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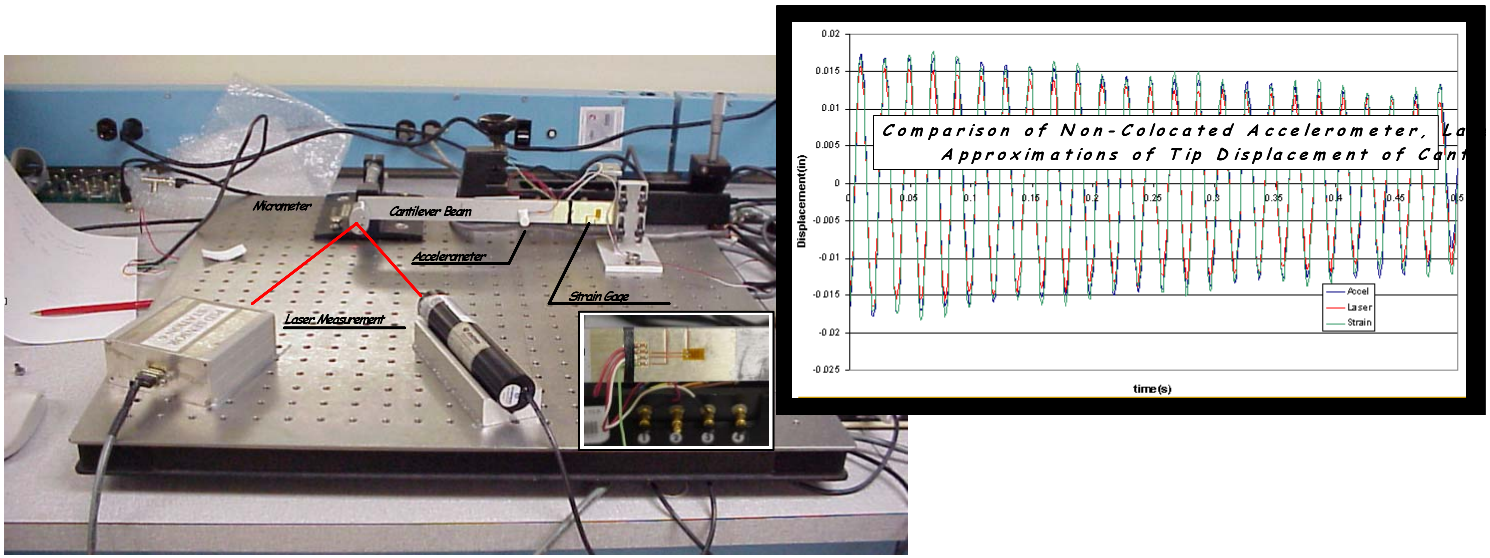
DEVELOPMENT OF A MEASUREMENT SYSTEM FOR RESPONSE OF A SECOND ORDER DYNAMIC SYSTEM



Dr. Peter Avitabile, Charles Goodman, Tracy Van Zandt
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Students rarely have the opportunity to make detailed measurements as part of their undergraduate curriculum

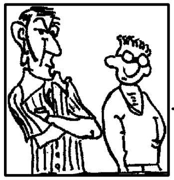
Laboratory experiments are an excellent opportunity for students to provide real-world practical solutions to problems that may not have an "answer at the back of the book".

Introduction

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"

Students learn best with hands-on projects and problems with practical purpose



Introduction

In laboratory courses, students are expected to understand and comprehend all of the pre-requisite STEM material.

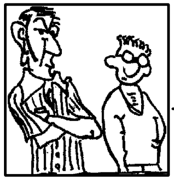
Laboratory courses generally have some review material to summarize the basic underlying theory and methodology required for particular laboratories.

The laboratory course can then concentrate on various measurement techniques.

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, pitot tubes, strain gages, thermocouples, accelerometers, LVDTs, etc)
- methods for data collection/reduction (regression analysis, curvefitting, numerical processing)

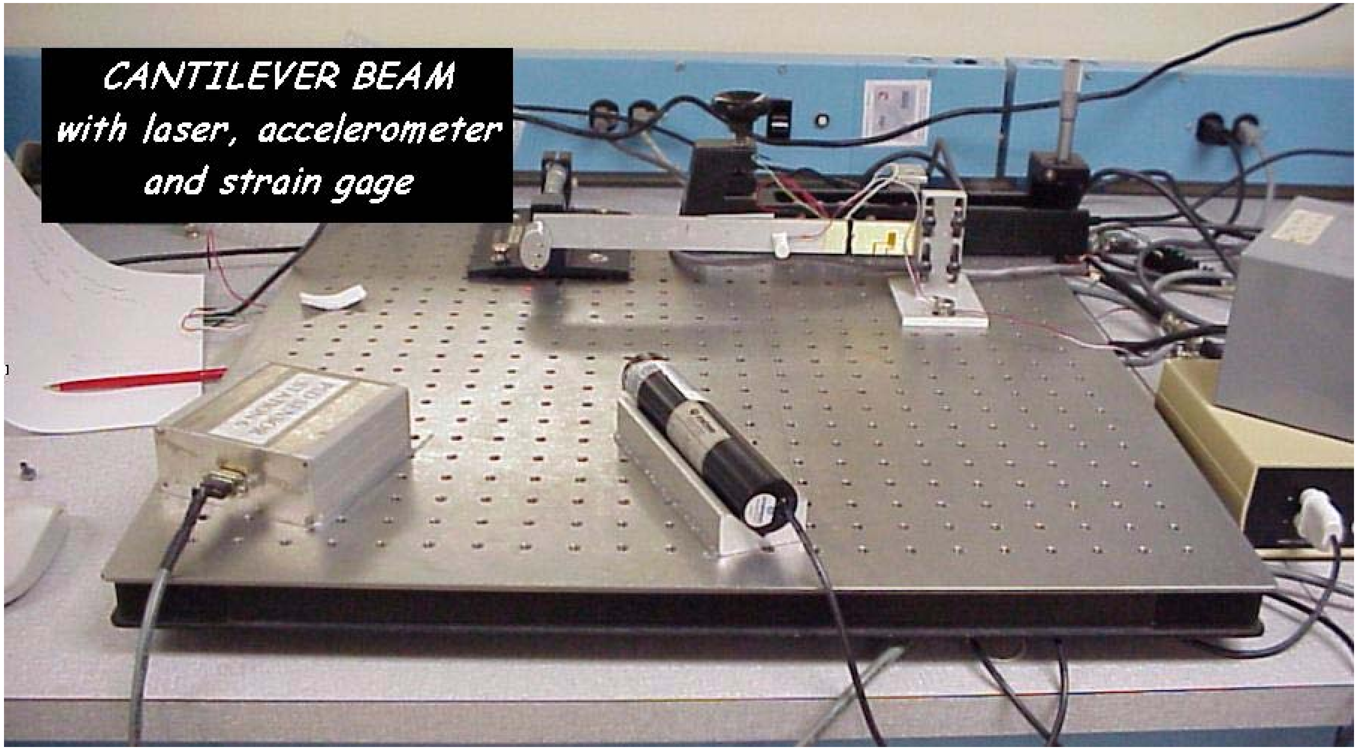


At UMASS Lowell, the laboratory courses are taught in a two semester sequence.

