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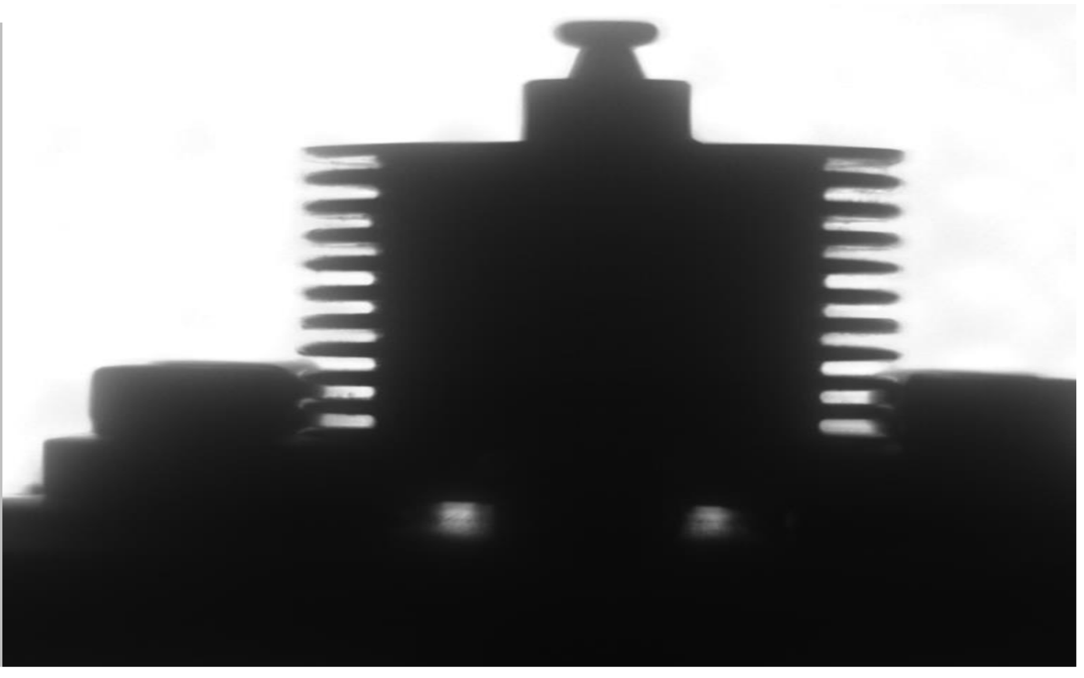
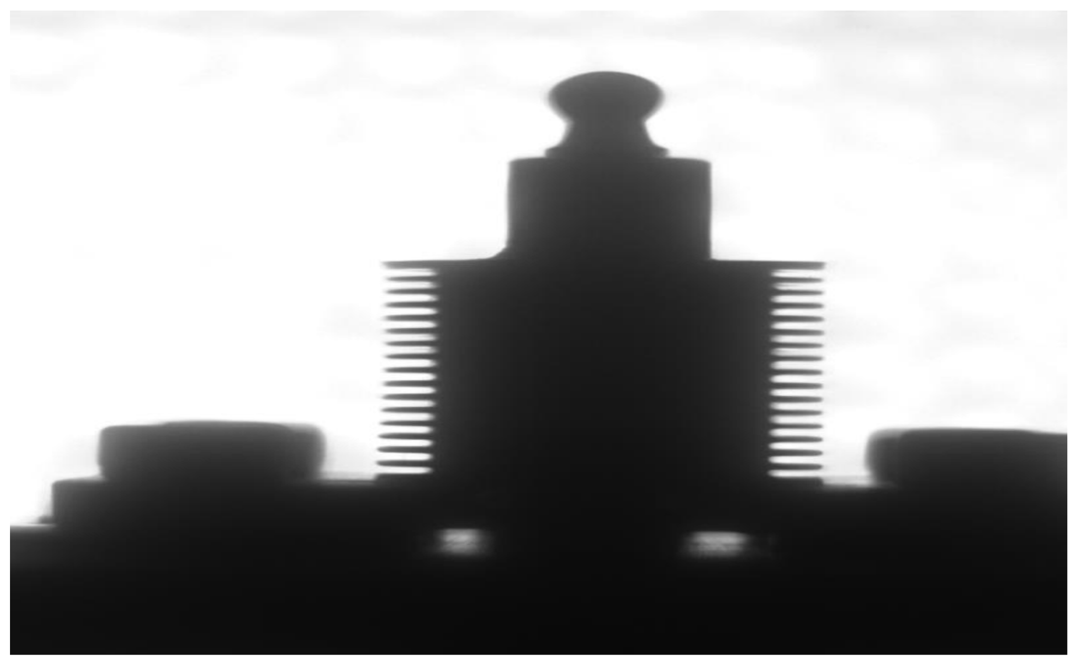
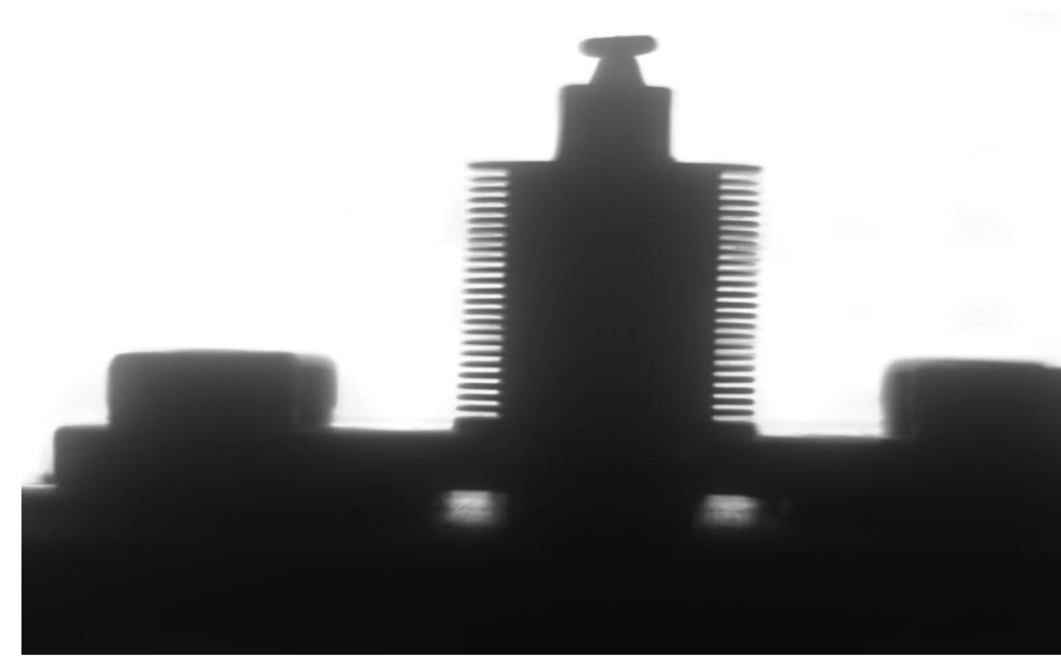

