



Developing a Virtual Model of a Second Order System to Simulation Real Laboratory Measurement Problems

System characteristics

Mass (kg), m: 100
 Damping (kg/sec), c: 5
 Stiffness (N/m), k: 1050

Initial condition and forcing function

Initial displacement (m), id: 0.01
 Impulse height, ih: 0
 Step height, sh: 0

Accelerometer

Sensitivity (V per m/sec²), as: 0.003
 Bias (V), ab: 0.04
 Slope of drift (V/sec), ad: -0.002

LVDT

LVDT sensitivity (V/m), Ls: 400
 LVDT bias (V), Lb: 10
 LVDT sinusoidal noise amplitude (V), Lna: 0
 LVDT sinusoidal noise frequency (Hz), Lnf: 150

RC Circuit Low-Pass Filter on LVDT

RCvalue, RC: 0.025

	m	c	k	id	sh	ih	as	ab	ad	an	Ls	Lb	Lna	Lnf	RC
Run1	50.0	5.0	50	0.010	0.00	0.00	0.003	0.04	-0.00	0.00	400	0.40	0.010	60.0	0.025
Run2	60.0	5.0	1050	0.010	0.00	0.00	0.003	0.04	-0.00	0.00	400	0.40	0.010	60.0	0.025

Simulation Output

Plot showing displacement (m) vs time (s) for Run1 (blue) and Run2 (green).

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The Problem

Most of the student's educational exposure is to well behaved, deterministic problems with known results.

Most courses expose students to

- material in modules in book chapters*
- with exercises/problems at end of the chapter*
- majority of the material found in chapter/book*





The Problem

Laboratory is the perfect place for students to become exposed to real world problems and solutions to those problems.

Laboratory is the perfect place to put student's knowledge of basic STEM material to the test.

However, many times the real world measurement is much more complicated than the textbook.

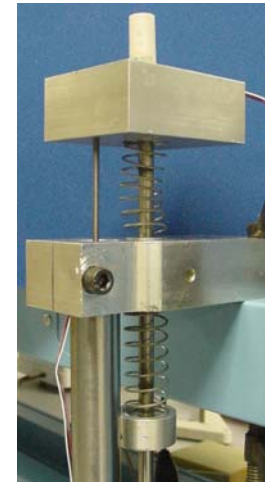
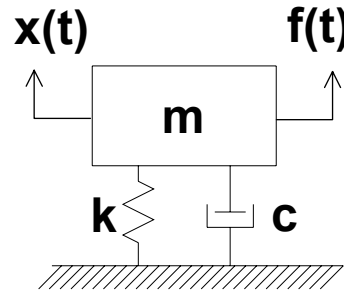
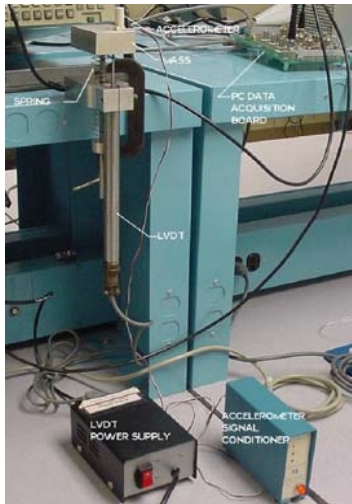
Students often struggle with methods and procedures to solve a real measurement problem (with no answer at the back of the book)





A Typical MCK Measurement System

A simple mass, spring, dashpot system is used to measure displacement and acceleration