The second semester is split into two halves

- first half continues the more structured lab environment but introduces more complicated labs
- second half of the semester concentrates on the student development of a measurement system

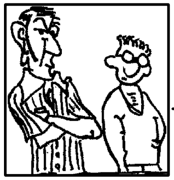
Development of a Measurement System to Characterize a 2nd Order Dynamic System



Development of Measurement System

General guidelines given:

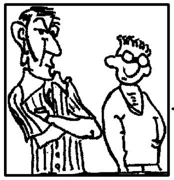
- required to select three non-colocated different measurement devices from LVDT, accelerometer, laser, eddy current probes, and strain gages
- determine suitable locations for the transducers, identify digital data acquisition requirements, etc.
- determine the "best" method to address problem
- ultimately predict dynamic response of the beam



Phase I - Brainstorming

First step take usually involves:

- determine what transducers are available
- issues of location, resolution, dynamic range
- struggle with concepts of spatial correlation of non-colocated devices
- consideration for comparing acceleration, displacement, strain and velocity measurements



Phase II – Thinking is Required!

Initially students believe all they need to do is

- *make some measurements*
- *calibrate transducers*
- *write a final report*

Ahhh - If life could be so easy !!!

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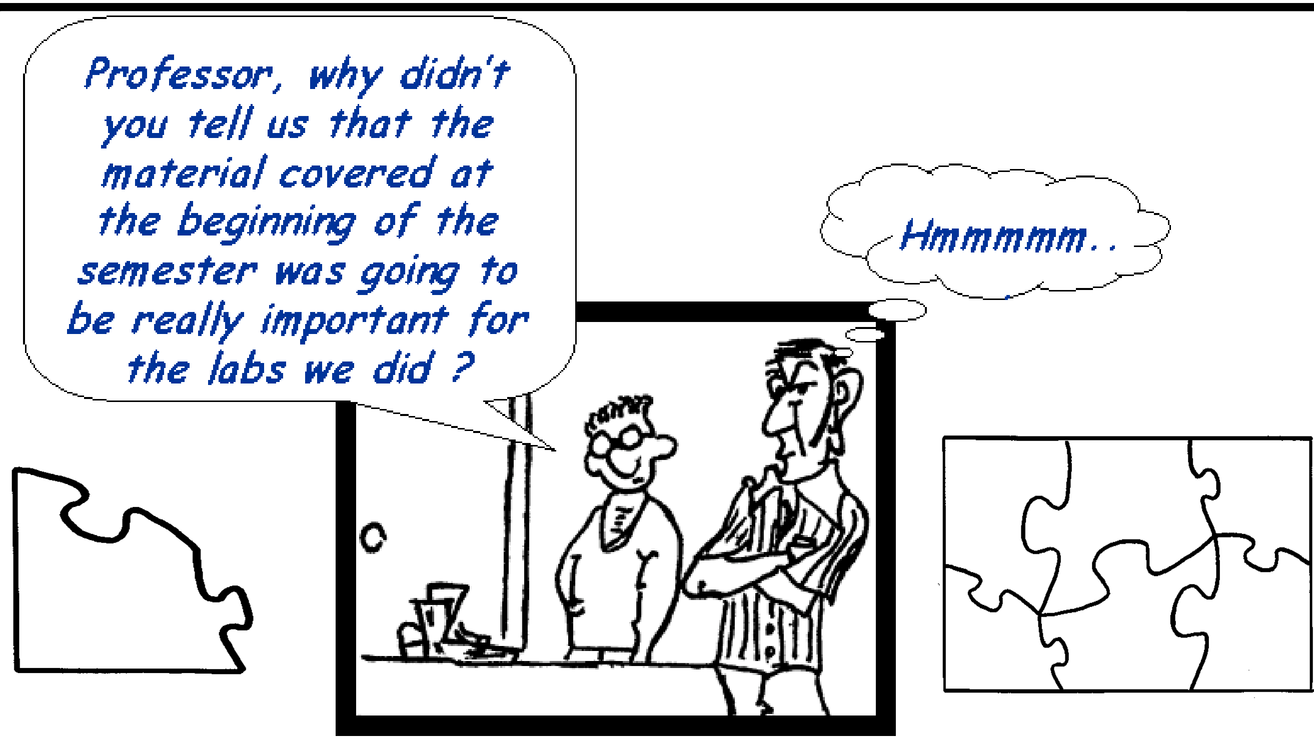
An intermediate phase

- pulling hair out

Students MUST struggle with difficult concepts in order to appreciate and understand the basic STEM material taught in previous courses

STEM – Science, Technology, Engineering and Math

You mean we have to know stuff from other course



Student views material in a disjointed fashion

Professor clearly sees how pieces fit together

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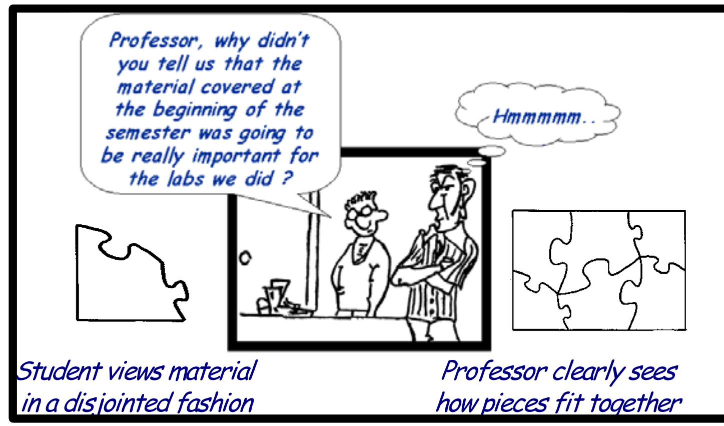
Phase II – Thinking is Required!

So those others courses we took are important !!!

The problem requires an understanding of

- *statics*
- *strength of materials*
- *dynamic systems*
- *numerical methods*
- *ordinary differential equations*
- *and others …*



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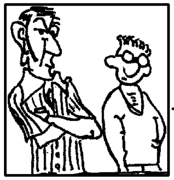
Phase II a – He's got to be kidding!

