Mechanical Engineering Department **Lowell, Massachusetts 01854**
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Response Tests of SDOF M,C,K Model (aka RUBE II)

Purpose

The intent of this project is to acquire data on a simple mass, spring, dashpot mechanical system in order to characterize this dynamic system. The system will be given an initial displacement and measurements of displacement and acceleration will be acquired. The generic MATLAB and Simulink models already developed will be modified to predict the system response.

Model for Evaluation

The system used for evaluation can be approximated by a single-degree-of-freedom lumped mass model defined by a second-order differential equation with constant coefficients. The physical system has a variable leaf spring support condition whose effective length is different for each collected data set. The mass of the system also varies due to a slowly changing water reservoir that comprises part of the effective mass of the system. The model is shown in Figure 1.

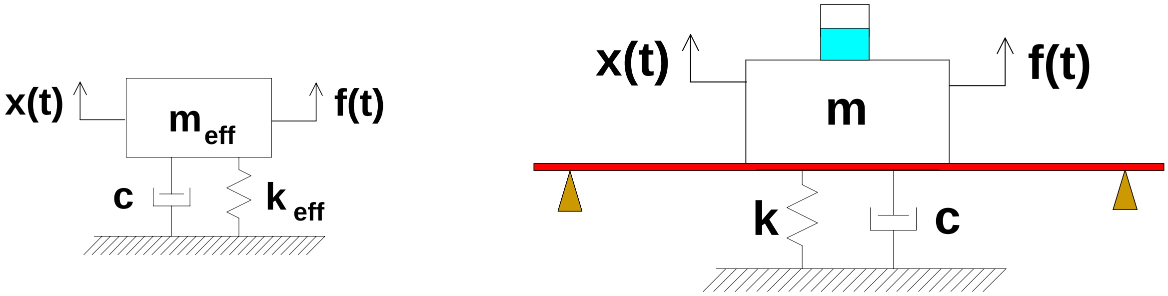


Figure 1 – Single Degree of Freedom Model of RUBE Configuration

The RUBE system (Response Under Basic Excitation) is described in more detail as an appendix. In this project, the system is excited with three different displacement initial conditions. The displacement of the system is measured with an LVDT (Linear Variable Differential Transformer) with a nominal sensitivity of 10 V/in. The acceleration of the system is measured with three accelerometers with nominal sensitivities of 10 mV/g, 100 mV/g and 1 V/g. The data is captured with a digital data acquisition system and stored as a text file (with data arranged in columns as time, displacement, the three accelerations in order of increasing sensitivity, and finally a force transducer used with impact excitations). Impact data should be taken at the time displacement data is taken and saved for use in a later project.

In order to determine physical parameters for use in the MATLAB and SIMULINK models, the mass, damping and stiffness must be determined. Estimates of the mass of the system can be obtained from weight measurements and/or volumetric calculations. Estimates of the stiffness of the system can be made from either effective stiffness calculations or from natural frequency and mass estimates. Details on the system's mass and stiffness can be found in Appendix B. Estimates of the damping can be made from time decay estimates of the measured data.

Task – Identify System Parameters From ONE IC and Predict Response for Another IC

Using the measured data from ***only one*** of the three displacement initial conditions, determine the effective properties of the system. Enter the system characteristics (m, c, and k) into the Simulink model to predict the response of the system. Compare this model result to the time response used to calculate the system characteristics. Overlay the estimated, derived model response on the measured response.

Using one of the other remaining sets of displacement initial conditions, predict the response of the system using the model developed, and compare to the actual measured result for that initial condition. (Do not use the same initial condition data that was used to characterize the system above). Overlay this predicted response on the measured response.

Impact data sets are not to be analyzed in this project, but should be obtained at the same time as the data used in the project and stored in a safe place for use in a later assignment.

For all analyses performed, a SIMULINK model ***must*** be developed. (Other solutions using closed form hand solutions or MATLAB solutions can be used to further justify results obtained; these are not required for the report write up since these are essentially the same as the SIMULINK model results.) All measurements are in the English system and results are to be reported in the English system.

Please make sure that all of the following items are clearly addressed in the report.
- The determination of the parameters of the model used (effective mass, estimated damping and equivalent stiffness) must be identified.
- Identify the natural frequency, damped natural frequency and percent of critical damping
- Assumptions used in the estimation of these parameters must be identified.
- The model predicting the response must be identified.
- A plot of the predicted displacement response must be provided and compared to (overlaid on) the measured response; the acceleration response may be used to further substantiate the results.

Post Analysis and Report– (GROUP Report)

A group memo report (signed by all members of the group) describing the estimation of parameters from the measured data is to be provided along with a comparison of the measured data and models described above. The format to be followed is typical of any report with at least