Numerical processing of integration/differential needed to process data



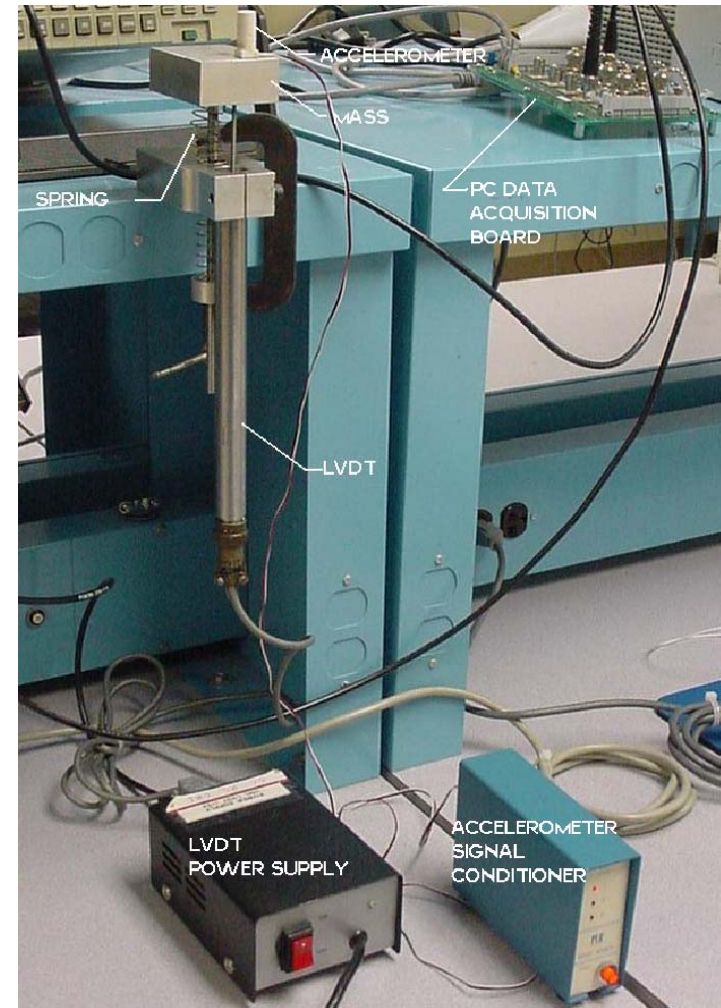


MCK Measurement System

Requires extensive use of a wide variety of different analytical tools.

Significant numerical data manipulation needed.

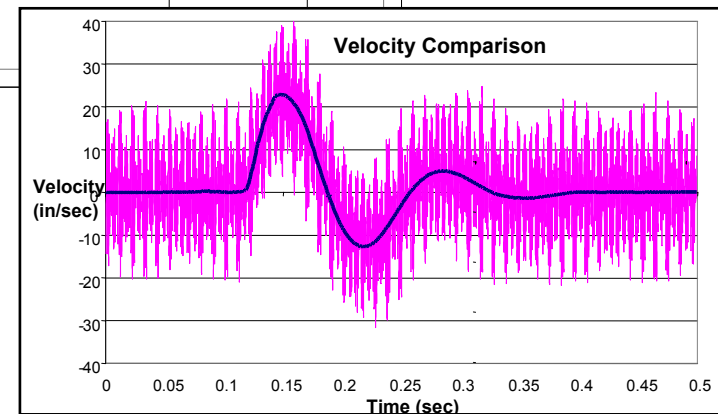
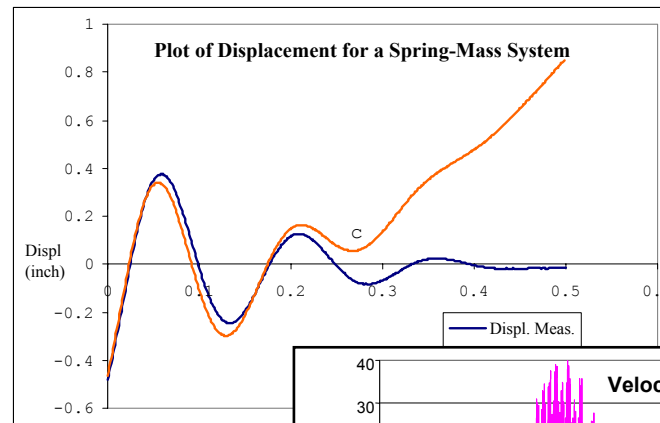
- *Regression Analysis*
- *Data Cleansing*
- *Integration*
- *Differentiation*





The data acquisition system and transducers are intentionally selected such that the majority of possible errors exist in the data