Some typical student comments heard in the hallways provide amusement for the professor

- Hey --- I thought this was just a lab course
- Why do I need to use and know all this other stuff from these other courses?
- I thought you were only allowed to ask me to do things that are related to lab???
- I wonder if we can protest this through the student council

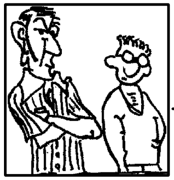


Phase III – Analysis

Analytical models can be developed to address various aspects of the assessment to be performed

Some material from previous courses contain material that are building blocks to the solution of this problem

MATLAB and Simulink are tools that assist in the development of an analytical model along with MATHCAD and spreadsheet tools



The beam can be modeled in an equivalent sense

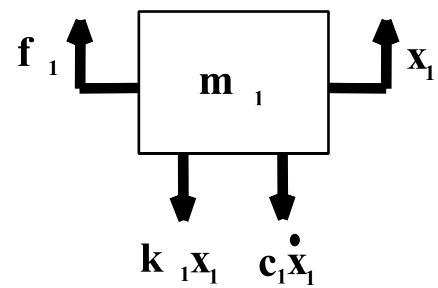
Homogenous equation is

$$m\ddot{x} + c\dot{x} + kx = 0$$

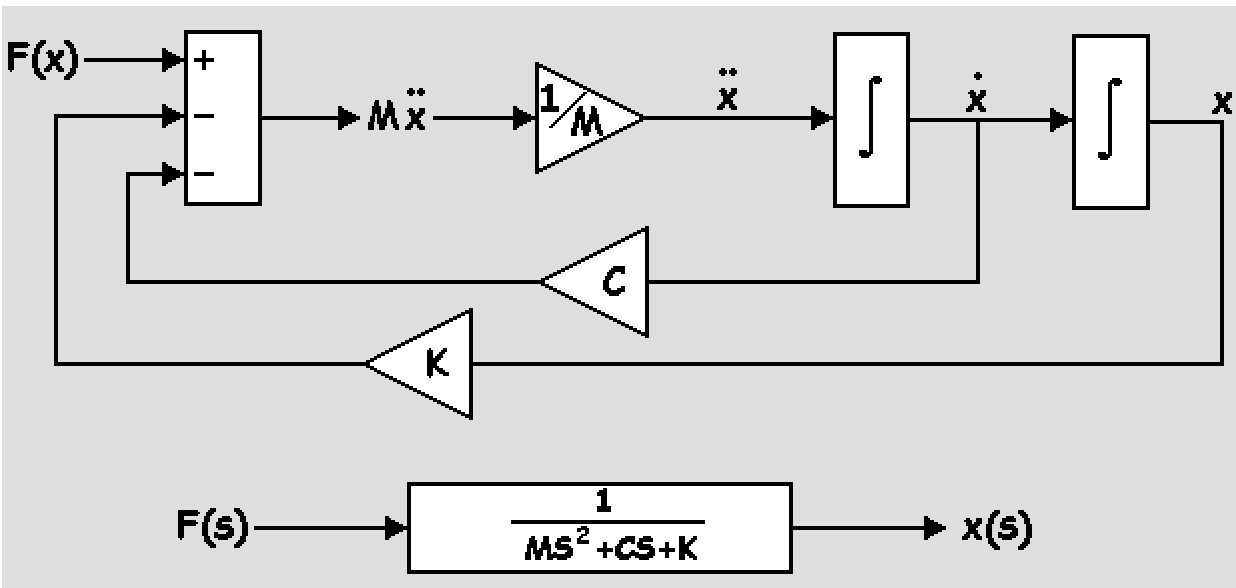
and assuming an exponential solution form gives

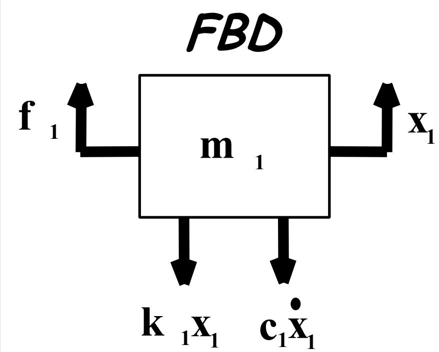
$$\left(ms^2 + cs + k\right)e^{st} = 0$$

FBD



The system can be modeled in block diagram form





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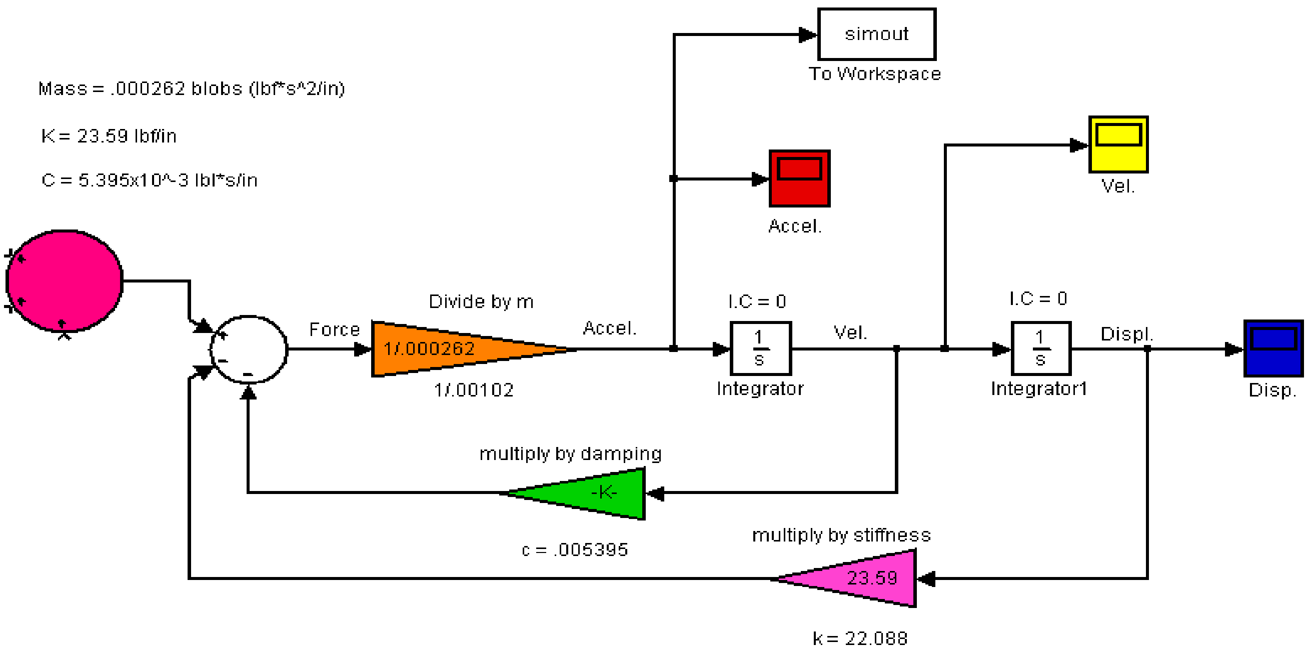
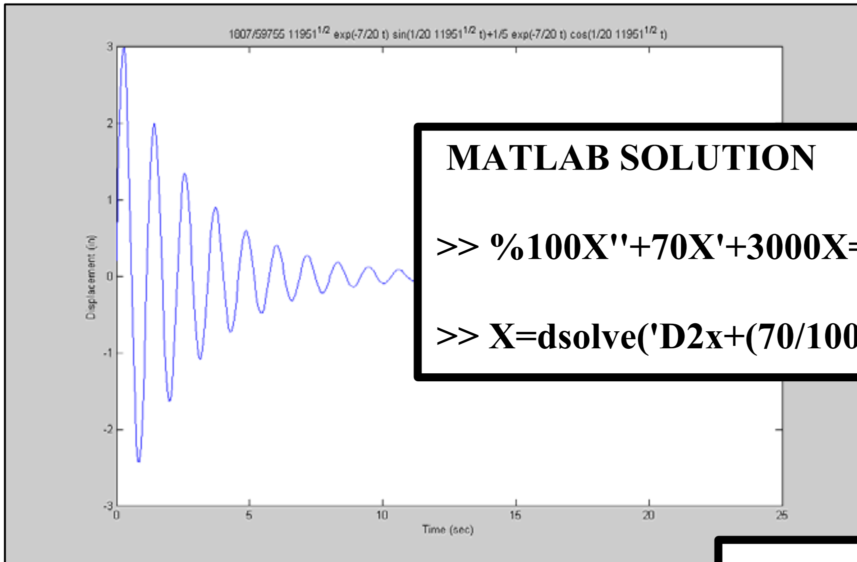
Simulink Model