1- Introduction, 2- Discussion, 3- Conclusions

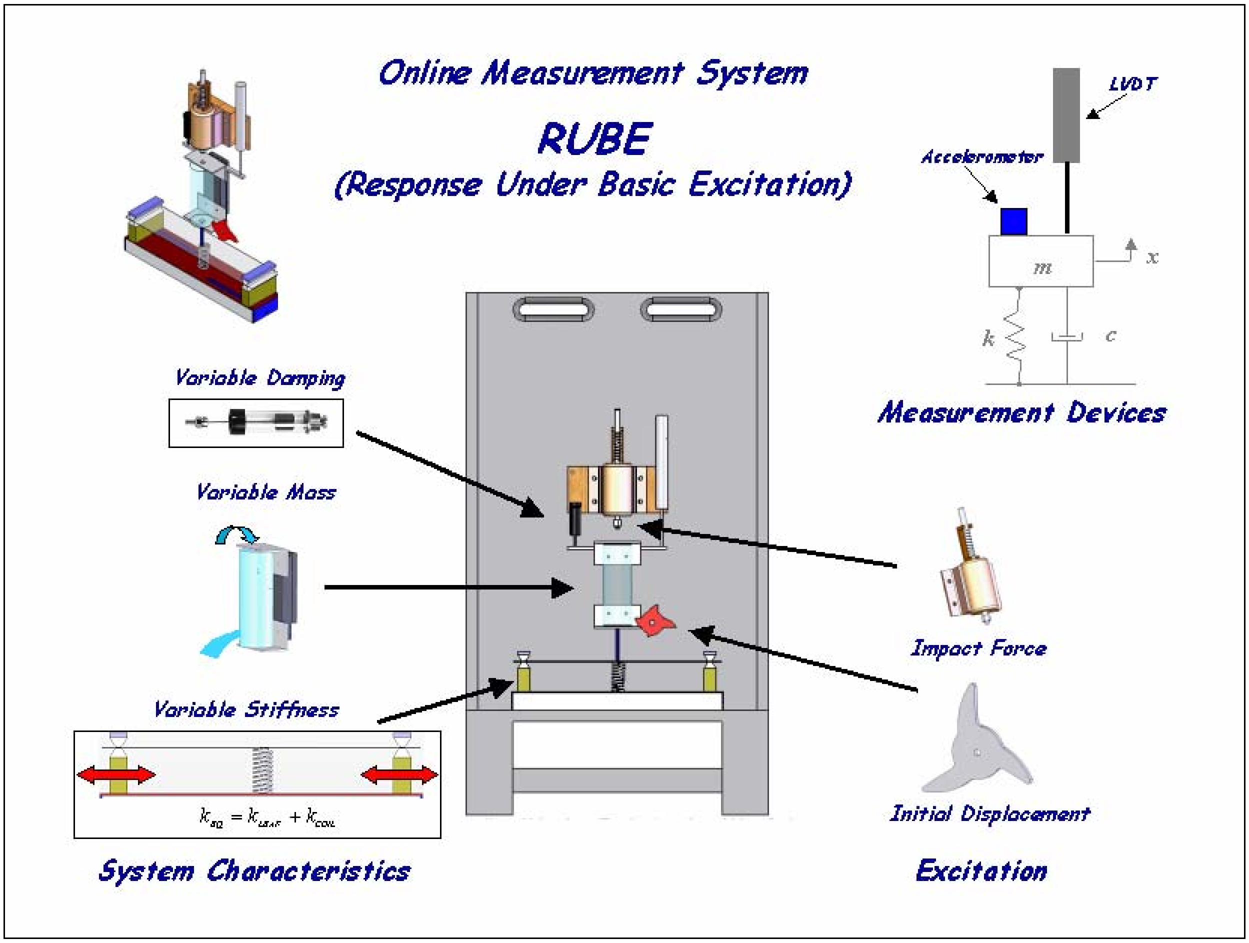
Appendices need to be included to address other information regarding test setup/acquisition, backup calculations or analytical derivations, detailed estimation of system characteristics and other material that is considered appropriate to justify and substantiate your model and analysis performed. The appendices are intended to contain detailed information that is too lengthy for the main part of the report. The main part of the report must be typed but the appendices may contain a combination of handwritten and computer generated results; all sections must be legible and clearly marked and organized appropriately.

APPENDIX A

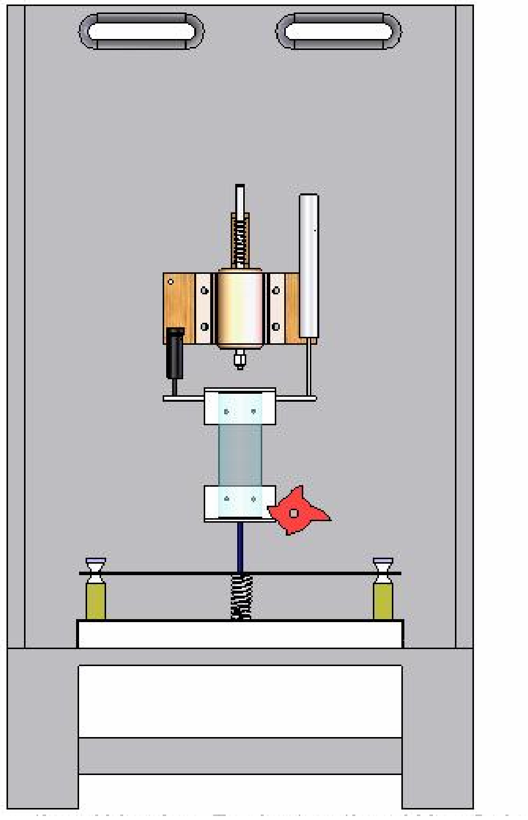
DESCRIPTION OF RUBE II (Response Under Basic Excitation) SYSTEM

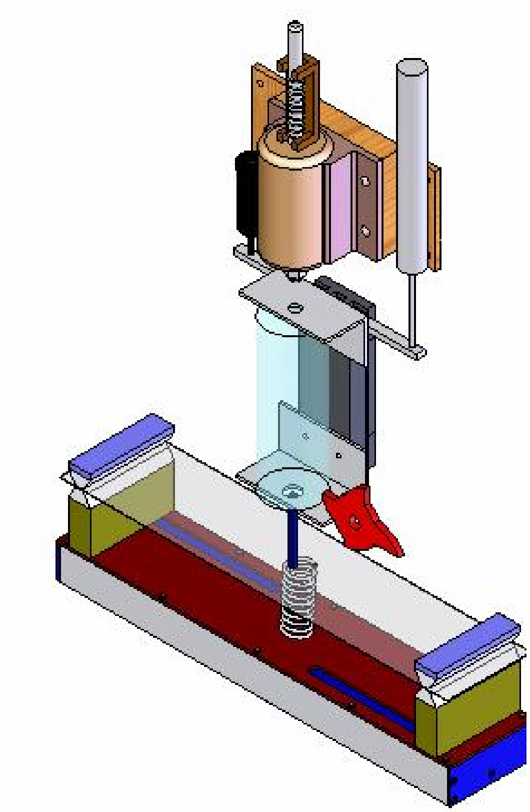
This appendix describes the components of the online acquisition system used for the second order system response characterization. The system is a second order mechanical mass, spring, dashpot system that can be subjected to initial displacement and impulsive excitations. The mass and stiffness are variable parameters that change each time the system is excited. The response of the system is measured using displacement and acceleration transducers to capture the dynamic response of the system. A data acquisition system is provided for the acquisition of the system response.