- *Drift*
- *Bias*
- *Offset*
- *Quantization*
- *Noise*

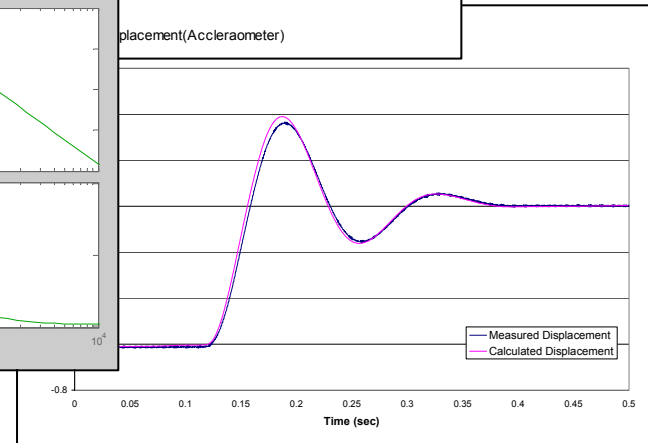
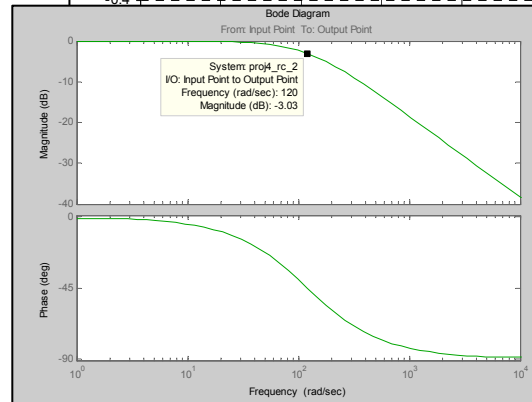
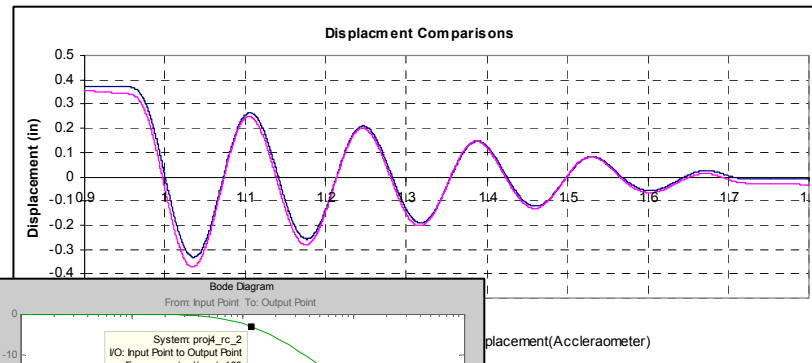




MCK Measurement System

The students are forced to integrate key STEM material and concepts to solve this problem

- *Numerical processing*
- *Filtering*
- *Thinking is required !!!*





The Virtual Measurement System

DYNAMIC
SYSTEMS

The real test configuration has many problems that all simultaneously plague the measurement.

Many times students are frustrated with the significant open-ended aspects of this exercise.

This is due to the large number of items that simultaneously plague the measurement.





The Virtual Measurement System

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In order to assist the student in understanding all of the individual effects, a virtual measurement system was developed.