Phase III - Analysis

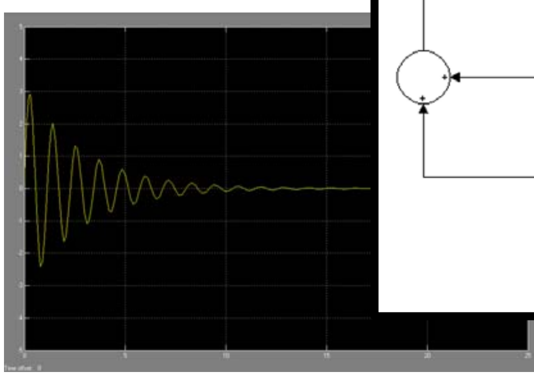


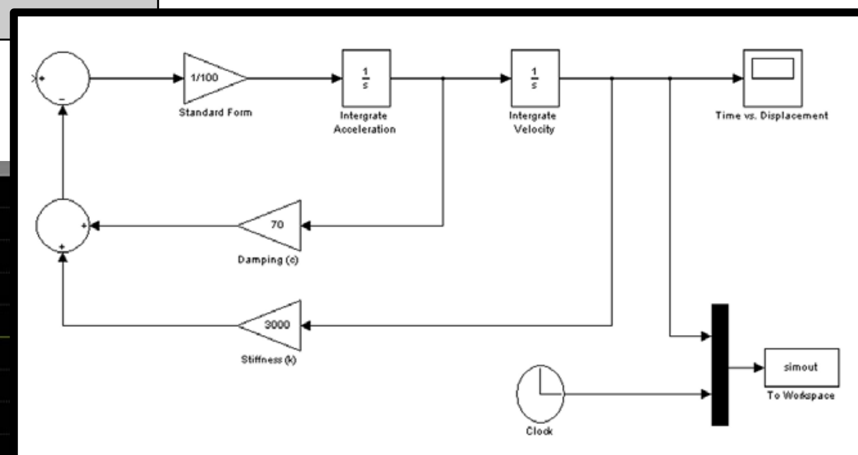
MATLAB SOLUTION

```
>> %100X''+70X'+3000X=f(t)     where:   X(0)=.2   X'(0)=18    f(t)=0

>> X=dsolve('D2x+(70/100)*Dx+(3000/100)*x=0','Dx(0)=18','x(0)=.2','t')
```

SIMULINK SOLUTION





Phase III – Analysis

Analytical models are developed to identify the spatial response characteristics of displacement, velocity and acceleration that are "expected" to be observed on the system.

This assists in the specification of transducers required – at particular locations – that provide sufficient voltage – to optimize the ADC of the data acquisition system

WOW – there's a lot to this problem!

Phase IV – Measurement Issues

Analytical models are great but the lab environment is riddled with other contaminates

- *measurement problems (noise, DC bias, drift)*
- *digital data acquisition (quantization errors, sampling rate, AC coupling, etc)*
- *numerical processing (integration/differentiation)*

Phase V – The Real Work Begins

Issues to be addressed

- calibration of all transducers selected
- model beam and verify frequency response
- filter noise – analog or digital filter
- correlate responses from non-colocated positions

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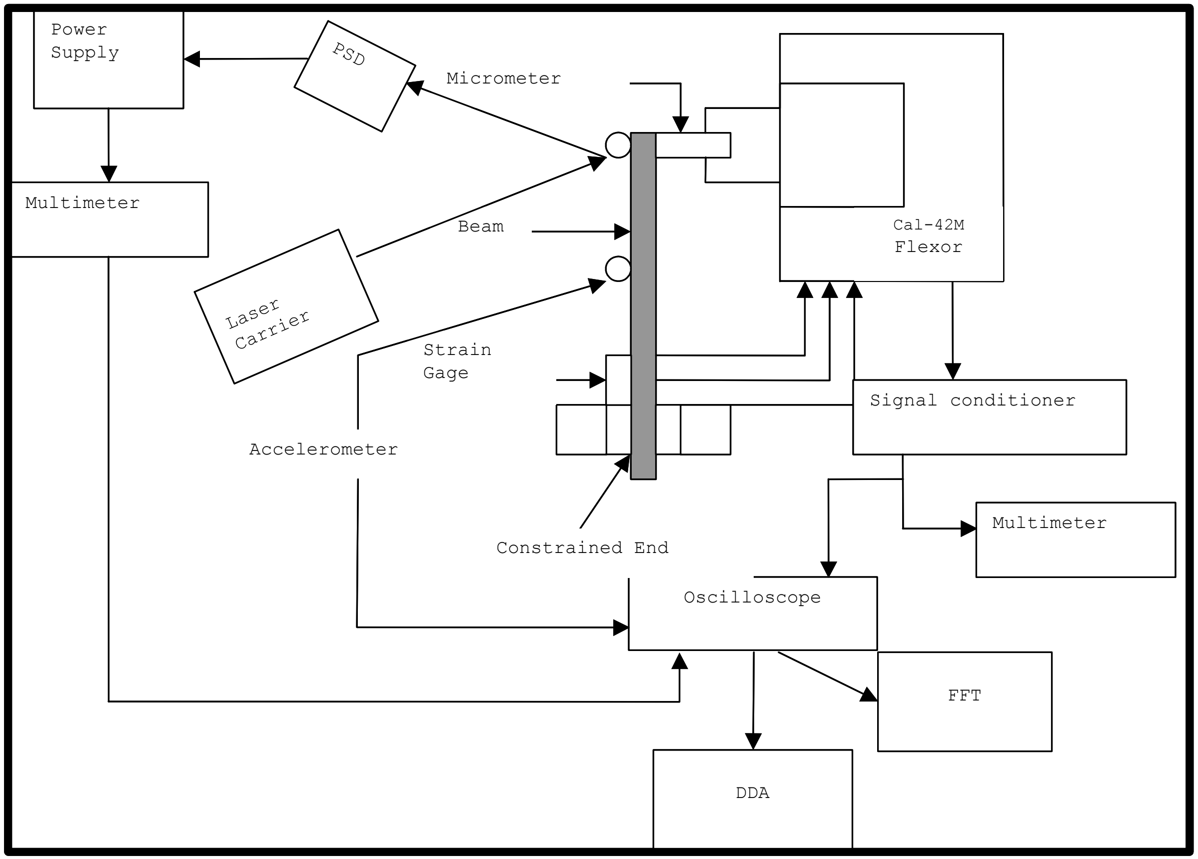
Selection and layout of instrumentation