# Bellows Characterization for Dynamic Systems with Damping and Multiphase Flow

Presenter: Nialah Wilson
School: Howard University
Major: Mechanical Engineering, BS Expected May 2017
Manager: Tracie Durbin, PhD
Mentor: Tim O’Hern, PhD
1512 Thermal/Fluids Experimentation Sciences

## Abstract

Experiments were run to characterize the spring constant, resonance, and damping of three different bellows types. The bellows have characteristics similar to bubbles, so the bellows can be used in their place which makes running repeatable spring-mass-damper system experiments possible. The conclusion of the tests proved that the bellows had low damping, thus a reasonable replacement for bubbles. The different bellows were chosen to test how their different effective bubble properties effected the system.

## Introduction

It has been observed that when bubbles form in liquid-filled mechanisms, unusual behavior can occur in a vibration environment. The resonance of the system changes under these conditions. In order to understand and model this behavior, it was decided to conduct experiments with simple pistons enclosed in PDMS liquid. PDMS was chosen for its viscosity and density. A gas was introduced to the system to observe at what acceleration bubbles formed and how those bubbles effected the overall dynamic response. These experiments with bubbles were very difficult to repeat since bubble sizes and locations could not be controlled from test to test. It was decided to use bellows, which were found to have properties similar to the bubbles so the experiments could be run multiple times to gather sufficient data to gain statistical significance.

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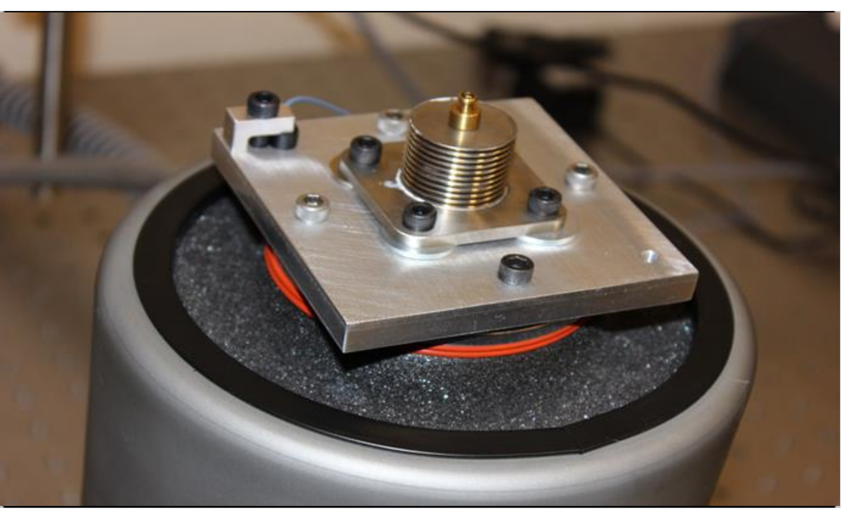

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# Methods

## Theory/Bellows Selection:

PV = nRT $K_B = (M_B + M_W)\omega_o^2$ F=ks

The pressures and volumes were determined for the specific bubble sizes to be tested. From there, using the gas law equation, and known atmospheric pressure and desired volume, it was possible to solve for the change in pressure with change in volume that corresponded to the bellows' spring constant. Using the equation for a lightly damped driven oscillator, with the known resonant frequencies at varying weights, it is possible to solve for the bellows effective mass, damping, and spring constant k.