The overview schematic of the online measurement system is shown in the figure below.



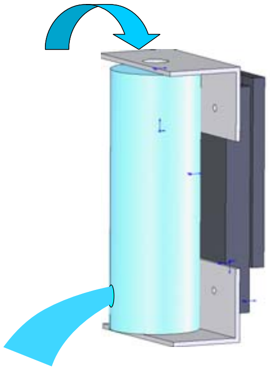
A larger view of the overall system as well as an isometric view of the system are shown below.



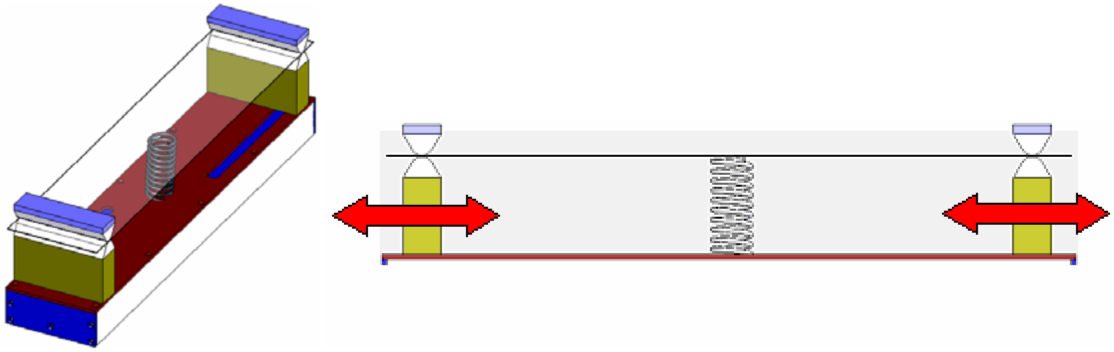


The mechanical system is described by a mass, damping and stiffness. The mass and stiffness are variable parameters; the damping is provided by an air dashpot.

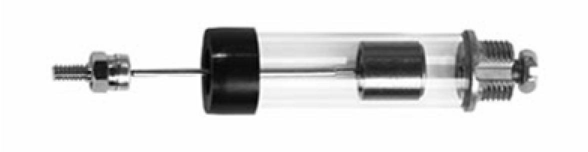
Variable mass is achieved by using a water reservoir to provide a constantly changing mass of the system. This variable mass allows the total mass of the system to vary by approximately 15%,



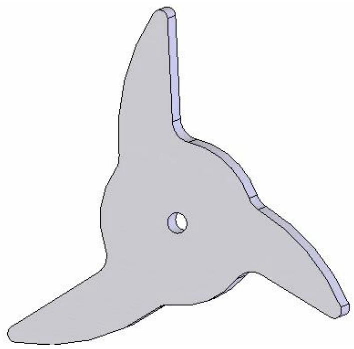
Variable spring stiffness is achieved with a variable length leaf spring supported with a coil spring. The variable spring stiffness allows the total spring stiffness to vary by approximately 20%. The leaf spring length is adjusted by a rack and pinion system that adjusts the support location for the leaf spring. A visual indication of the distance between the supports is identified by a scale and can be determined from the video file.

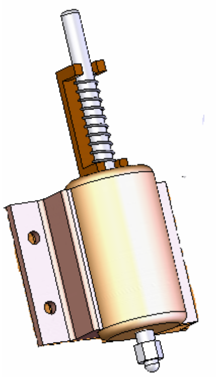


Dissipative forces are provided by an air dashpot with variable bleed orifice; the entire system is guided by a low friction linear bearing system which is a very small portion of the entire dissipative force.



Input excitations are provided as an initial displacement via cam with three different length lobes and an impulse via a solenoid device.





APPENDIX B:

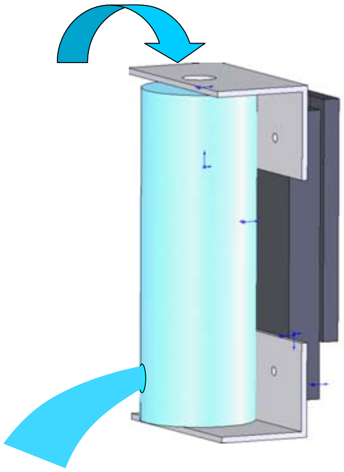
ADDITIONAL INFORMATION ON THE RUBE II SYSTEM

This online experiment allows the user to collect data on the motion of a second-order mass-spring-dashpot system. The properties of the system vary with time—the moving mass of the system includes a small water tank which fills and gradually drains, and the spring portion of the system includes a leaf spring which changes in length each time the system is activated. In addition, three different initial displacements and an impulse are available as inputs to the system. Consequently, each user of the system will obtain slightly different results. Multiple different transducers are used to collect acceleration, displacement and input force data. Good transducers are available, which provide relatively clean data. However, “bad” transducers—contaminated by noise, drift, or bias—are also used.

Mass Related Components

The moving mass of the system consists of the sum of the mass of the water and the mass of all of the other moving parts of the system.

The water tank has an inner diameter of 2.4 inches, and a maximum possible water height of 6 inches. The height of the water in the tank for each run can be determined from the video/photograph of the system. Though the level of water in the tank is changing continuously, the mass of water in the tank only changes a very small amount during one system run (think leaky faucet).



The assembled mass of the system was measured by unbolting the oscillatory system from the coil and leaf springs and weighing it repeatedly with two fish scales (one mechanical and one digital). The system was weighted in configurations with the water bottle both empty and filled to the ’10 oz’ mark. The measured weight of the assembled system in the empty and full configurations can be seen in the table Below.

