IDENTIFYING THE EFFECTS OF STIFFNESS CHANGES IN A 5-DOF SYSTEM

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Overview

- Introduction
- Experimental Procedure
- Data Analysis
- Analytical Model
- Comparison Methods
- Conclusion

Introduction
Motivation

Damage: a change introduced into the system that adversely affects its current or future performance. – C. Farrar, S. Doebling

- Changes in M, C, and K
- Linear or Nonlinear

Introduction
Vibration Response

Benefits

- Nondestructive
- Provides global means of detection
- Applicability to complex structures

Drawback

- Must know about system before damage

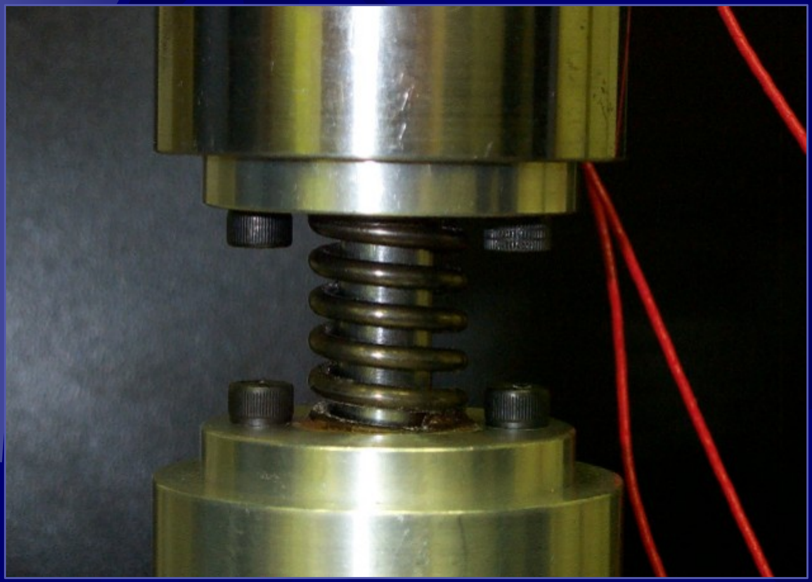
Experimental Procedure

Setup

Original System		
Item	Mass (kg)	Stiffness (N/m)
Mass 5	0.1642	
Spring 4		2626.903
Mass 4	0.06695	
Spring 3		11383.25
Mass 3	1.30345	
Spring 2		25568.52
Mass 2	0.28675	
Spring 1		56390.85
Mass 1	6.87075	

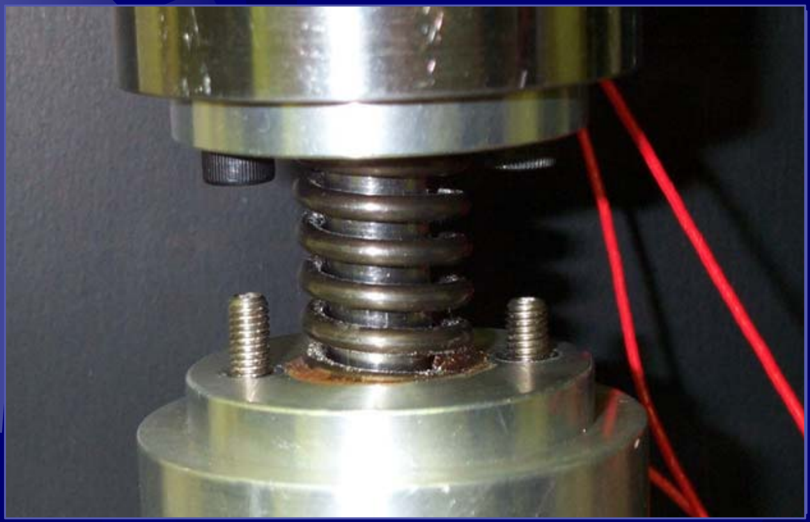
- Five Degree of Freedom System test setup
- Discrete springs and masses
- Free-free boundary conditions
- Rod constrains motion to vertical
- Shaker attached to Mass 1
- Accelerometer on each mass

Experimental Procedure
Linear Changes



- Swapped in springs with lower stiffness for K1 and K2
- Each linear trial was completed in two runs
- Runs were “spliced” together at the cutoff point