## Experimental Procedures:

A Labworks ET-140 Electrodynamic Shaker was used to determine the resonance of the bellows. A weight was glued on top of the bellows and then mounted to the shaker. A sinusoidal wave was sent to the shaker causing it to oscillate over a determined frequency range. Voltage was held constant and acceleration was allowed to vary thoughout the tests. The motion of the bellows was captured by an Allied Vison Technologies camera. Since the camera could not capture the entire motion of the bellows at every point of the test, two different camera frame rates were used for the trials. The camera frame rate was selected so that there would never be a synchronization point where the frequency was a multiple of the camera frame rate. This would cause a gap in the data as the bellows would be in the same position every time the camera took an image. A Texture Tester was used to verify the calculations of k determined from the data and equations given by the Shaker. A force was applied to the bellows and it was allowed to compress 5mm before unloading began. The formula for force of a spring was then used to calculate the constant k. An Ultrasonic Cleaner was used to remove the weights from the bellows. The bellows were soaked in a beaker of acetone then the beaker was placed in the cleaner filled with water where an ultrasonic wave could be applied. This dispersed the acetone and allowed the glue to completely dissolve from the bellows and weight.

## Analysis Procedures:

By dividing the instantaneous stretch of the bellows by the instantaneous acceleration, a plot can be made against frequency to produce a curve. The peak of the curve signifies the point where the bellows reached resonance. Original code was written in MATLAB to fit a curve to the data and determine the peak. MATLAB was also utilized to analyze the data from the Texture Tester. By dividing the values of force by the distance compressed, the spring constant, k, was determined. Using the data obtained from the Shaker, it is also possible to find the bellows' spring constant, k, and effective mass, $M_T$, by plotting the resonances against their respective weights and fitting a curve. This was done in Excel. LabVIEW was utilized to run the shaker, and Exponent was used to run the texture tester.

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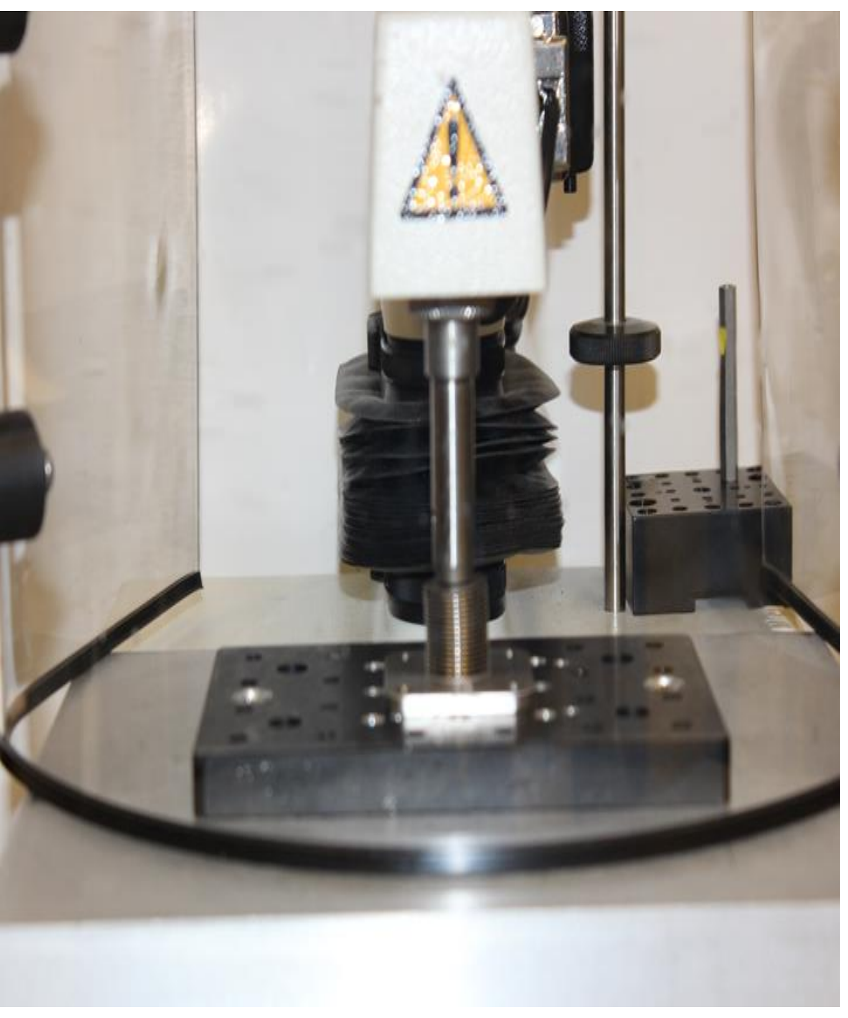