Weight of Assembled RUBE System.

Condition	Weight (lb)
Empty Water Bottle	3.81
Water Bottle Filled to '10 oz' (4.3") Mark	4.51

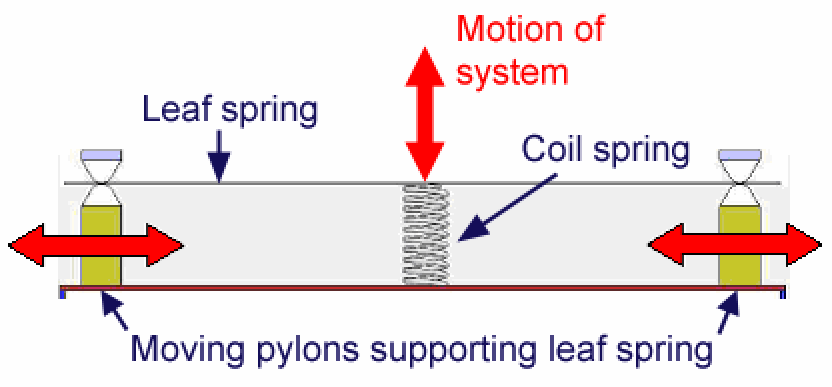
In addition to the assembled system, certain components of the system were weighted individually and can be seen in the table below.

Component Weights

Component	Weight (Ounces)
Water Reservoir (with valve)	1.73
Inlet hose	0.54
Outlet hose (including water)	0.18
Linear bearing	28.80
Brackets, nuts, washers, etc.	13.56

Stiffness Related Components

The stiffness related components consist of a coil spring and a leaf spring as shown in the figure below. The coil spring is fixed in dimension but the leaf spring has a variable length (between 10 to 14 inches) which changes every time the acquisition system is initiated.



The properties of the coil spring are:

Property	Value
Spring material	Round steel music wire, closed ends close
Uncompressed Length	3.1 in
Outside Diameter (OD)	0.89 in
Wire Diameter (d)	0.062 in
Total Number of Coils	18.5

The properties of the leaf spring are:

Property	Value
Material	2024-T3 Aluminum
Length	9 in to 14 in
Thickness	0.032 in
Width	4 in

Effective stiffness characteristics can be determined from a Dynamic Systems textbook, from material on mechanical systems, from any Design of Machine Elements textbook or from Mechanical Engineering handbooks.

In addition to analytical methods for determining these stiffnesses, extensive data on the leaf and coil springs were collected for various effective lengths and is shown in the tables and figures below.

Using a model 4464 Instron machine, the stiffness of the leaf spring and coil spring were determined. For the coil spring, the force-deflection data can be seen in Table B1.

Table B1. Force Deflection Data for Coil Spring.

Displacement (in)	Force (lb)
0	-0.08
0.222	0.84
0.465	1.68
0.63	2.27
0.863	3.09
1.055	3.82
1.348	4.94
1.477	5.47

The data seen in Table B1 was plotted as can be seen in Figure 1.

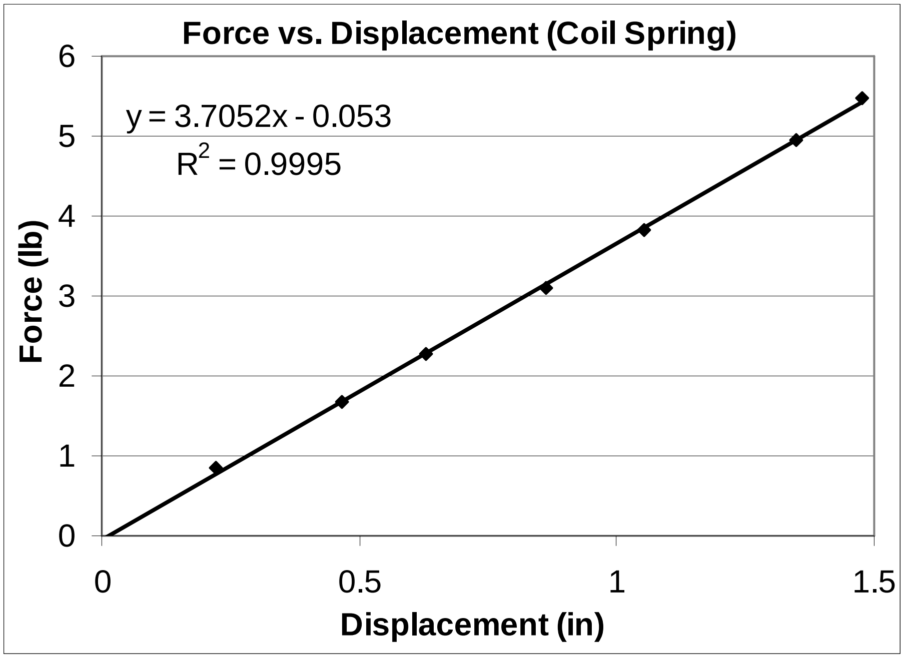


Figure B1: Force vs. Displacement of Coil Spring.

Force vs. displacement data was also taken for the leaf spring, The leaf spring force-displacement data was taken with the support clamps in place. The force-displacement data for the leaf spring can be seen in Table B2.

Table B2: Force-Displacement Data for Leaf Spring with Support Clamps in Place.

Supports 14" Apart		Supports 13" Apart		Supports 12" Apart	
Deflection (in)	Load (lb)	Deflection (in)	Load (lb)	Deflection (in)	Load (lb)
0.115	0.35	0.119	0.44	0.132	0.68
0.237	0.7	0.186	0.68	0.211	1.04
0.33	0.96	0.252	0.9	0.301	1.46
0.418	1.21	0.361	1.29	0.402	2
0.484	1.4	0.473	1.72	0.505	2.54
0.577	1.68	0.556	2.08	0.647	3.35
0.662	1.99	0.673	2.58	0.764	4.07
0.753	2.29	0.751	2.92	0.892	5.1
0.806	2.5	0.823	3.26		
0.904	2.8	0.912	3.77		

Table B2: Cont.