Experimental Procedure
Nonlinear Changes



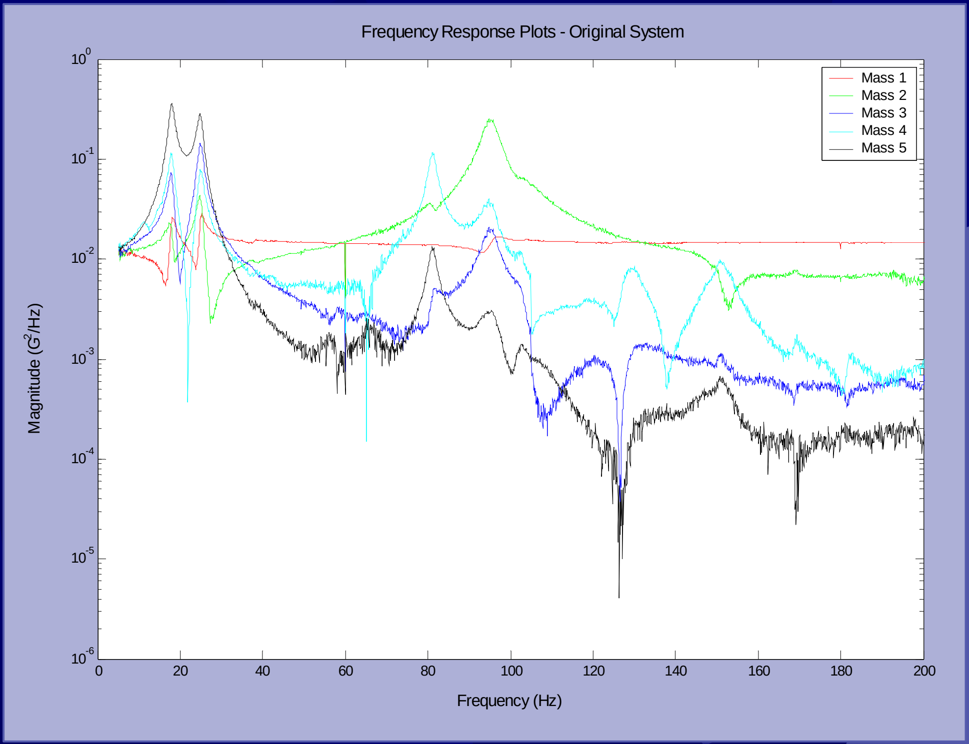
- First change came from allowing "bumpers" to hit between Mass 4 and Mass 5
- Second change came from removing the bolts securing Spring 2 and replacing them with threaded rod

Experimental Procedure
Data Acquisition

- DACTRON Spectrabook™- an 8 channel 24-bit spectral analyzer
- RT Pro™ software
- Collected time responses, FRF's, coherence, and power spectra data from the software

Data Analysis
Frequency Response Plots

- Experimental: calculated by the DACTRON system
- Theoretical: computed using the TFE function in Matlab™