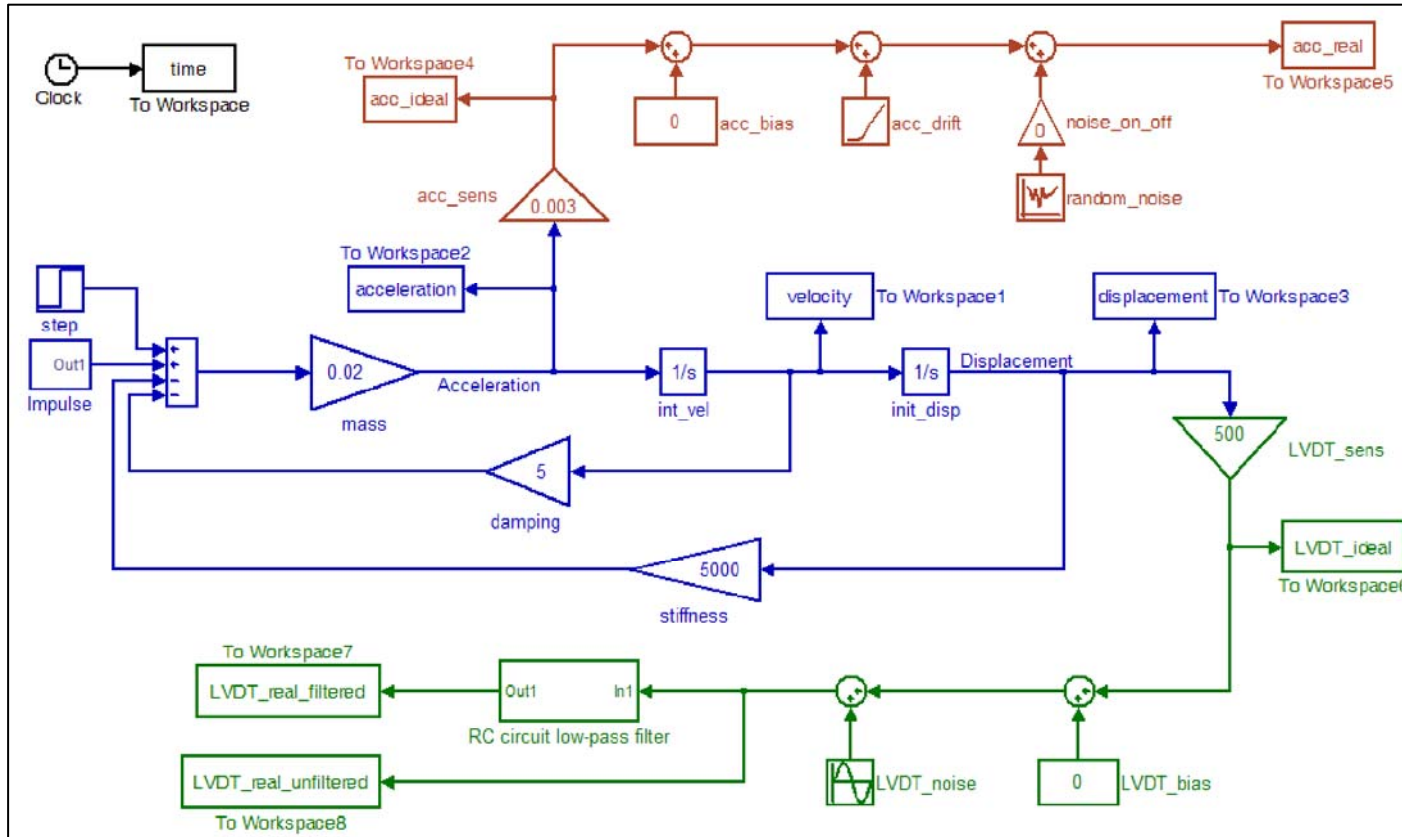
This enables the student to add individual effects and see the result on the measurement made.

The pieces of the Virtual Measurement System are described in the following sections.