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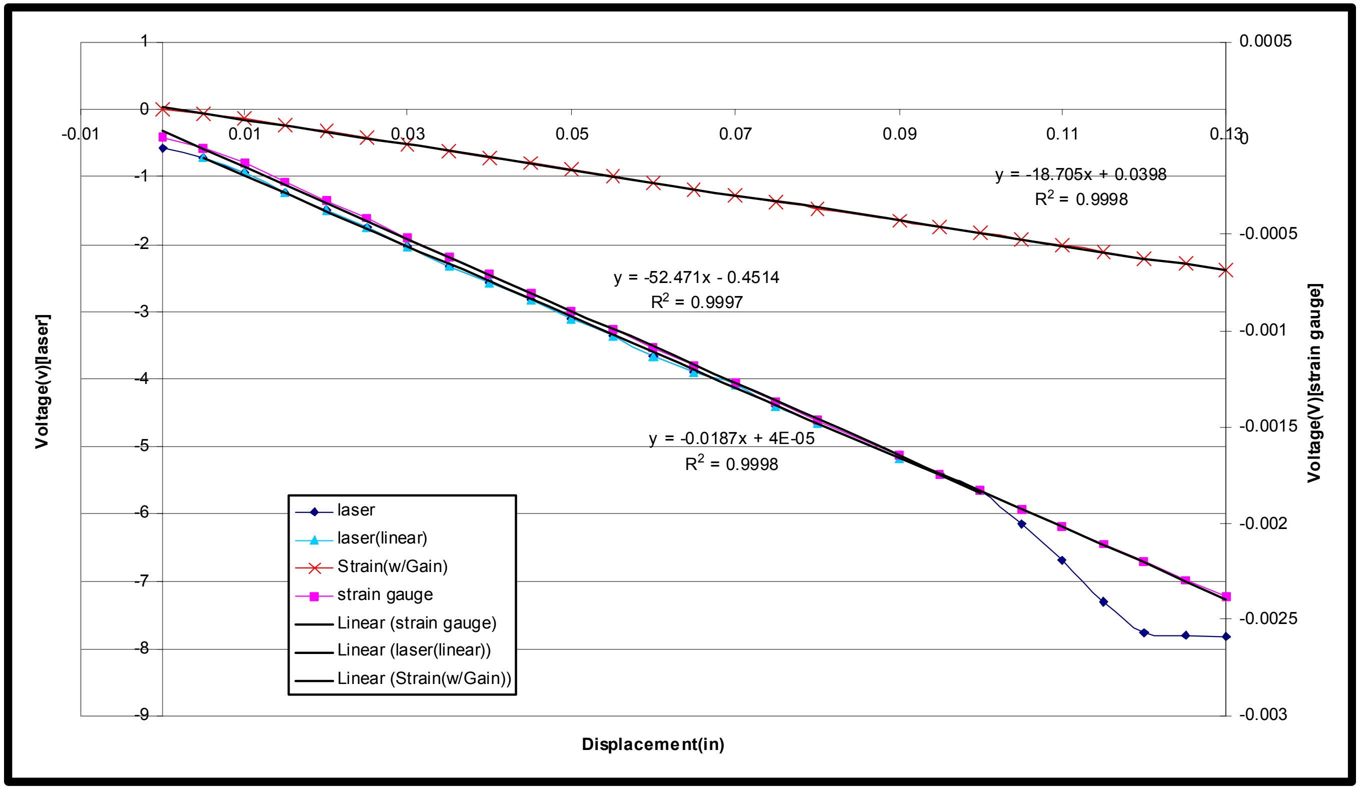
Calibration of transducers