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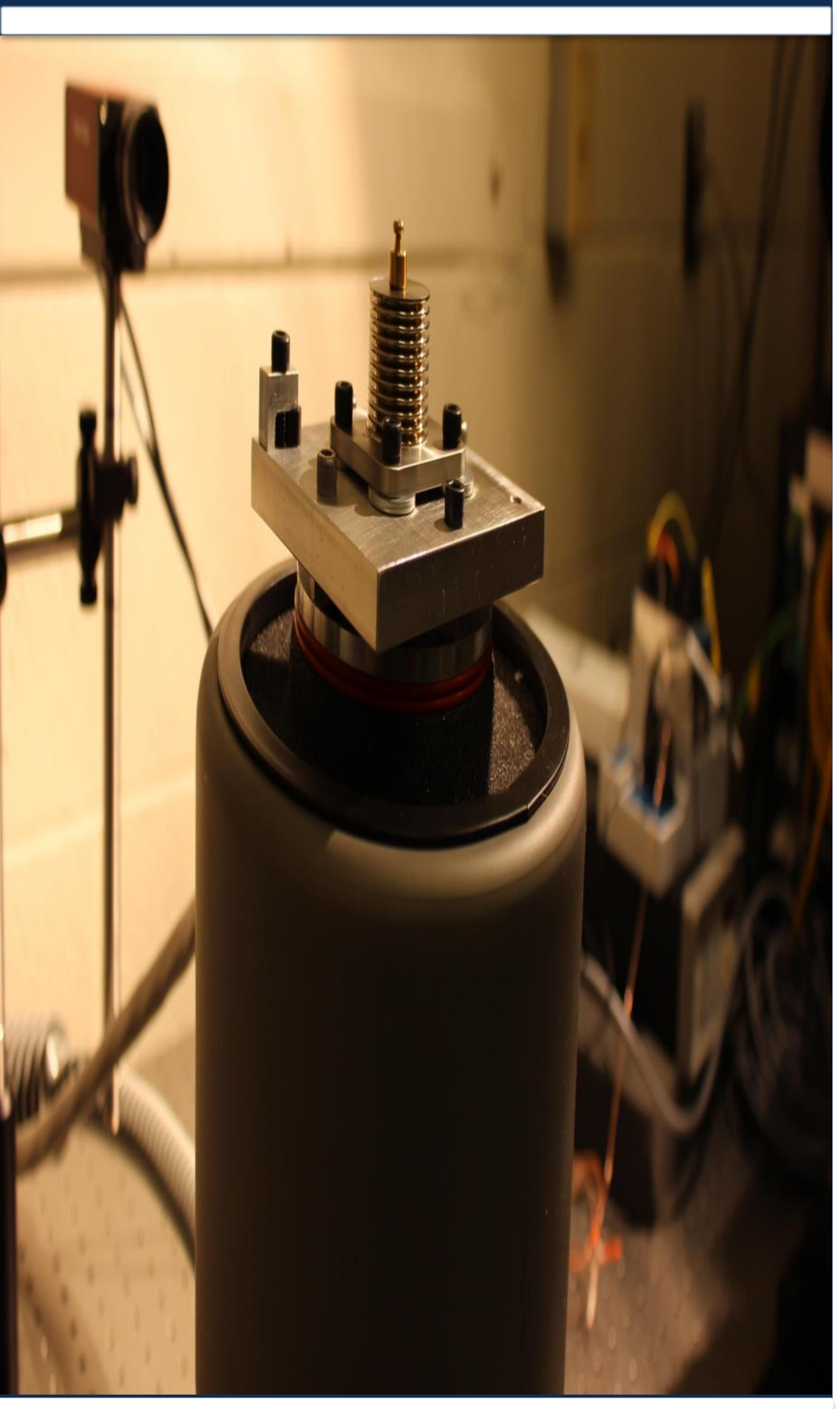
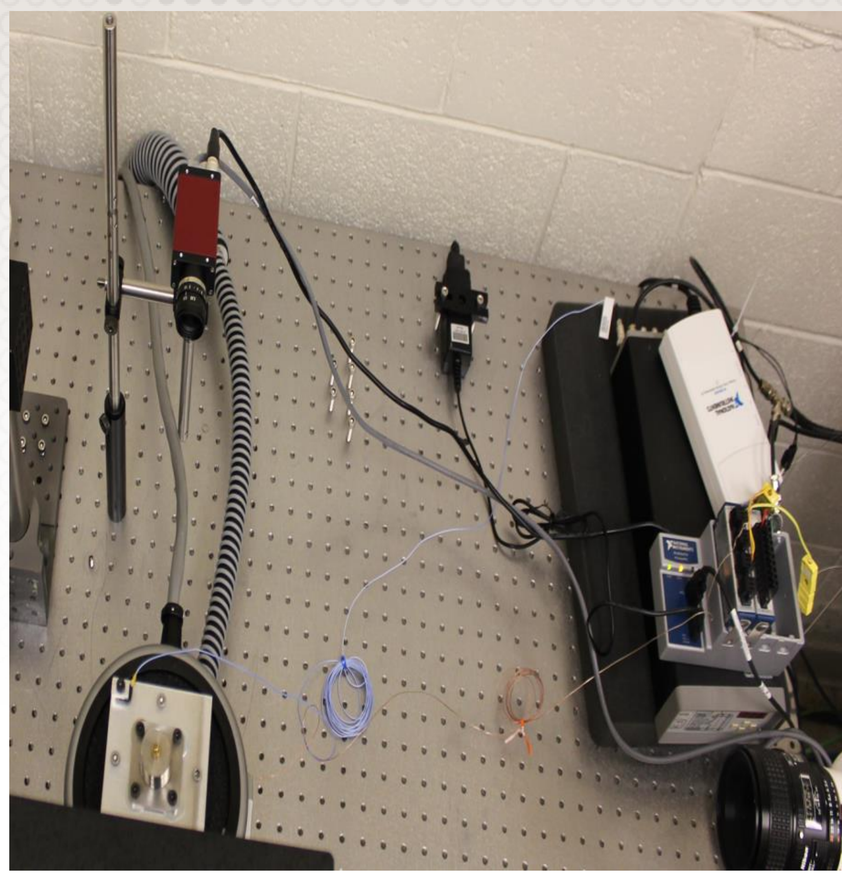
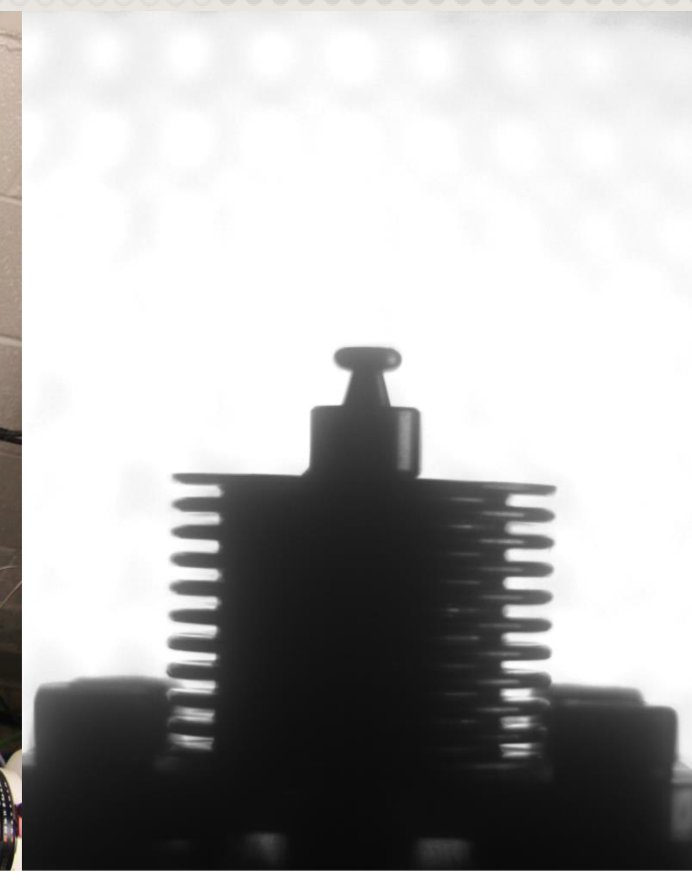