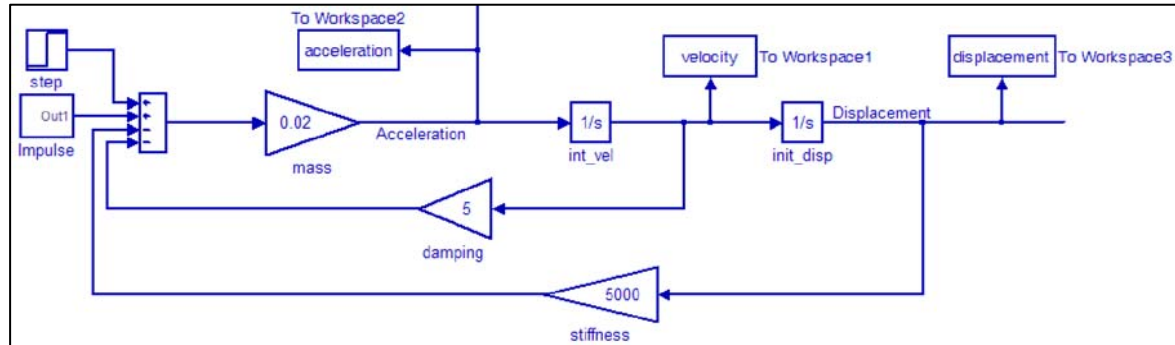


The entire Simulink model



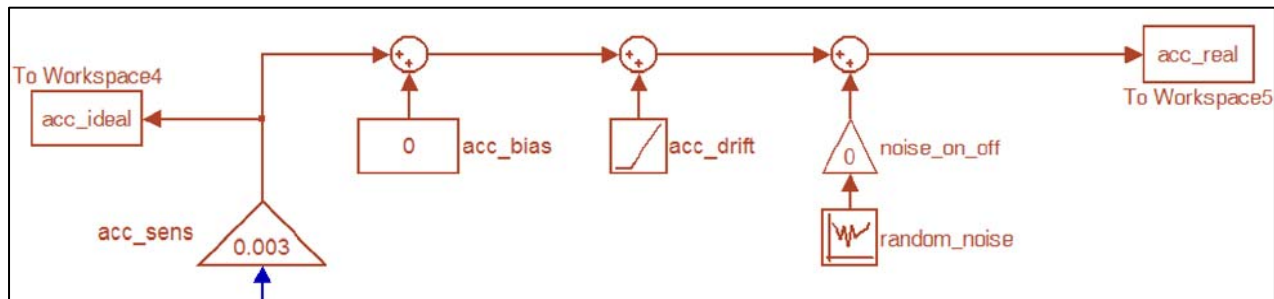


The SDOF system portion

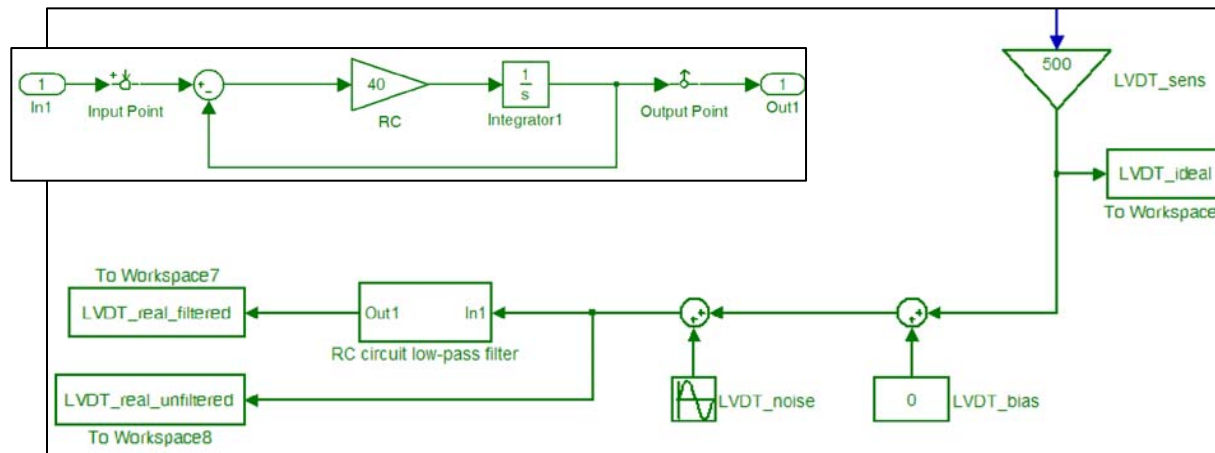




The accelerometer measurement portion



The LVDT & RC filter measurement portion





The Virtual Measurement System

DYNAMIC SYSTEMS

The entire GUI Interface

System characteristics

Mass (kg), m: 0 to 100 (50)

Damping (kg/sec), c: 5 to 100 (13.585)

Stiffness (N/m), k: 0 to 10,000 (5000)

Initial condition and forcing functions

Initial displacement (m), id: 0.01

Impulse height ih: 0

Step height sh: 0

Accelerometer

Sensitivity (V per m/sec²), as: 0.003

Bias (V), ab: -2 to 2 (0)

Slope of drift (V/sec), ad: -0.1 to 0.1 (0)

Add random noise

Peak noise amplitude (V), an: 1e+000 to 1 (0.001)

LVDT

LVDT sensitivity (V/m), Ls: 400

LVDT bias (V), Lb: -10 to 10 (0)

LVDT sinusoidal noise amplitude (V), Lna: 0 to 1 (0)

LVDT sinusoidal noise frequency (Hz), Lnf: 1 to 150 (60)

RC Circuit Low-Pass Filter on LVDT

RC value, RC: 1e-5 to 1 (0.025)