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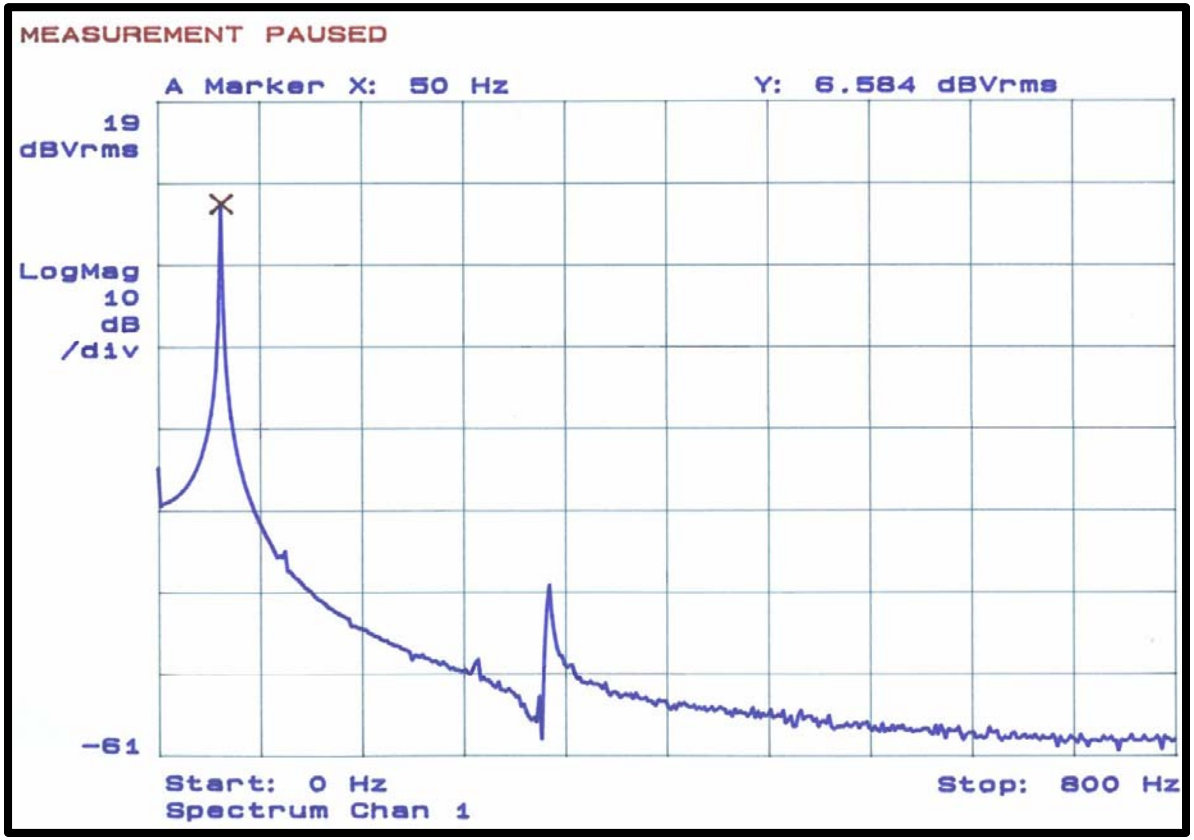
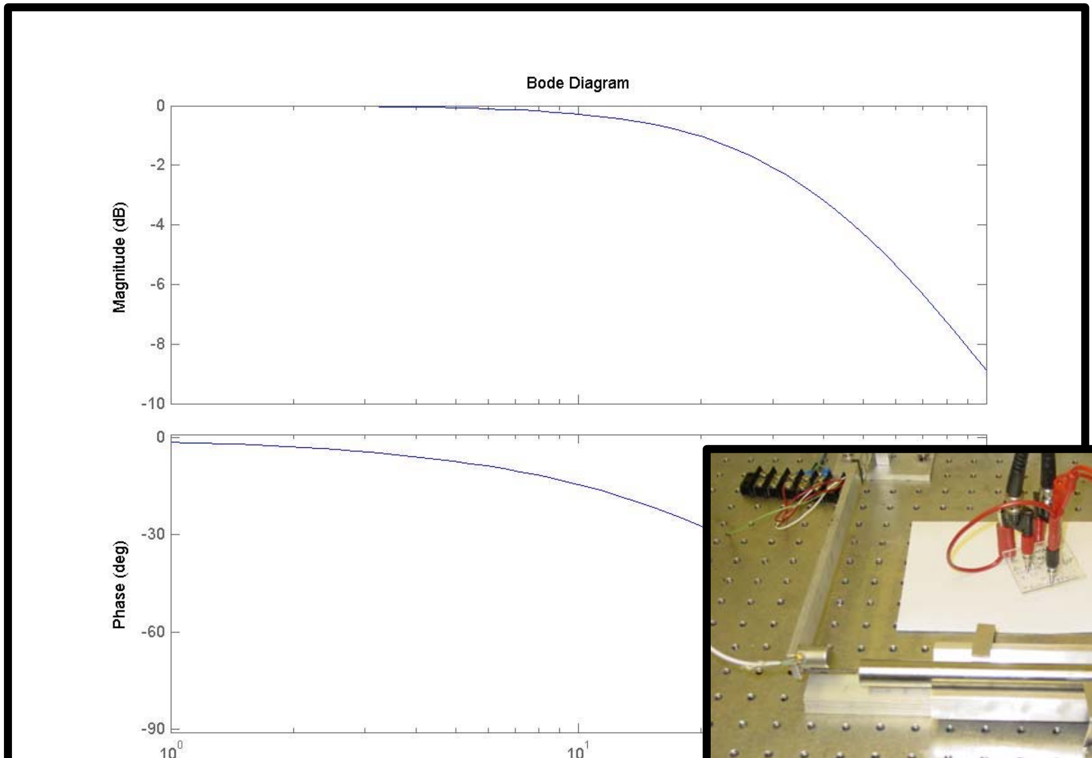
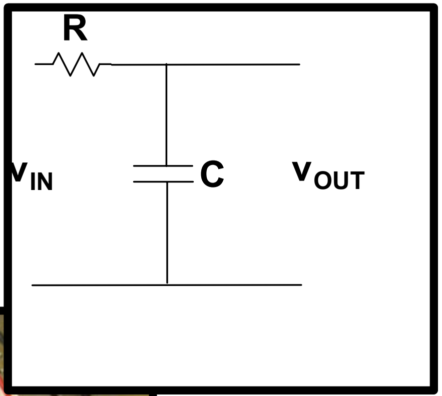
Phase V – The Real Work Begins

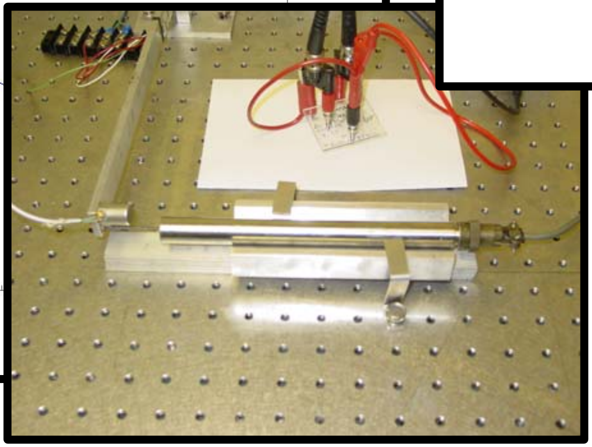
Frequency response verification



Noise filter – design RC circuit







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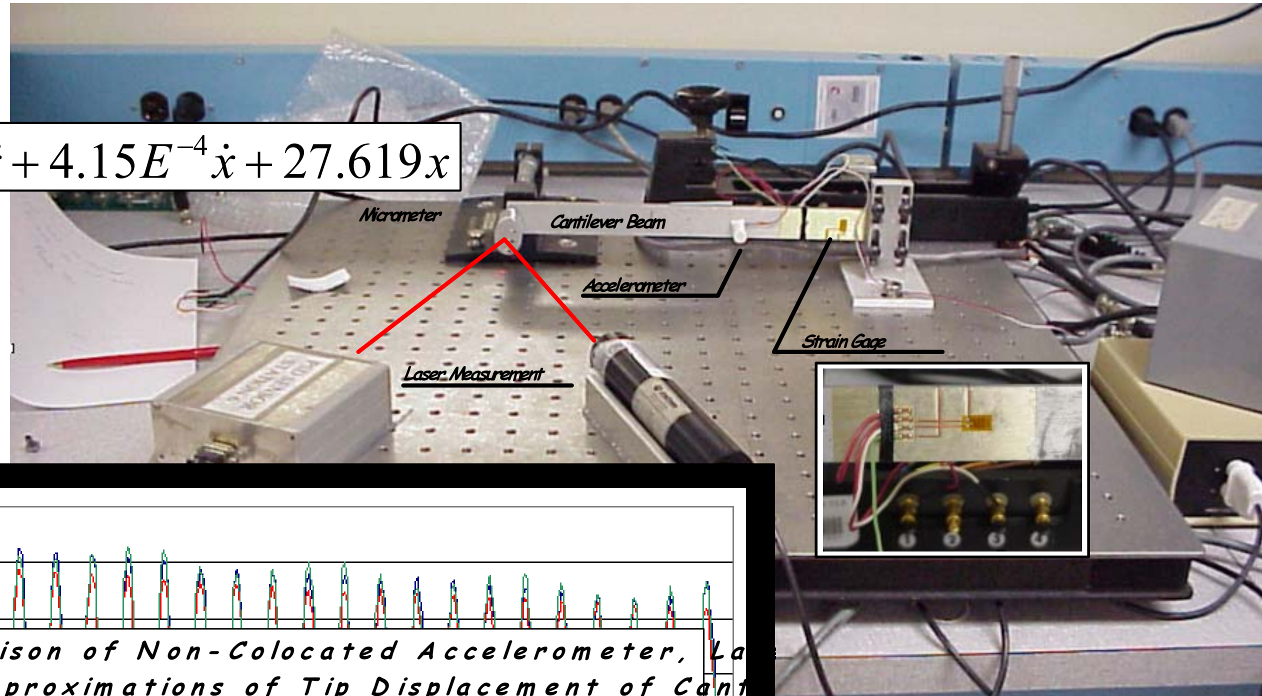
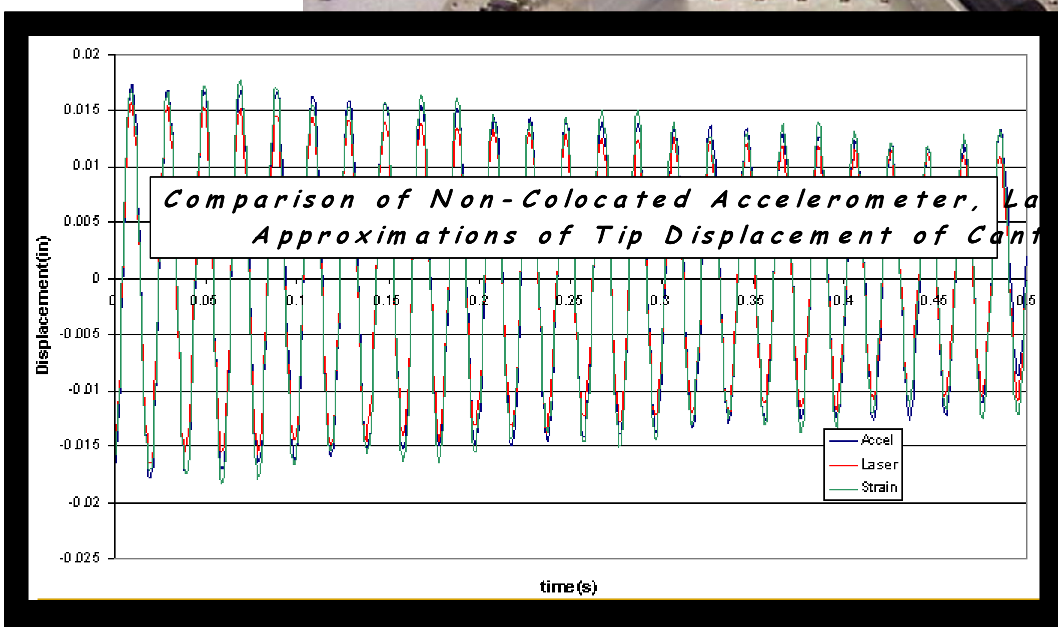
Phase V – Results Achieved

