having spent significant time processing the data as seen in Figure 9.

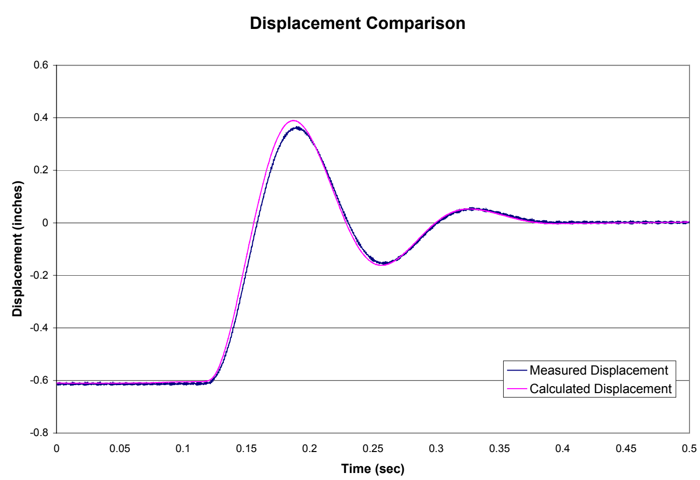

Figure 9 –Comparison of Displacements for the LVDT and Integrated Accelerometer

III Observations

The students only learn critical STEM material after having struggled with complex concepts and issues. The laboratory is a perfect place for the students to do this. The students need to take ownership of the material in order for this to happen.

The laboratory is a perfect place for this to occur since a measurement will not be exactly the same each time the measurement is made. As a result, each data set is different from every other data set that the students process. While the students can help each other with various technical aspects of the problem, each measurement has its own unique personality. The students must learn how to interpret each of their own individual data sets. Obviously, cheating and copying of homework problems is circumvented in this way. Each student must rise to the occasion and present their data which is unique from every other set of data collected by other students. They must become comfortable with all the STEM concepts in order to be able to process this real-world data that does not have an answer at the back of the book. (Of course, the professor needs to be comfortable with this idea since he does not receive an answer guide either!)

IV Summary

A laboratory experiment was presented that embodies many technical aspects of measurements, data collection and processing of the data in one self-contained project. Students must measure displacement and acceleration of a simple single degree of freedom mechanical system. Through the use of non-optimal measurement transducers and digital data acquisition system, the students learn that numerical processing can be close to impossible. Errors associated with drift, bias, offset, quantization, etc. cause nightmarish numerical processing scenarios. The students struggle with this data to help emphasize the importance of good measurements.

Once the laboratory is completed by mid-semester, the students re-visit the laboratory at the end of the semester with improved transducers, signal conditioners and data acquisition system to acquire improved (but still not optimal) data. The students are better equipped to revisit this laboratory at the end of the semester after having been exposed to a wide variety of different measurement problems.

In addition to a detailed evaluation of the data, each student is required to write a final report addressing all aspects of the test and analysis of the data. The report must address the data with summary, conclusions and, most importantly, recommendations for future improvement of the test/analysis process.

V Acknowledgement

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VI References

1 Higley,K.A., Marianno,C.M., "Making Engineering Education Fun", Journal of Engineering Education, Vol 90, No. 1, pp105-107, January 2001
2 Davis,B.G., "Tools for Teaching", Jossey-Bass Publishers, San Francisco, 1993, p100.
3 Piaget,J., "To Understand is to Invent", Grossman, New York, 1973.
4 Vygotsky,L., "Mind in Society: The Development of Higher Psychological Processes", Harvard University Press, MA, 1978.
5 Starrett,S., Morcos,M., "Hands-On, Minds-On Electric Power Education", Journal of Engineering Education, Vol 90, No. 1, pp93-100, January 2001
6 Felder,R., Peretti,S., "A Learning Theory-Based Approach to the Undergraduate Laboratory", ASEE Conference Proceedings, Session 2413 , June 1998
7 Pavelich,M.J., "Integrating Piaget's Principles of Intellectual Growth into the Engineering Classroom", Proceedings of the ASEE Annual Conference, pp719-722, 1984, Wash, DC
8 Dale,E., "Audio-Visual Methods in Teaching", 3rd Edition, Holt, Rinehart, and Winston, 1969
9 Wolkson,A. "Employers Demand New Skills", Machine Design, Sept 1992
10 Knight,C.V., McDonald,G.H., "Modernization of a Mechanical Engineering Laboratory using Data Acquisition with LABVIEW", ASEE Session 2266
11 Onaral,B., "A Road Less Traveled", ASEE Prism, September 1992
12 Wankat,P., Oreovicz,F., "Learning Outside the Classroom", ASEE Prism, p32, Jan 2000
13 McConnaughay,K., Welsford,I., Stabenau,E., "Inquiry, Investigation, and Integration in Undergraduate Science Curricula", Council on Undergraduate Research Quartley, pp14-18, September 1999

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