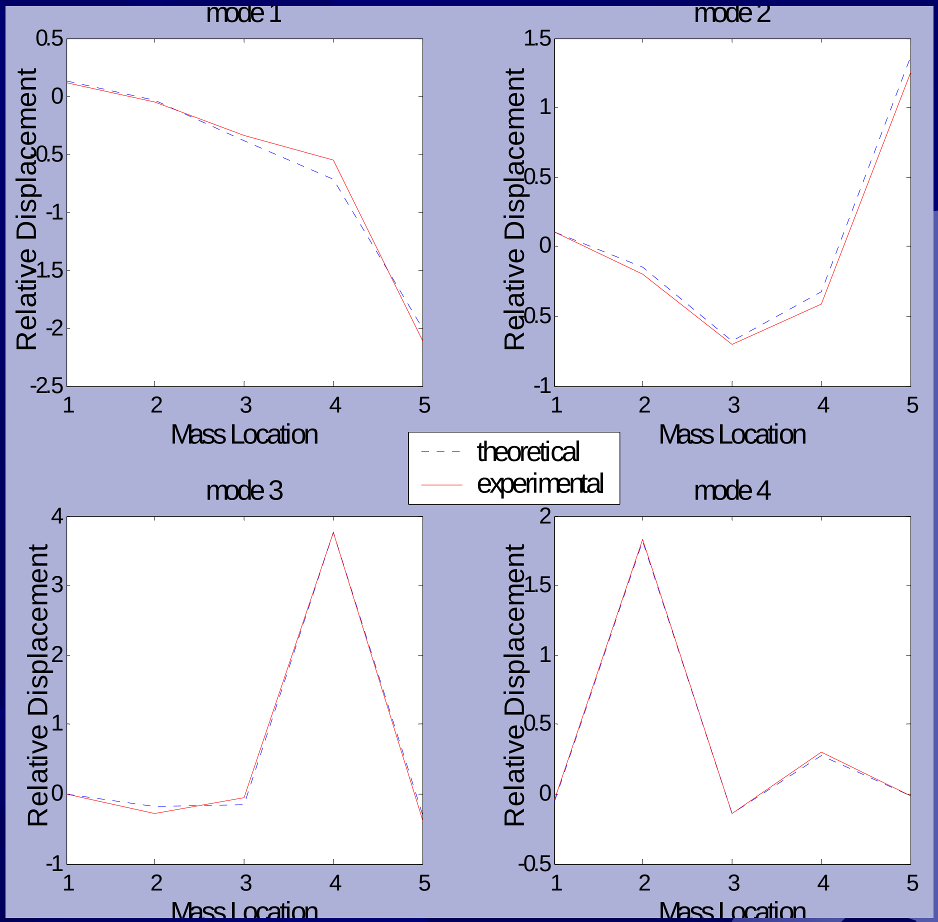


Data Analysis
Modal Analysis

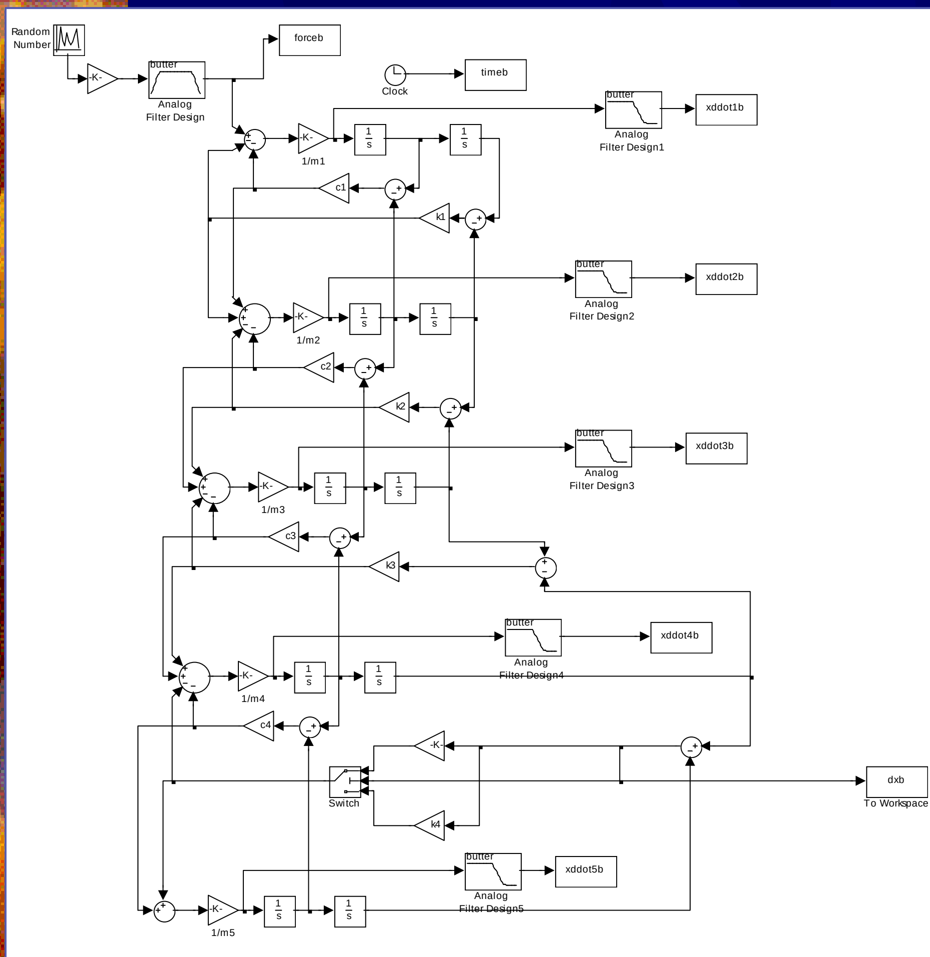
- Five natural frequencies and mode shapes
- Theoretical:

  calculated from eigenvalues and eigenvectors
- Experimental:

  From ME'scope



Analytical Model



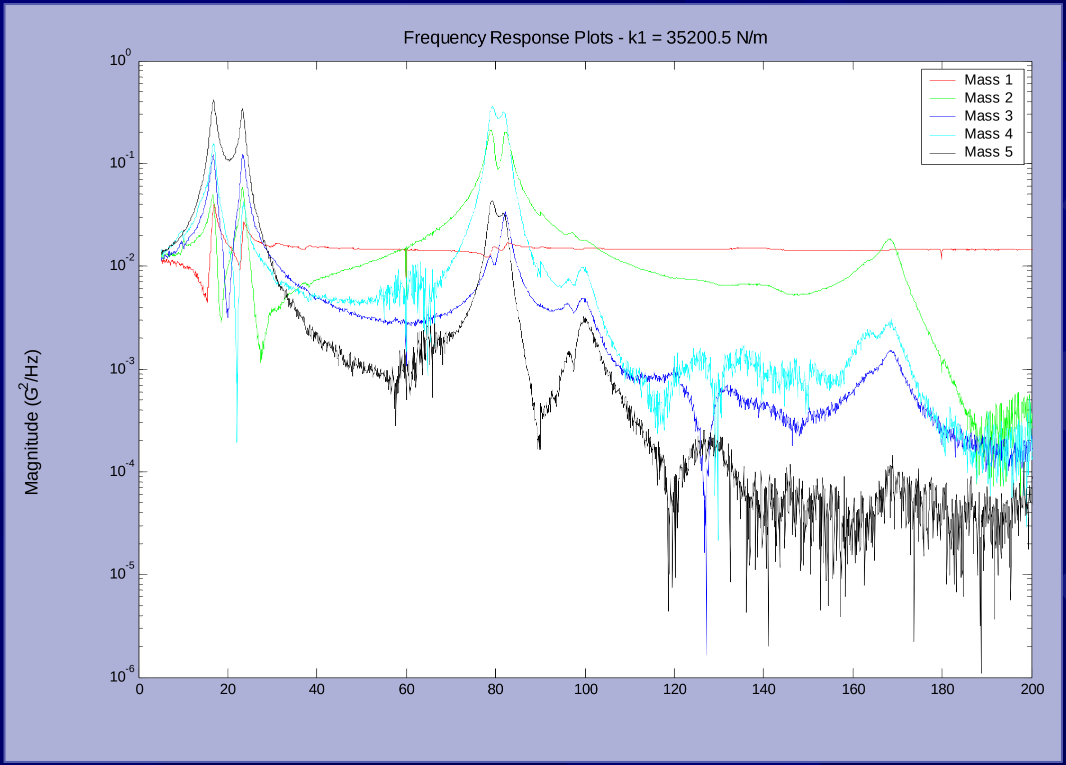
- For the linear model, the equations of motion were put into matrix form:

$$[M]\ddot{X}+[C]\dot{X}+[K]X=[F]$$

- For the nonlinear system, the matrix form of the equations of motion could not be used. A block diagram for each mass had to be derived and formed.