DYNamic SYStems

$$2.96E^{-4}\ddot{x} + 4.15E^{-4}\dot{x} + 27.619x$$



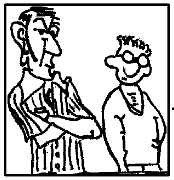


Course Administration

This project has been integrated into the second semester of the Mechanical Engineering laboratory for several years now.

The students are seniors when taking this required course and generally have had supporting courses

Dynamic Systems and Numerical Methods where dynamic models have been evaluated using tools such as MATLAB and Simulink



Course Administration

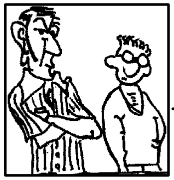
Laboratory time for each group is limited to 3 to 4 hour slots, once a week.

Students must do substantial "pre-work" to optimize their time available in the lab.

Usually 2 to 3 setups available for the AM and PM laboratory time slots, two days a week (normally Tuesday and Thursday lab times).

Additional time can be scheduled upon request

Students advised to utilize their time efficiently.



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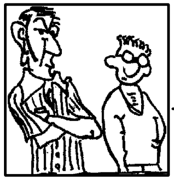
Course Administration

Project lasts 5 weeks at the end of the semester

Students work in teams of 3 to 4 people

Meet once a week with their professor to provide status, problems encountered, items to be performed next, etc.

Meetings conducted in an "employee/ supervisor" styled interaction.



Course Administration

Students need to organize their material and budget time in order to complete the project.

The professor's role is mainly to supervise and mentor the group.

A full format report is generated and an oral presentation is given.

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Observations

The students generally learn a tremendous amount of material in an integrated fashion to solve this problem. The task is not trivial.

The students generally enjoy the laboratory-based, hands-on project.

The real measurements tend to help the students clearly understand the need for basic STEM material to solve real engineering problems.

Summary

A complete measurement system is designed to obtain the response of a second order mechanical system.

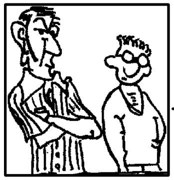
Students work in teams to measure the dynamic response at the tip of a cantilever beam using three non-colocated measurement devices.

Models are developed using spreadsheet calculations, MATLAB and/or SIMULINK to aid in the determination of the dynamic system response and provide a baseline for the expected results.

Summary

The students select three measurement devices from five possible types of transducers (including LVDT, accelerometer, laser, eddy current probe, and strain gage) and determine suitable locations for the transducers on the beam.

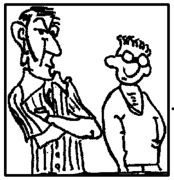
They must consider signal type, transducer sensitivity, etc. to provide the "maximum" signal for the ADC to be used for data acquisition.



Summary

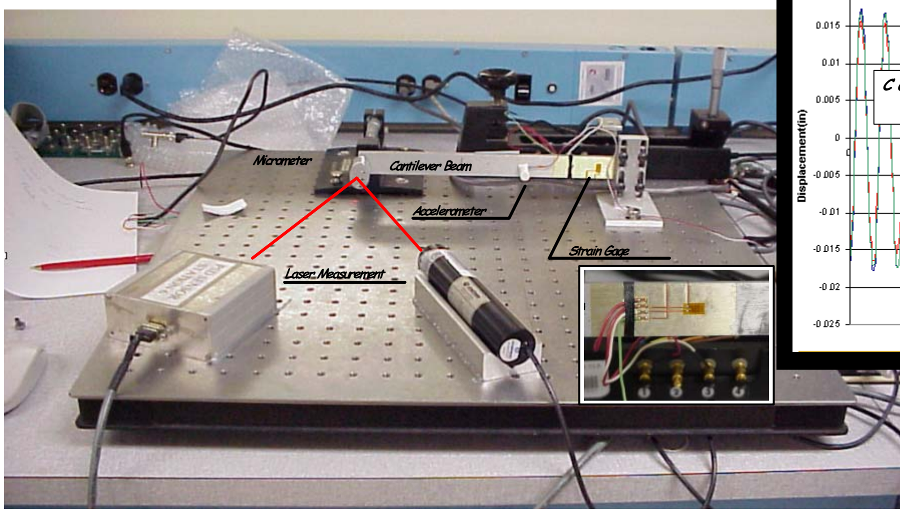
The non-colocated measurements are then spatially adjusted and integrated/differentiated to predict the tip displacement and acceleration of the cantilever beam.