Supports 11" Apart		Supports 10" Apart		Supports 9" Apart	
Deflection (in)	Load (lb)	Deflection (in)	Load (lb)	Deflection (in)	Load (lb)
0.117	0.77	0.095	0.74	0.094	1.01
0.196	1.22	0.218	1.75	0.183	2.02
0.269	1.68	0.334	2.71	0.294	3.32
0.365	2.27	0.419	3.43	0.353	4.05
0.47	2.99	0.494	4.16	0.434	5.11
0.582	3.8	0.577	4.98	0.509	6.13
0.704	4.75	0.641	5.63	0.6	7.42
0.798	5.58	0.727	6.56	0.687	8.83
		0.834	8.06	0.756	10.07

The force-displacement curves of the leaf spring with varying distances between supports can be seen in Figures B2-B7.

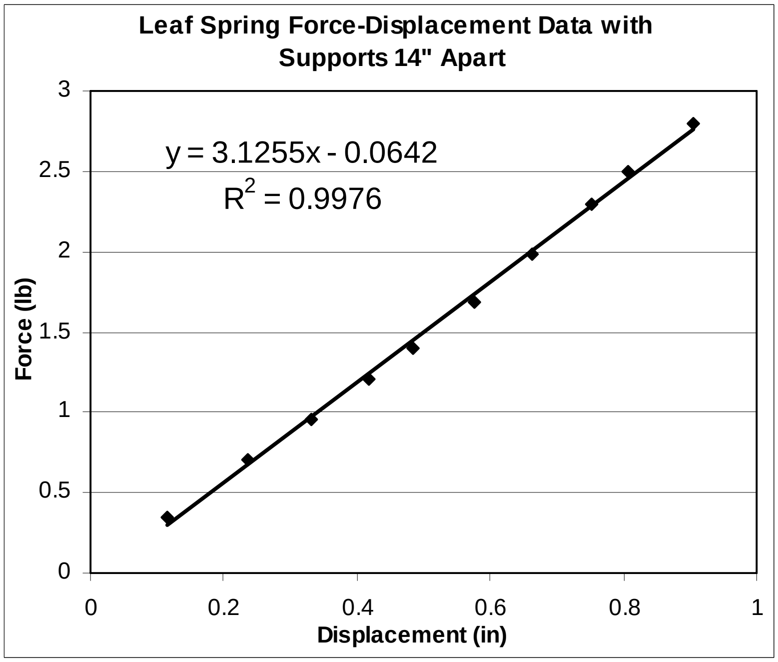


Figure B2: Leaf Spring Force-Displacement Data with Supports 14” Apart.

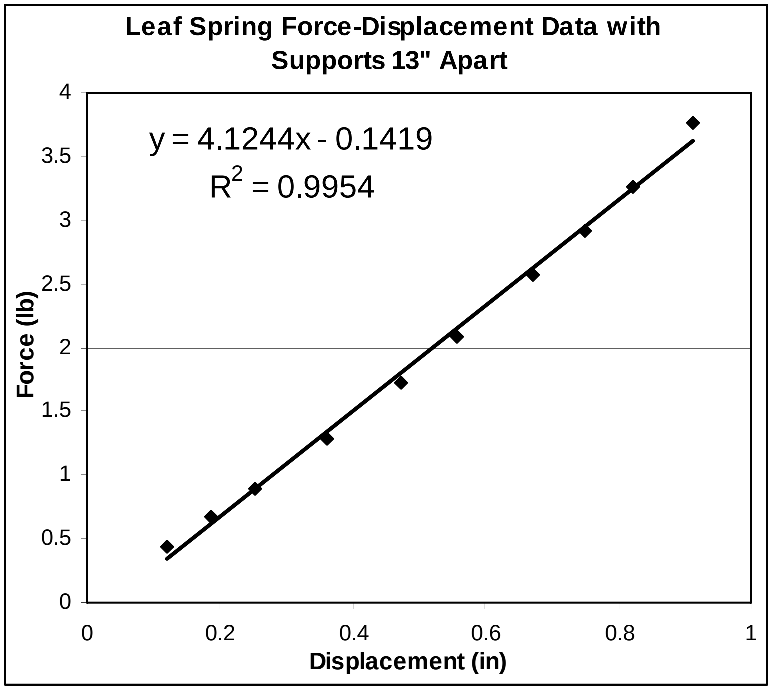


Figure B3: Leaf Spring Force-Displacement Data with Supports 13” Apart.

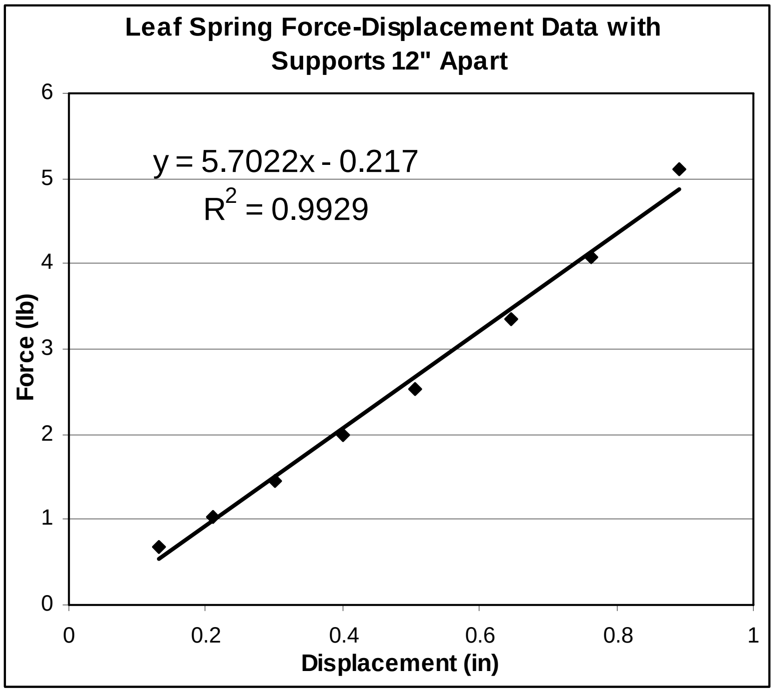


Figure B4: Leaf Spring Force-Displacement Data with Supports 12” Apart.