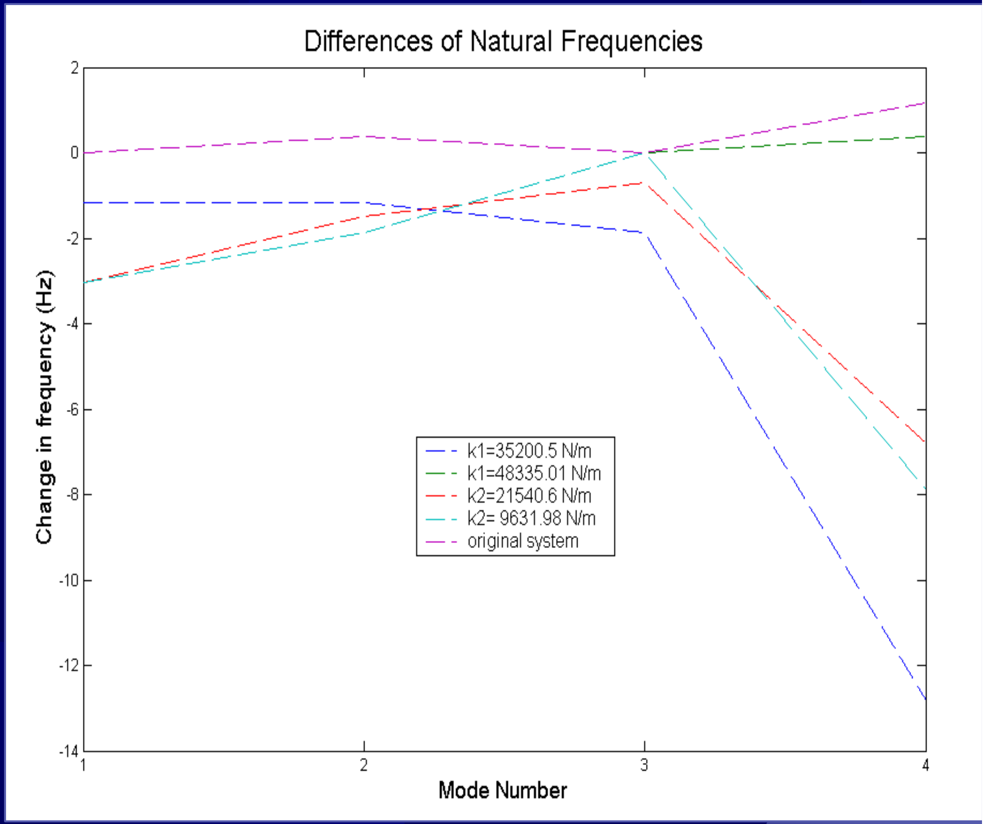
Comparison Methods
Linear Changes

- FRFs: visualize changes to frequencies and mode shapes



Comparison Methods
Linear Changes

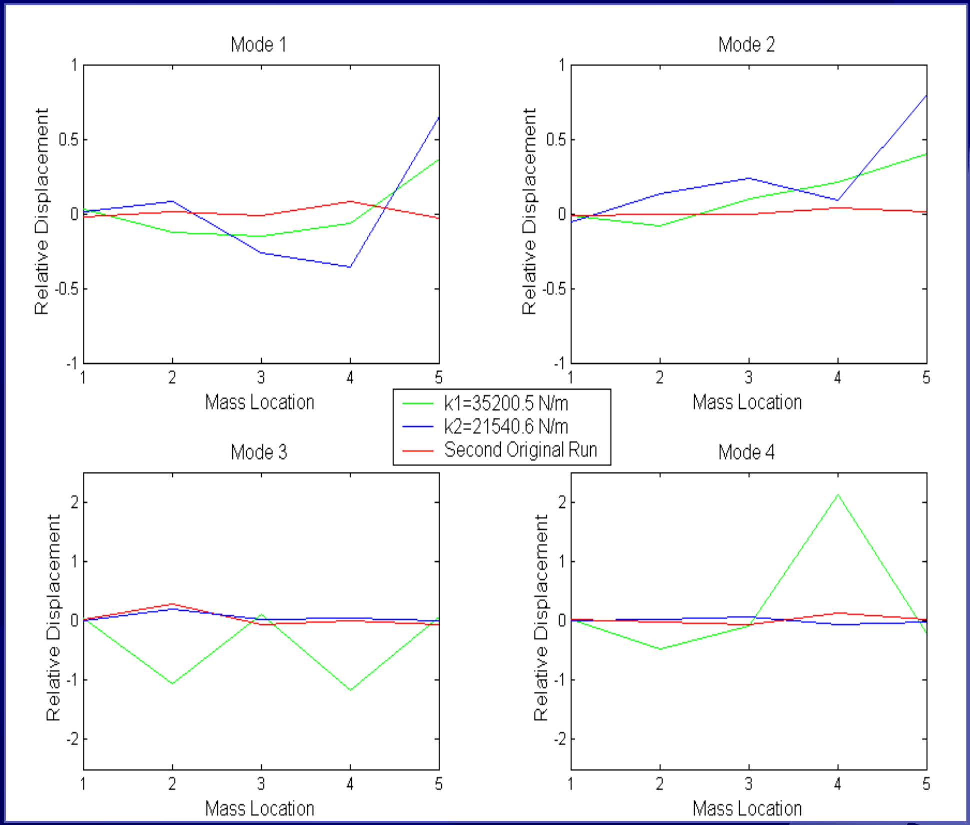
- Difference between the new natural frequencies and those of the original system were plotted
- Changing Spring 1 affected Mode 4
- Changing Spring 2 affected Modes 1 & 4