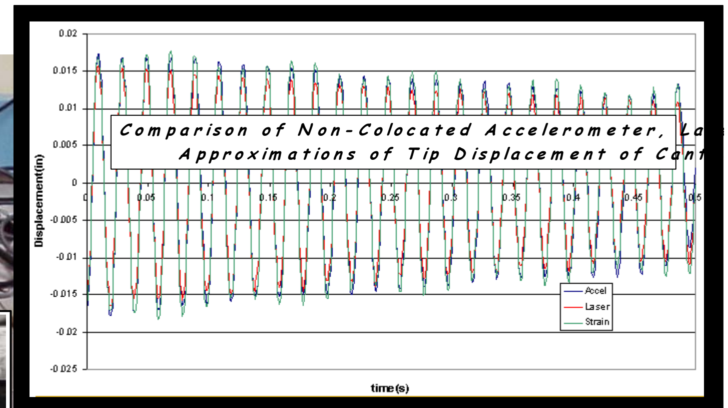
A full formal report is prepared to document all aspects of the project effort along with a formal presentation.



Outcome – Better Overall Understanding

DEVELOPMENT OF A MEASUREMENT SYSTEM FOR RESPONSE OF A SECOND ORDER DYNAMIC SYSTEM





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Acknowledgements

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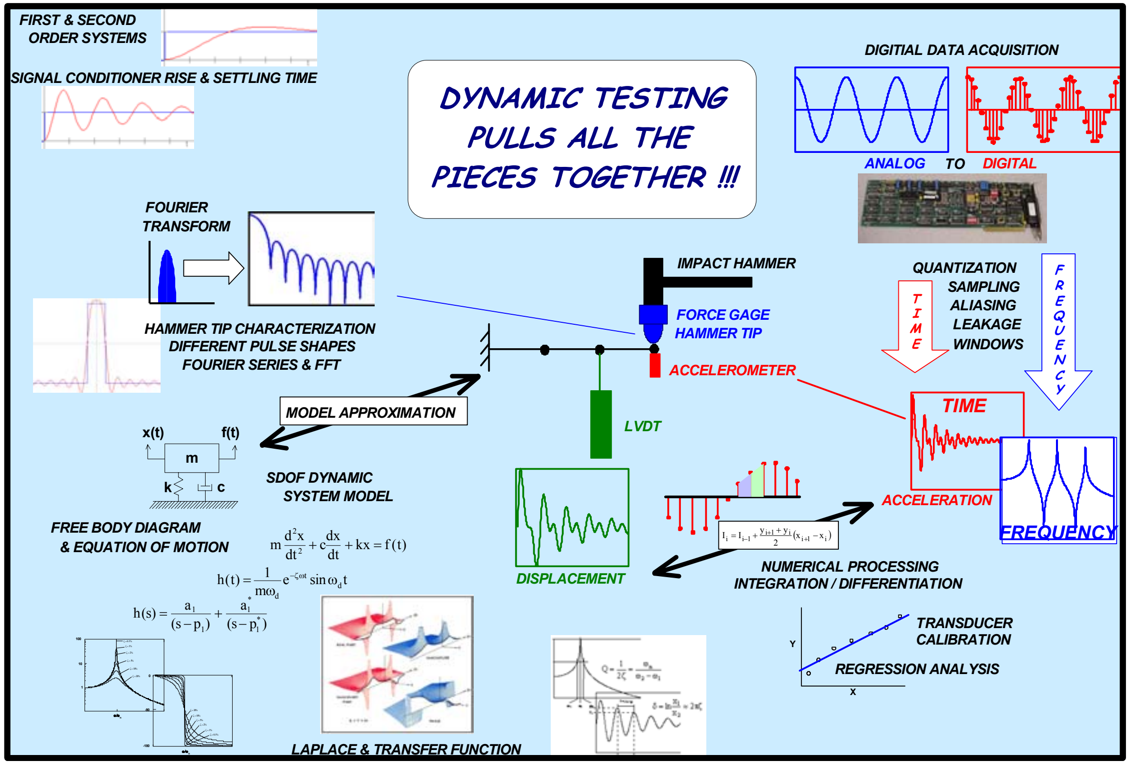
Multi-Semester Interwoven Project for Teaching Basic Core STEM Material Critical for Solving Dynamic Systems Problems



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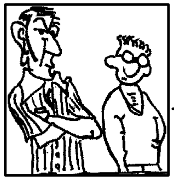
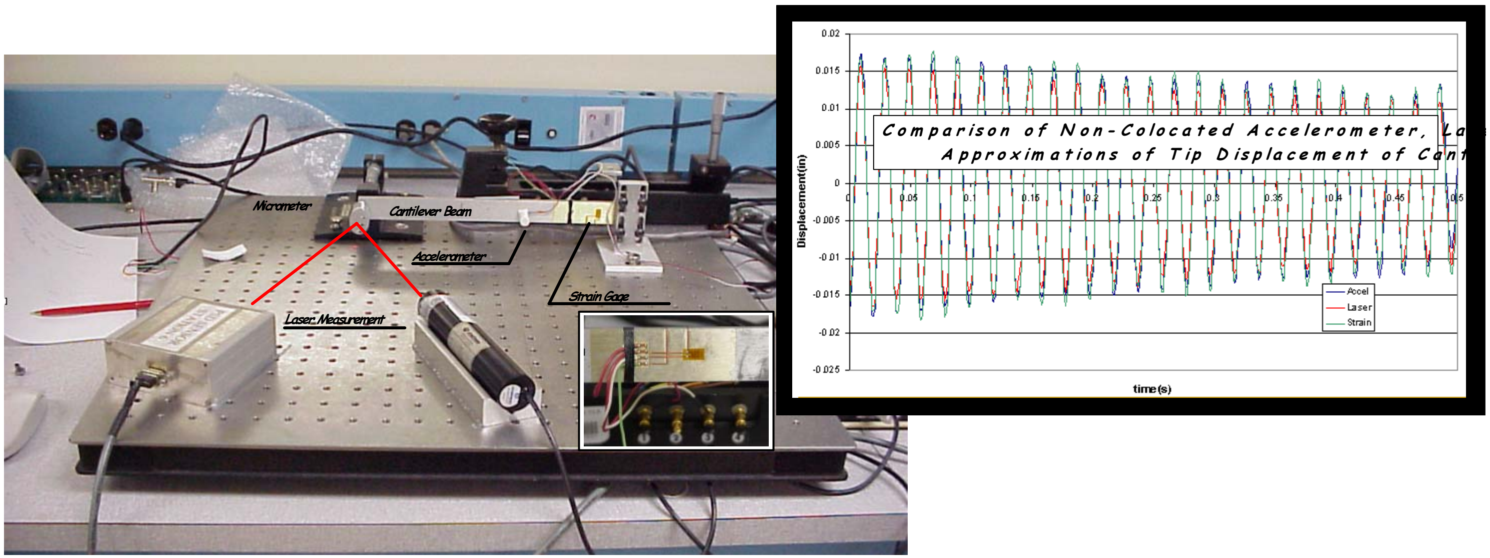


Outcome – Better Overall Understanding

DEVELOPMENT OF A MEASUREMENT SYSTEM FOR RESPONSE OF A SECOND ORDER DYNAMIC SYSTEM



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