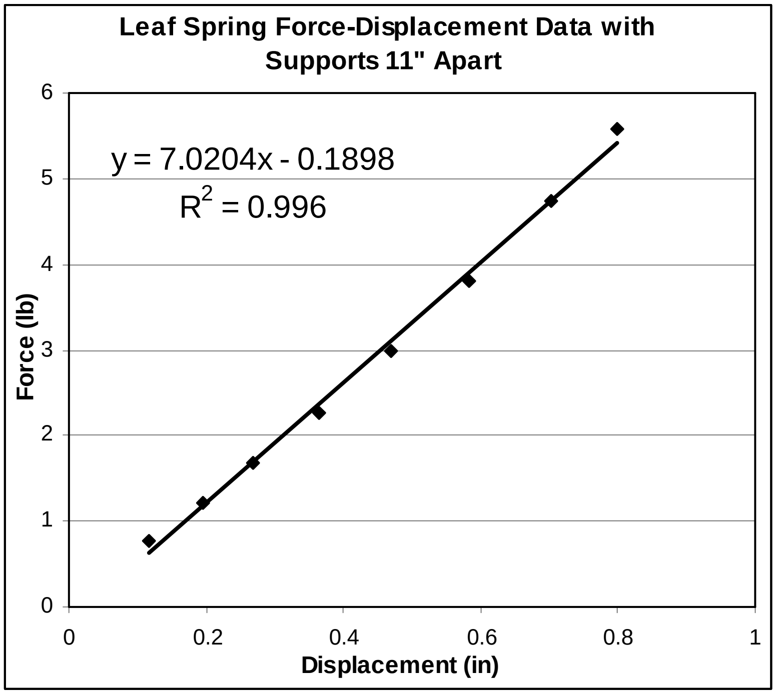


Figure B5: Leaf Spring Force-Displacement Data with Supports 11” Apart.

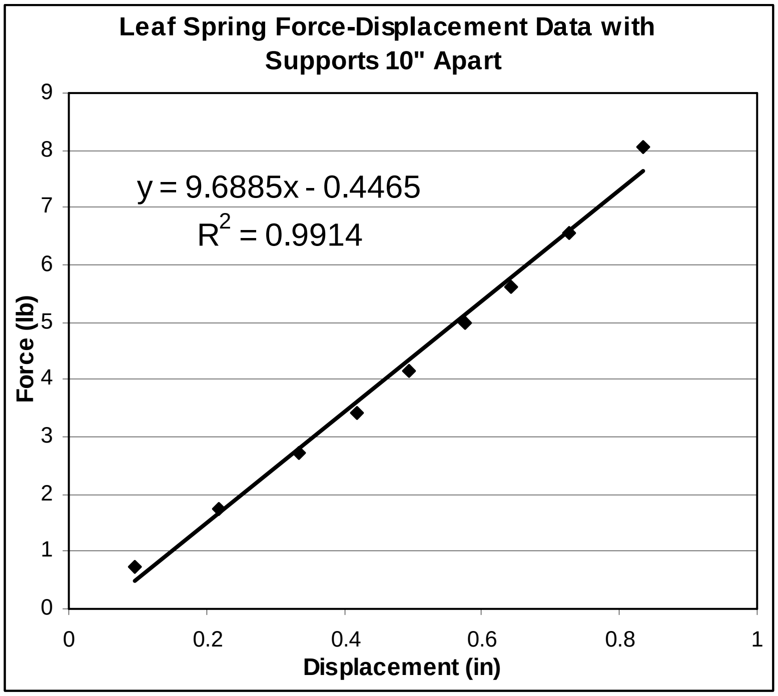


Figure B6: Leaf Spring Force-Displacement Data with Supports 10” Apart.

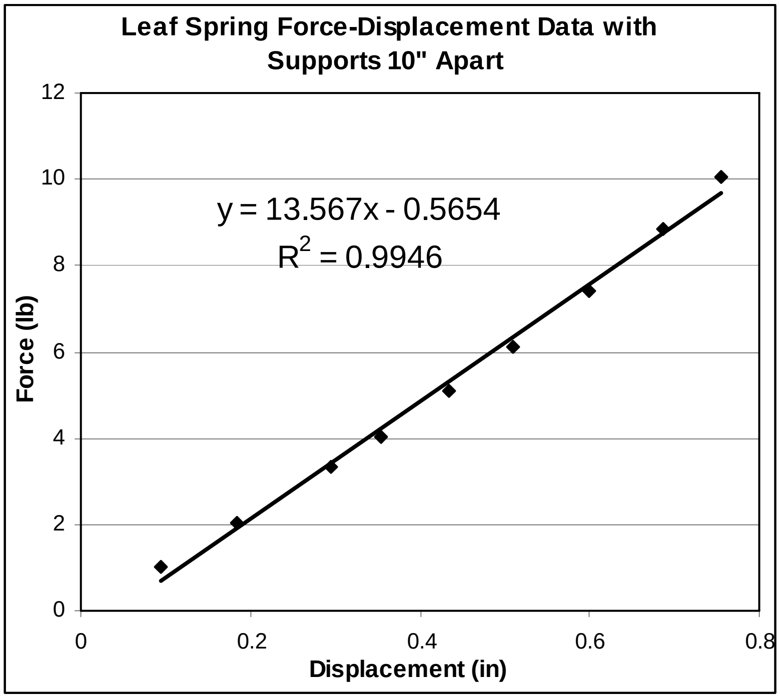


Figure B7: Leaf Spring Force-Displacement Data with Supports 9” Apart.