Comparison Methods

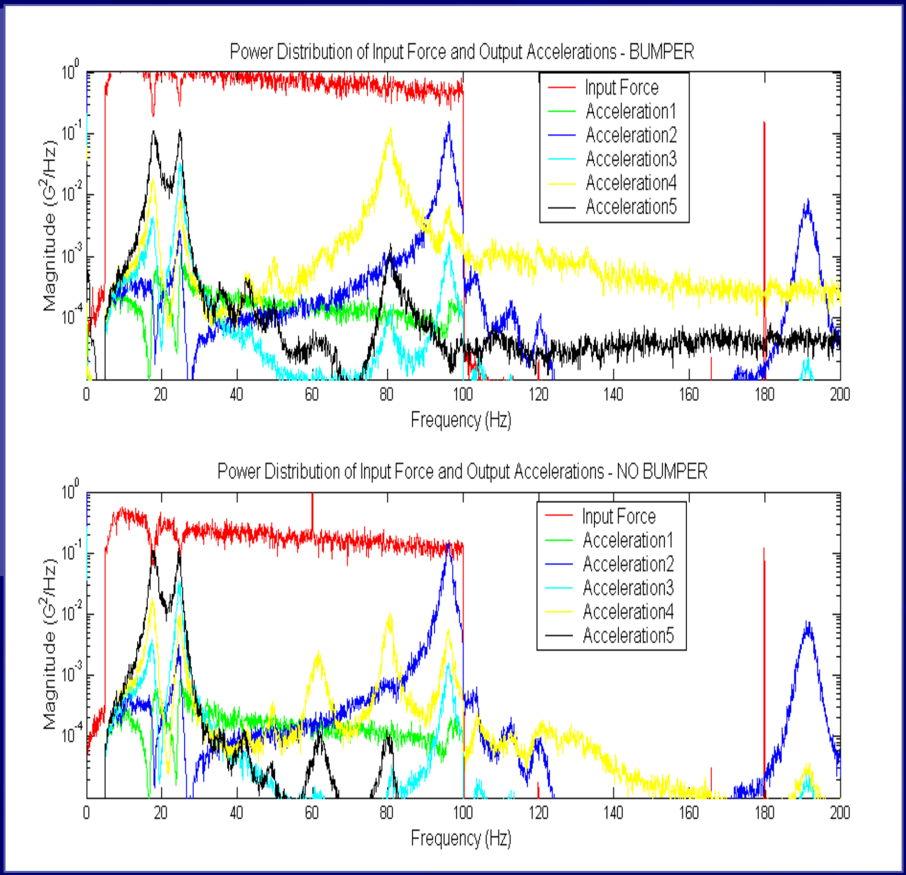
Linear Changes

- The difference in mode shapes illustrate the behavior of each mass at the natural frequencies
- Changing Spring 1 affects Modes 3 & 4
- Changing Spring 2 affects Modes 1 & 2