# Example

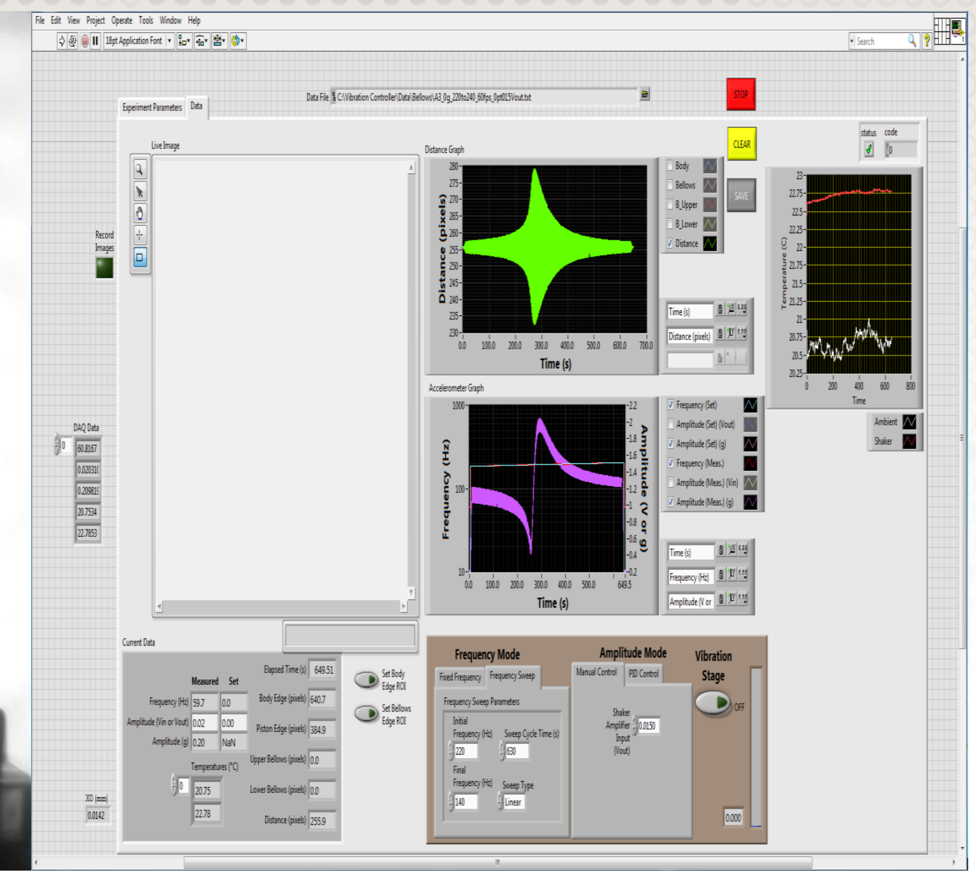
## Experimentation



Arial view of bellows Shaker set up including DAQ system. Camera looking directly at the bellows.