A summary of Figures B2-B7 can be seen in Table 3.

Table B3: Distance Between Supports vs. Measured. Leaf Spring Stiffness

Support Distance (in)	Stiffness (lb/in)
14	3.13
13	4.12
12	5.70
11	7.02
10	9.69
9	13.57

A plot of how spring stiffness varies with distance between supports can be seen in Figure B8.

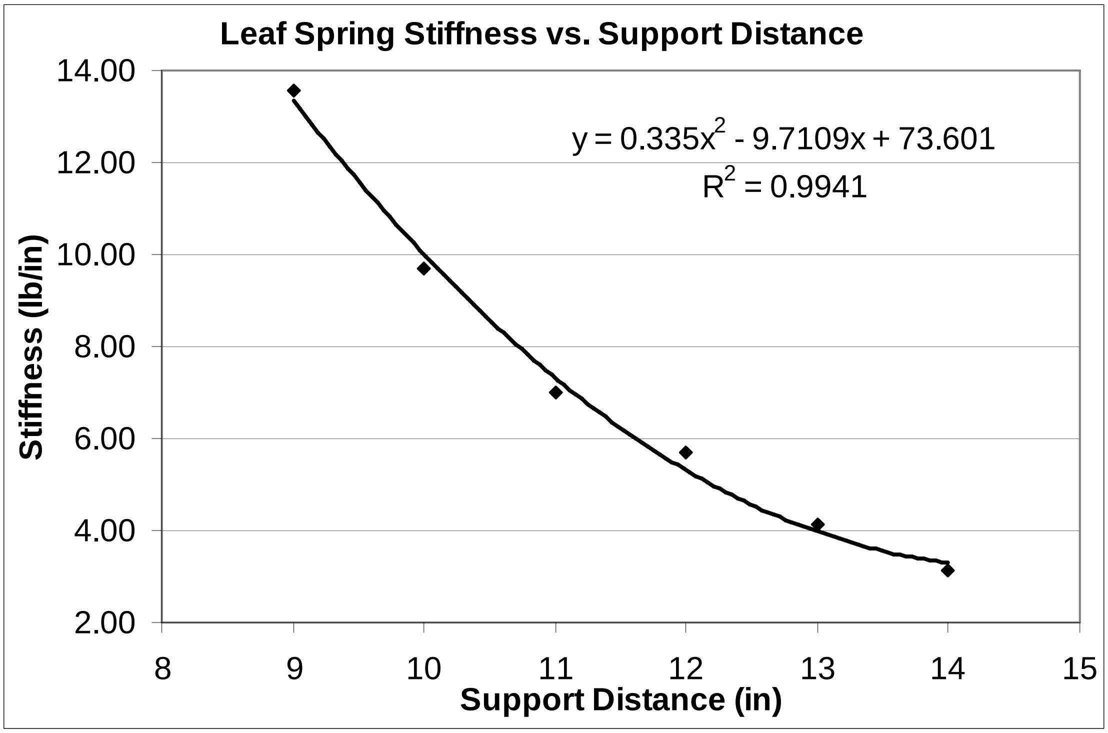


Figure B8: Leaf Spring Stiffness vs. Support Distance.

In addition to the component measurements of stiffness, the static stiffness of the system was measured at the two extremes of stiffness variability; leaf spring supports 10” apart and 14” apart. This measurement was performed by applying weights to the system in 5 Newton increments and recording displacement data from the LVDT. The force-displacement curve of the system with the leaf spring supports 10” apart can be seen in Figure B9.

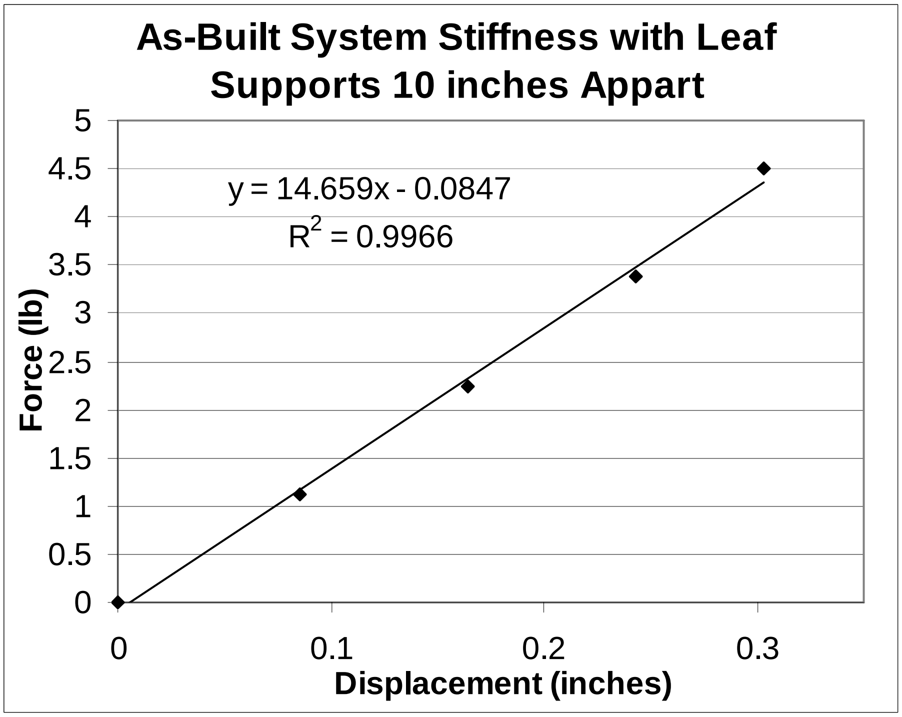


Figure B9. System As-Built Stiffness with Leaf Supports 10” Apart.

The force-displacement curve of the system with the leaf spring supports 14” apart can be seen in Figure B10.