Simulate and store results

	m	c	k	id	sh	ih	as	ab	ad	an	Ls	Lb	Lna	Lnf	RC
Run1	50.0	13.6	5000	0.010	0.00	0.00	0.003	0.00	0.00	0.00	400	0.00	0.000	60.0	0.025

Plot options:

Remove | For selected run(s), plot:

- Displacement
- Velocity
- Acceleration
- Ideal accelerometer output
- Real-world accelerometer output
- Ideal LVDT output
- Real-world LVDT output, unfiltered
- Real-world LVDT output, filtered





The system characteristic definition of

*mass,
damping and
stiffness*

System characteristics

Mass (kg), m	0	100	50
Damping (kg/sec), c	-5	100	13.585
Stiffness (N/m), k	0	10,000	5000

*along with IC
and forcing function*

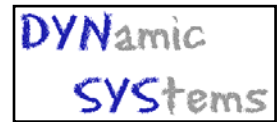
Initial condition and forcing functions

Initial displacement (m), id	0.01
Impulse height ih	0
Step height sh	0





The Virtual Measurement System



The accelerometer parameters can be entered

Accelerometer

Sensitivity (V per m/sec²), as: 0.003

Bias (V), ab: -2 2 0

Slope of drift (V/sec), ad: -0.1 0.1 0

Add random noise

Peak noise amplitude (V), an: 1e-100 1 0.001

along with the LVDT

LVDT

LVDT sensitivity (V/m), Ls: 400

LVDT bias (V), Lb: -10 10 0

LVDT sinusoidal noise amplitude (V), Lna: 0 1 0

LVDT sinusoidal noise frequency (Hz), Lnf: 1 150 60

and RC filter setting

RC Circuit Low-Pass Filter on LVDT

RC value, RC: 1e-5 1 0.025





Virtual Measurement System GUI

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User enters M , C , K system. User enters the amount of experimental distortion on the accel. (sensitivity, bias, drift) and displacement LVDT (sensitivity, bias, noise) and the low pass filter characteristics to virtually "simulate" the measurement environment.

Data can be exported with ability to select which outputs and what effects are included on the measurement.

The screenshot shows the 'basic_system' GUI with the following sections:

- System characteristics:** Mass (kg), m : 0.001 to 100 (59.9999); Damping (kg/sec), c : 5 to 100 (5); Stiffness (N/m), k : 0 to 10,000 (1050).
- Accelerometer:** Sensitivity (\sqrt{V} per m/sec^2), a_s : 0.003; Bias (V), a_b : -2 to 2 (0.04); Slope of drift (V/sec), a_d : -0.1 to 0.1 (-0.002); Add random noise: ; Peak noise amplitude (V), a_n : 1e-100 to 1 (0.001).
- Initial condition and forcing functions:** Initial displacement (m), i_d : 0.01; Impulse height, i_h : 0; Step height, s_h : 0.
- LVDT:** LVDT sensitivity (V/m), L_s : 400; LVDT bias (V), L_b : -10 to 10 (0.4); LVDT sinusoidal noise amplitude (V), L_{na} : 0 to 1 (0.01); LVDT sinusoidal noise frequency (Hz), L_{nf} : 1 to 150 (60).
- RC Circuit Low-Pass Filter on LVDT:** RC value, RC: 1e-5 to 1 (0.025).
- Simulation Results Table:**

	m	c	k	i_d	s_h	i_h	a_s	a_b	a_d	a_n	L_s	L_b	L_{na}	L_{nf}	RC
Run1	50.0	5.0	50	0.010	0.00	0.00	0.003	0.04	-0.00	0.00	400	0.40	0.010	60.0	0.025
Run2	60.0	5.0	1050	0.010	0.00	0.00	0.003	0.04	-0.00	0.00	400	0.40	0.010	60.0	0.025
- Simulation Output Plot:** Shows displacement (m) vs time (s) for Run1 (blue) and Run2 (green). Run1 shows a smooth sinusoidal wave, while Run2 shows a noisy sinusoidal wave.





Virtual Measurement Simulation

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The student can quickly study the measurement issues associated with drift, bias and offset.