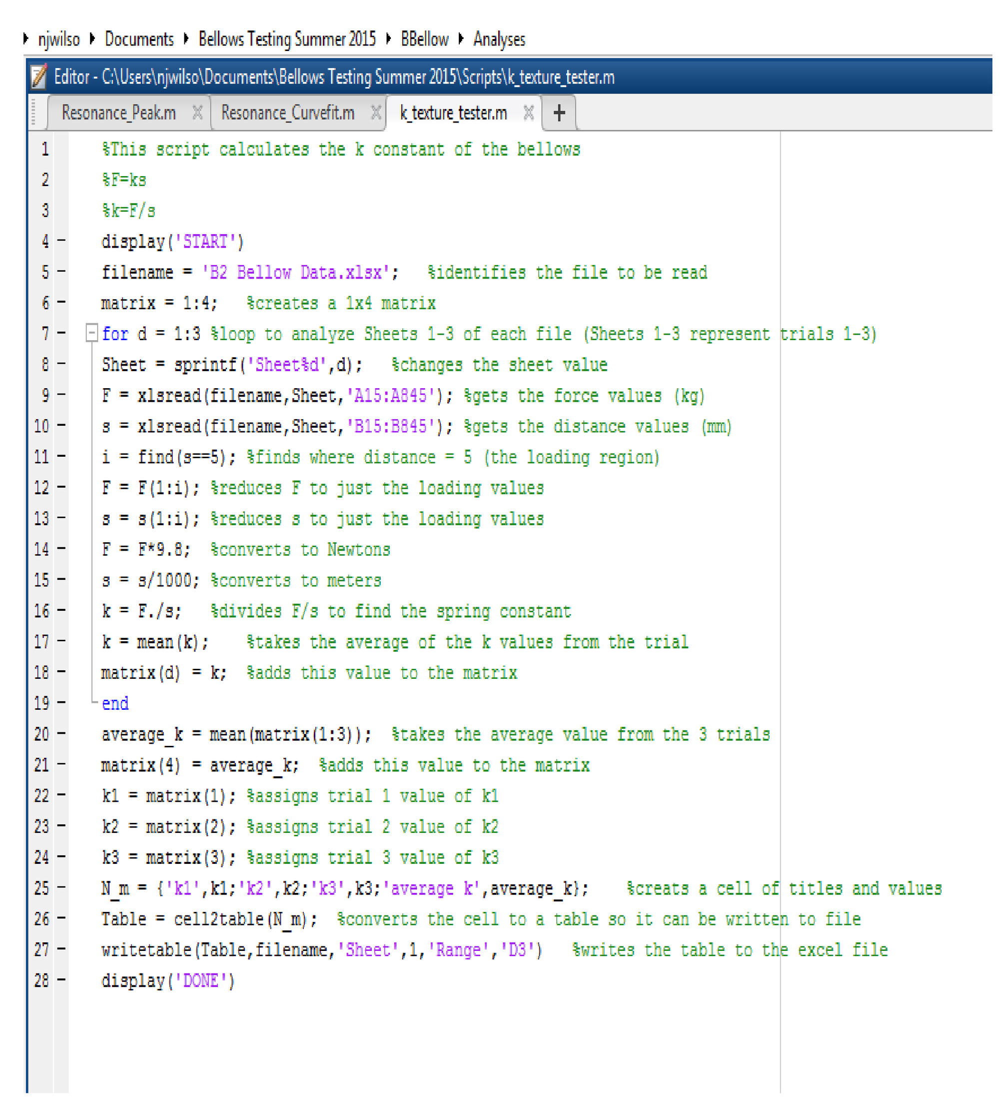
View of the camera.



LabVIEW screen display.