Comparison Methods

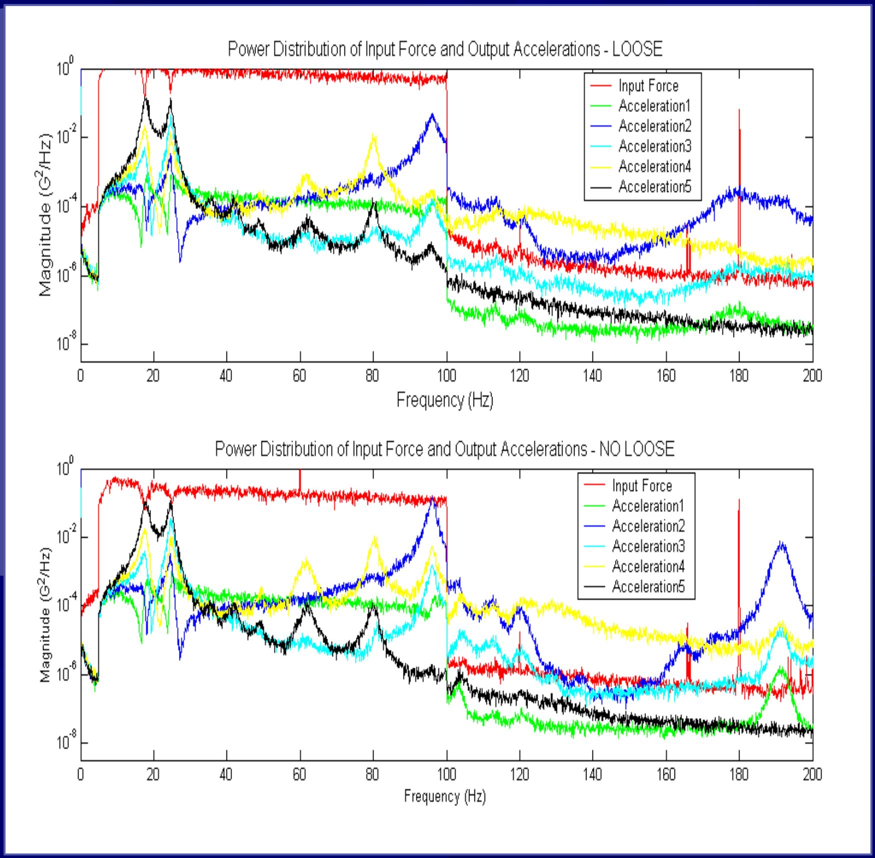
Nonlinear Change - Bumper



- The power spectra of accelerations closest to the bumpers had more high frequency content than the non bumper case
- More high frequency content for Masses 4 & 5, which are nearest to the non-linearity in the bumper case

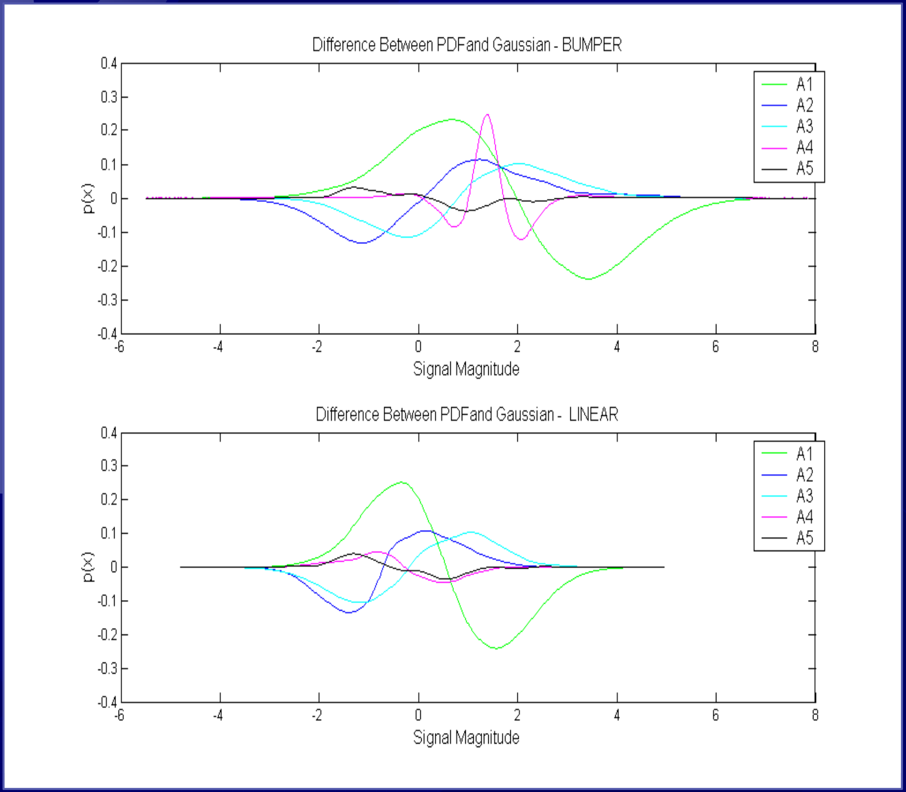
Comparison Methods

Nonlinear Change - Loose



- The loose model gave the same results as the bumper model, with higher frequency content near the non-linearity, especially in the power spectra of Masses 2 & 3