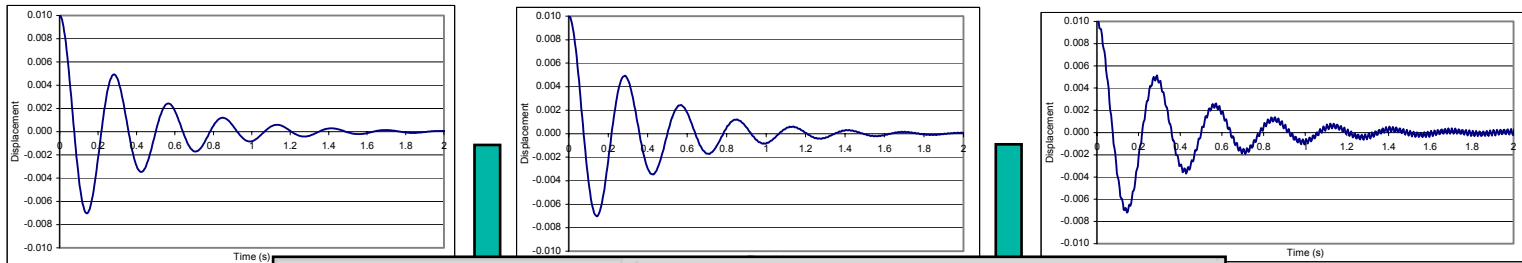
These effects are significant when numerically processing the data to perform differentiation and integration.

Several cases are shown to illustrate the usefulness of the Virtual Measurement System.





Differentiation of LVDT measurement and noise



No Noise

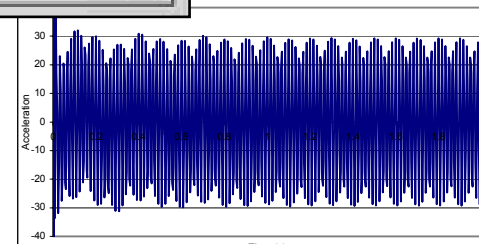
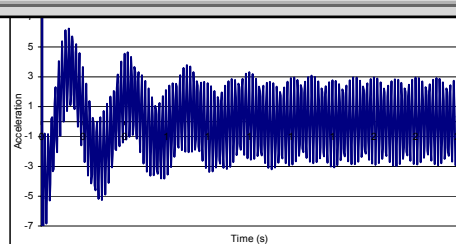
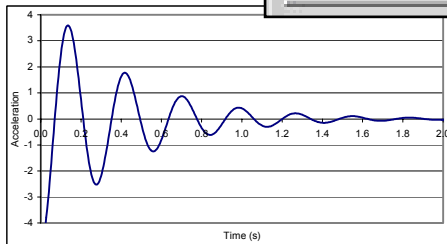
High Noise

LVDT

LVDT sensitivity (V/m), Ls

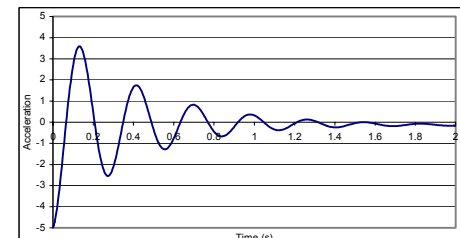
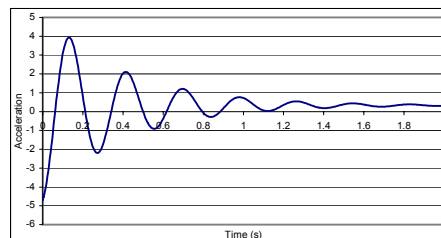
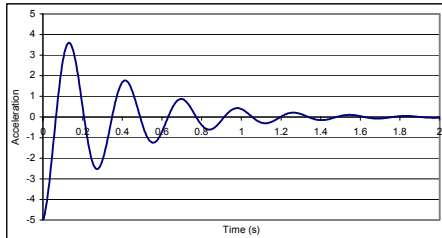
LVDT bias (V), Lb