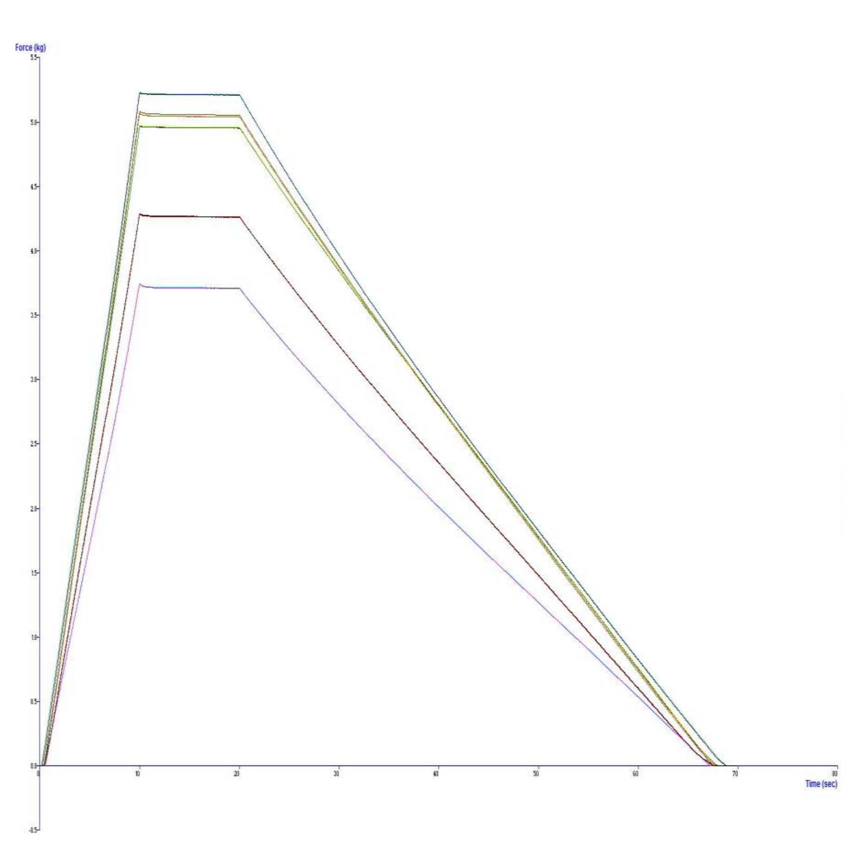
## Data Analysis

Peak finding script

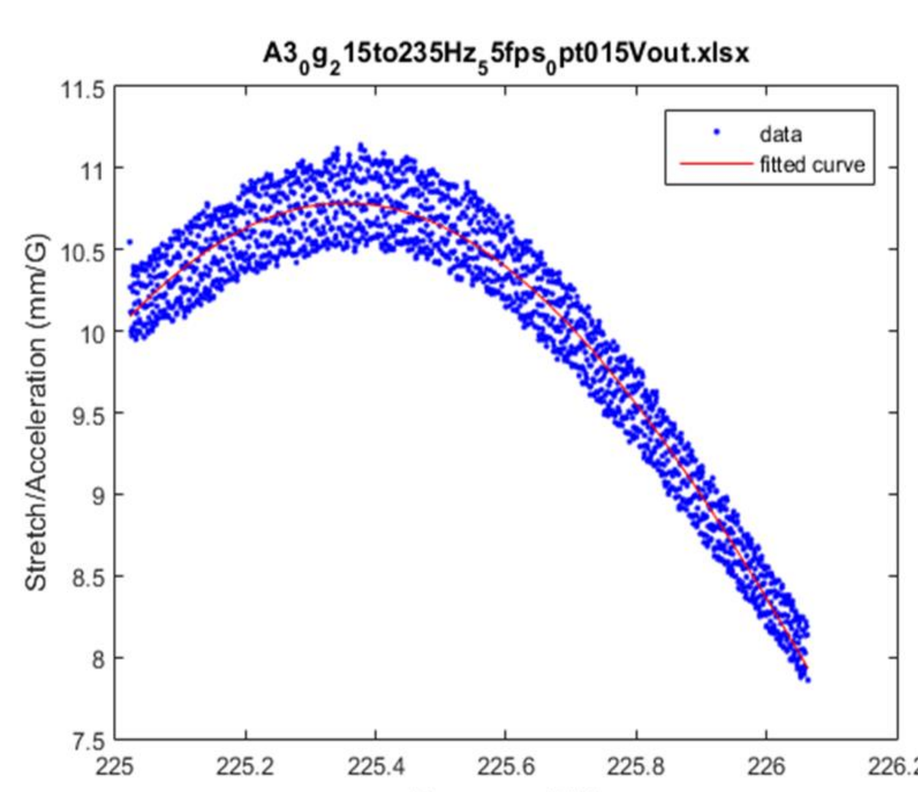



k constant determining script

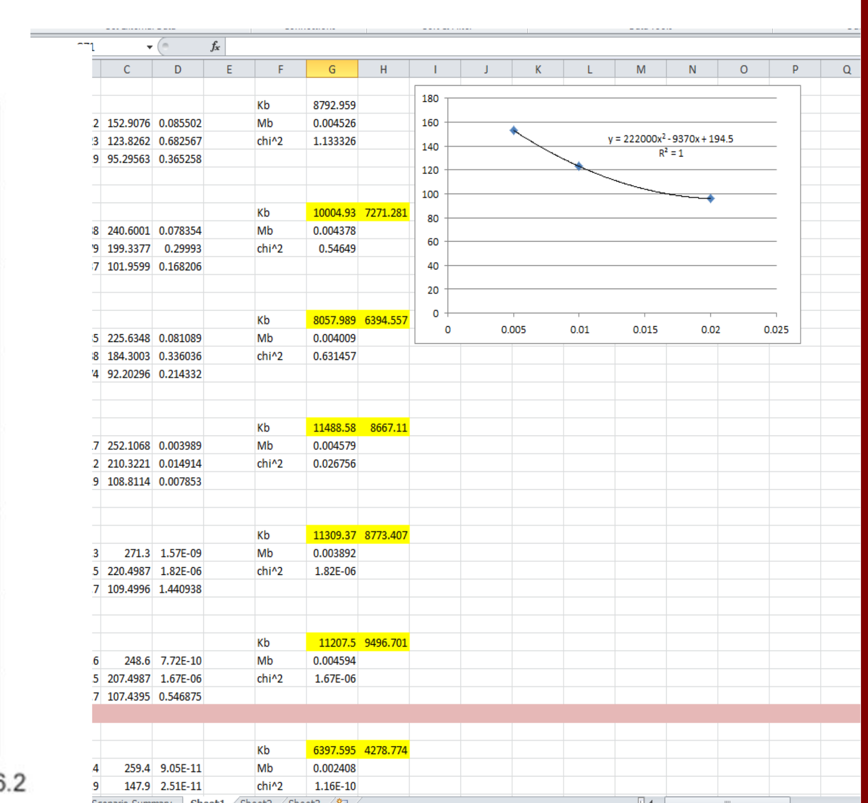
## Results



Plotted results from the Texture Tester for the A Bellows.