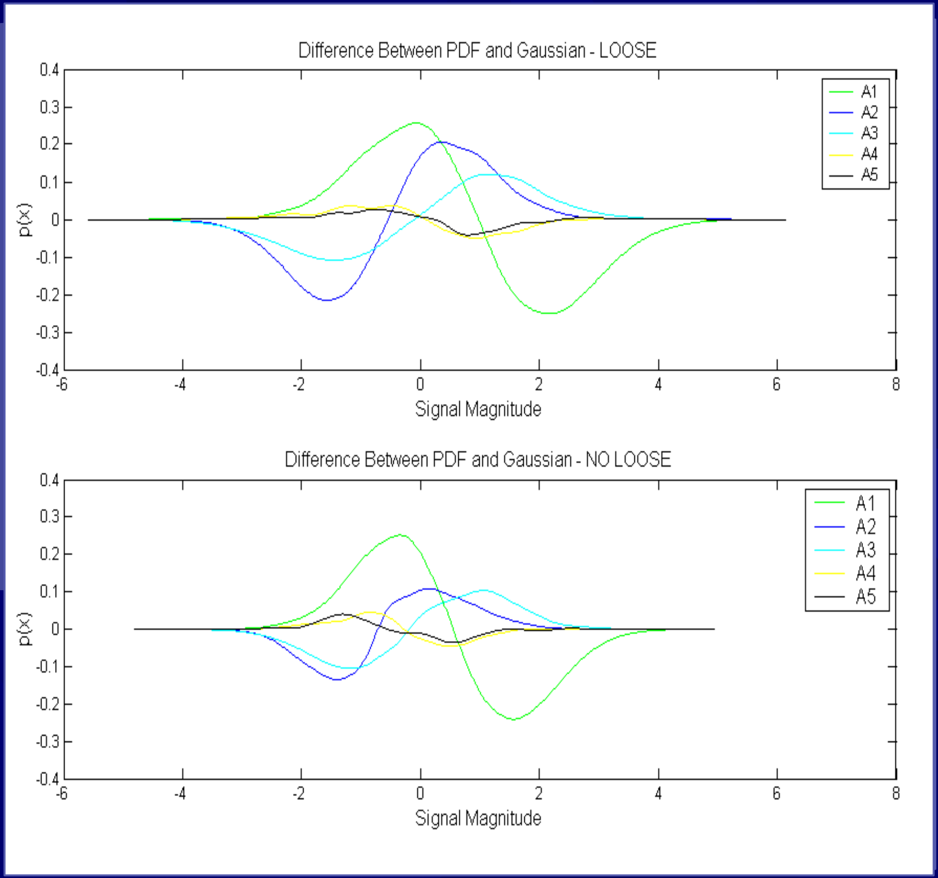
Comparison Methods
Nonlinear Change - Bumper



- The difference between the Probably Density Function (PDF) of the nonlinear runs and a Gaussian distribution was plotted
- At Mass 4, the location closest to the bumper, there is a larger deviation from a Gaussian distribution in the PDF

Comparison Methods

Nonlinear Change - Loose



- The PDF of Mass 2, which is closest to the non-linearity, deviates more from a Gaussian distribution when the non-linearity is introduced

Conclusions
Linear Changes

- For multi-DOF systems, linear changes to the stiffnesses in the system mainly affected the natural frequencies and mode shapes
- This could be seen easily in the FRF's for the system
- However, no way to pinpoint location of linear stiffness change

Conclusions

Nonlinear Changes

- For nonlinear changes to the system, the FRF's did not change noticeably

- The changes were detected by examining the power spectra and probability density functions of each mass in the system

Next Time…

- Try different types of inputs to single out some of the nonlinearities inherent to the system
- More time could be spent on identifying and eliminating some of the nonlinearities in the original system
- Use statistical means to quantify some of the linear and nonlinear changes

Questions?