LVDT sinusoidal noise amplitude (V), Lna





Integration of the accelerometer measurement



No Drift or Offset

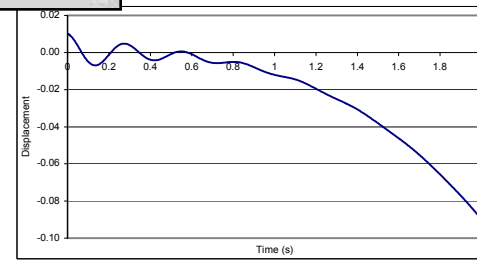
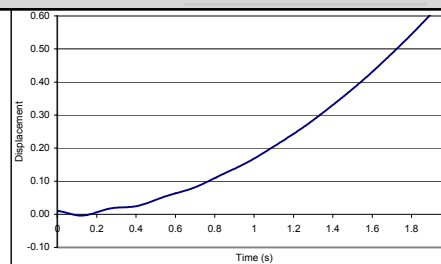
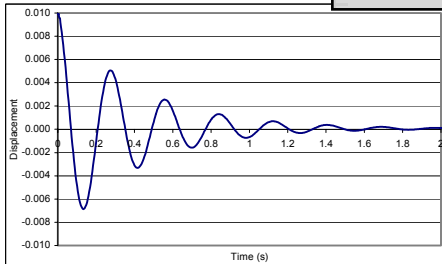
Negative Drift

Accelerometer

Sensitivity (V per m/sec²), as

Bias (V), ab

Slope of drift (V/sec), ad





Summary

Students tend to struggle when trying to process real world measurements.

All of their STEM knowledge must come to bear to solve these types of problems.

A Virtual Measurement System was developed to assist students in breaking down the measurement problem into pieces which all contribute to the distortion of the real measurement.

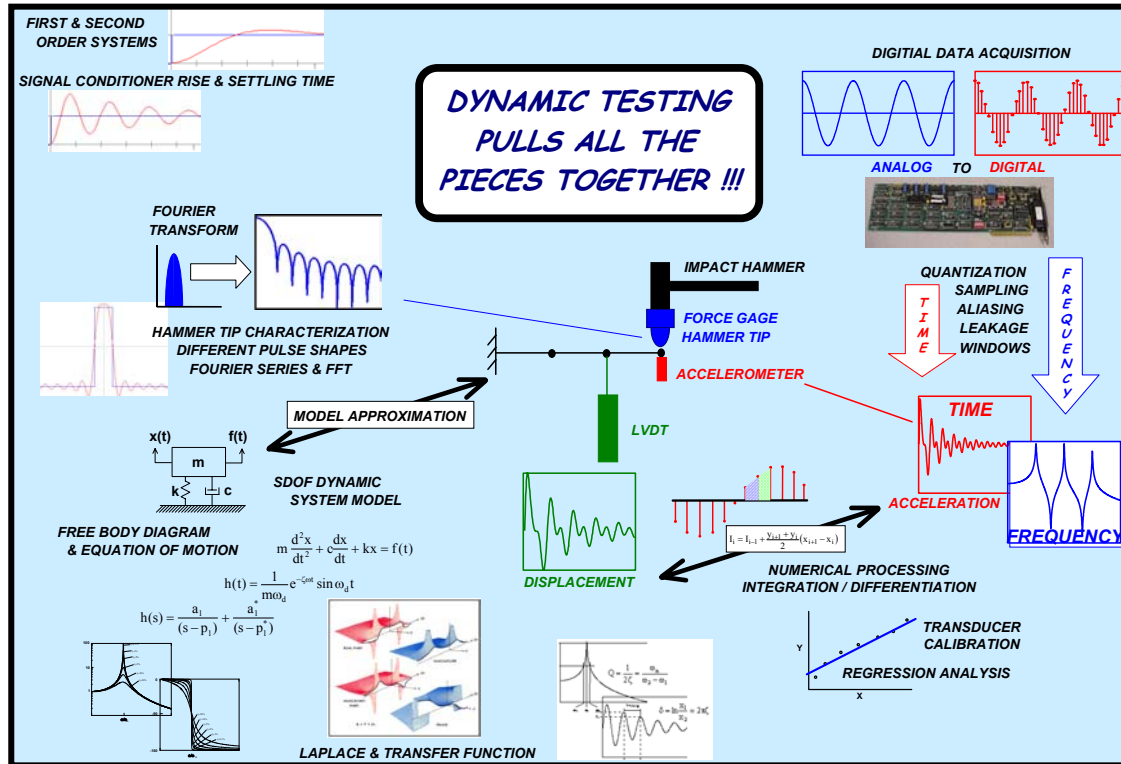




Acknowledgements

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



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