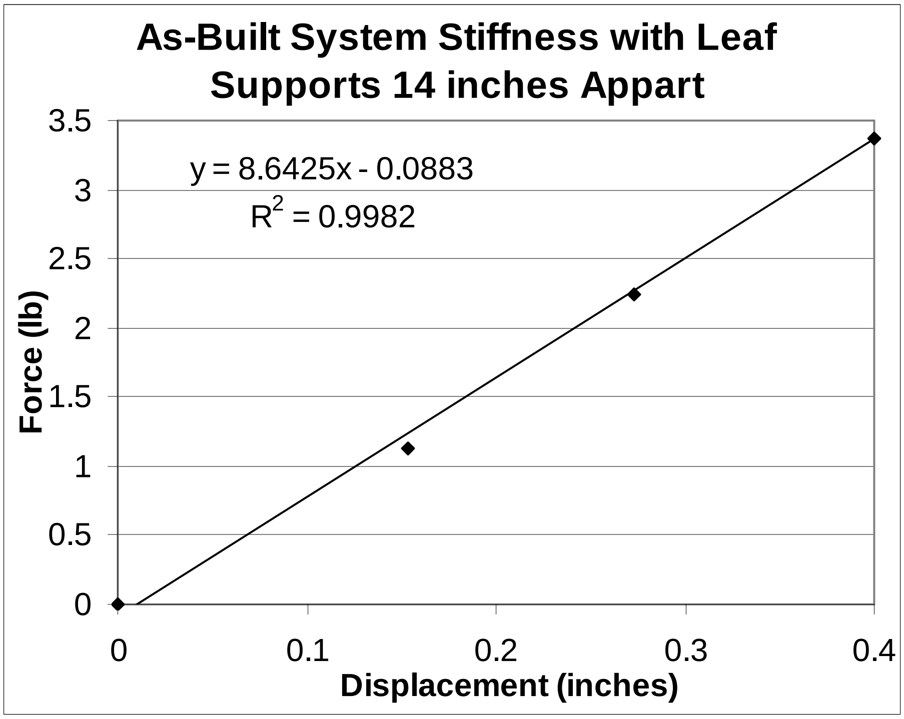
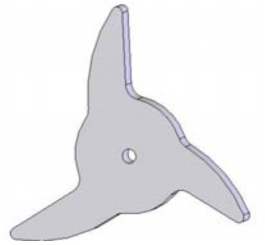


Figure B10. System As-Built Stiffness with Leaf Supports 10” Apart.

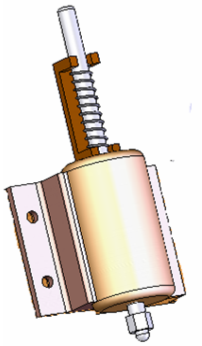
Displacement Initial Conditions

A tri-lobed cam is used to give the system an initial displacement. Each of the three lobes applies a different displacement. The magnitude of the initial displacement for each run can be determined from the LVDT displacement data. Nominally, the initial displacements are 0.25 in, 0.375 in and 0.5 in but these displacements change with the varying effective stiffness.



Impulse Initial Conditions

An electric solenoid is used to give the system an impulse excitation. The magnitude of the impact for each run can be determined from the force transducer data.



Instrumentation

Five transducers obtain data from the system via the digital data acquisition system: one LVDT (Linear Variable Displacement Transducer), three accelerometers of varying sensitivity and a force transducer used during impact excitations.

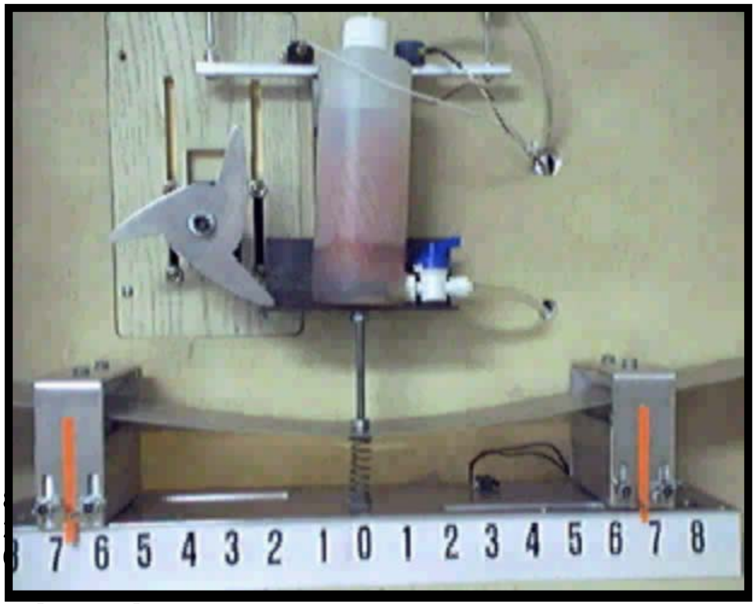
Column number in dataset	Data description	Sensitivity of transducer
1	Time (sec)	-
2	LVDT (V)	9.97 V/in
3	Accelerometer 1 (V)	10.4 mV/g
4	Accelerometer 2 (V)	92.9 mV/g
5	Accelerometer 3 (V)	994 mV/g
6	Force Transducer (V)	51.5 mV/lbf

NOTE: The accelerometers used have an order of magnitude increase in sensitivity from nominal values of 10 mv/g to 1 V/g. The accelerometers weigh 0.12 oz, 0.15 oz and 0.28 oz for column 3, 4 and 5, respectively. The LVDT has a nominal sensitivity of 10V/in and the

LVDT core weighs approximately 0.52 oz. Also, note that the third accelerometer in column 5 of the data set has a 4th order Butterworth filter with a 25 Hz cutoff frequency applied to the data and therefore will experience some amplitude/phase distortion in the data.

Typical Data File Layout

A typical excerpt of the text file containing the data acquired is shown below for reference.



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