Graph of the peak finding script with a A3 Bellows.



Excel sheet calculating the Bellows' effective masses and k constants.

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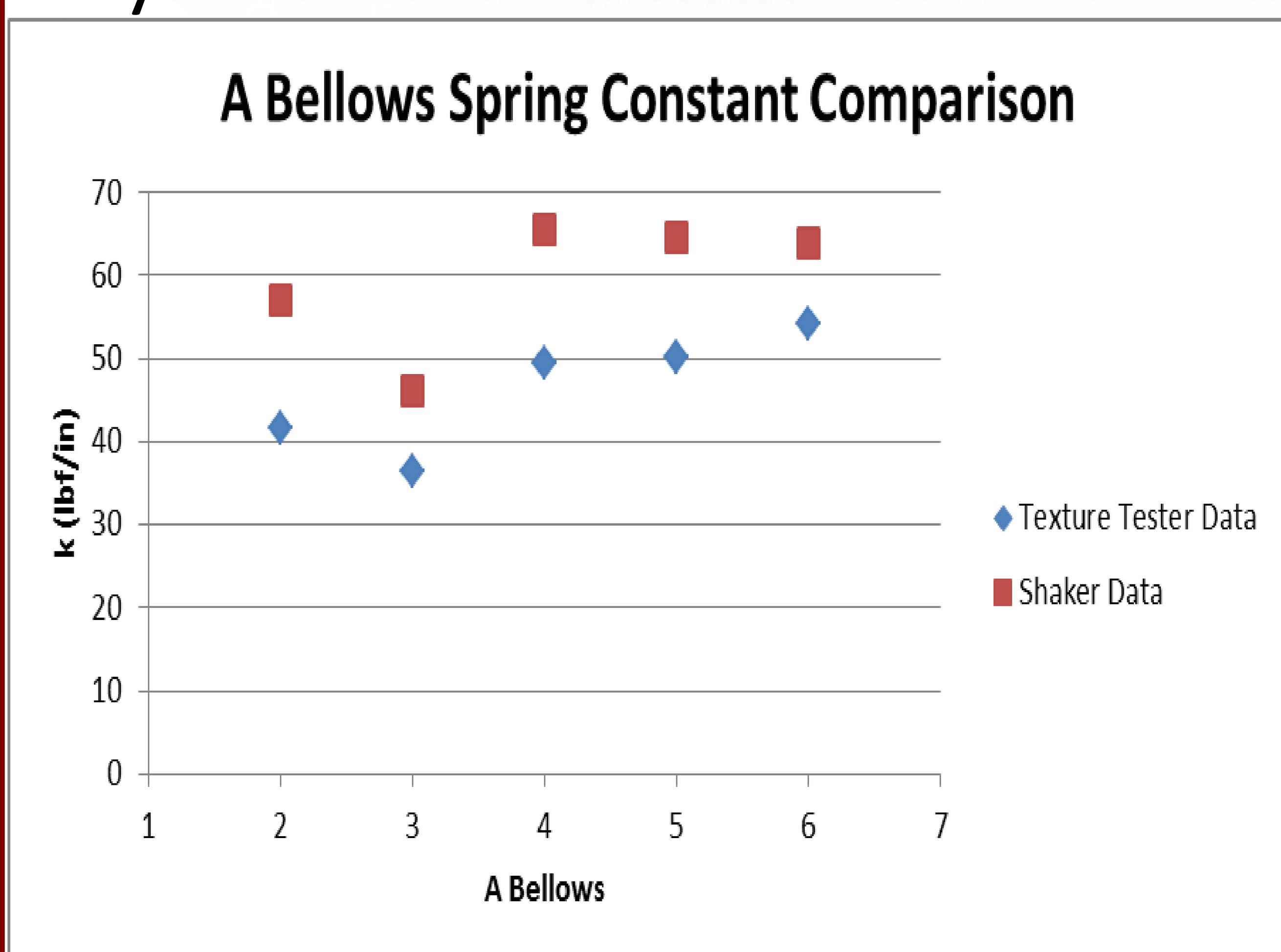
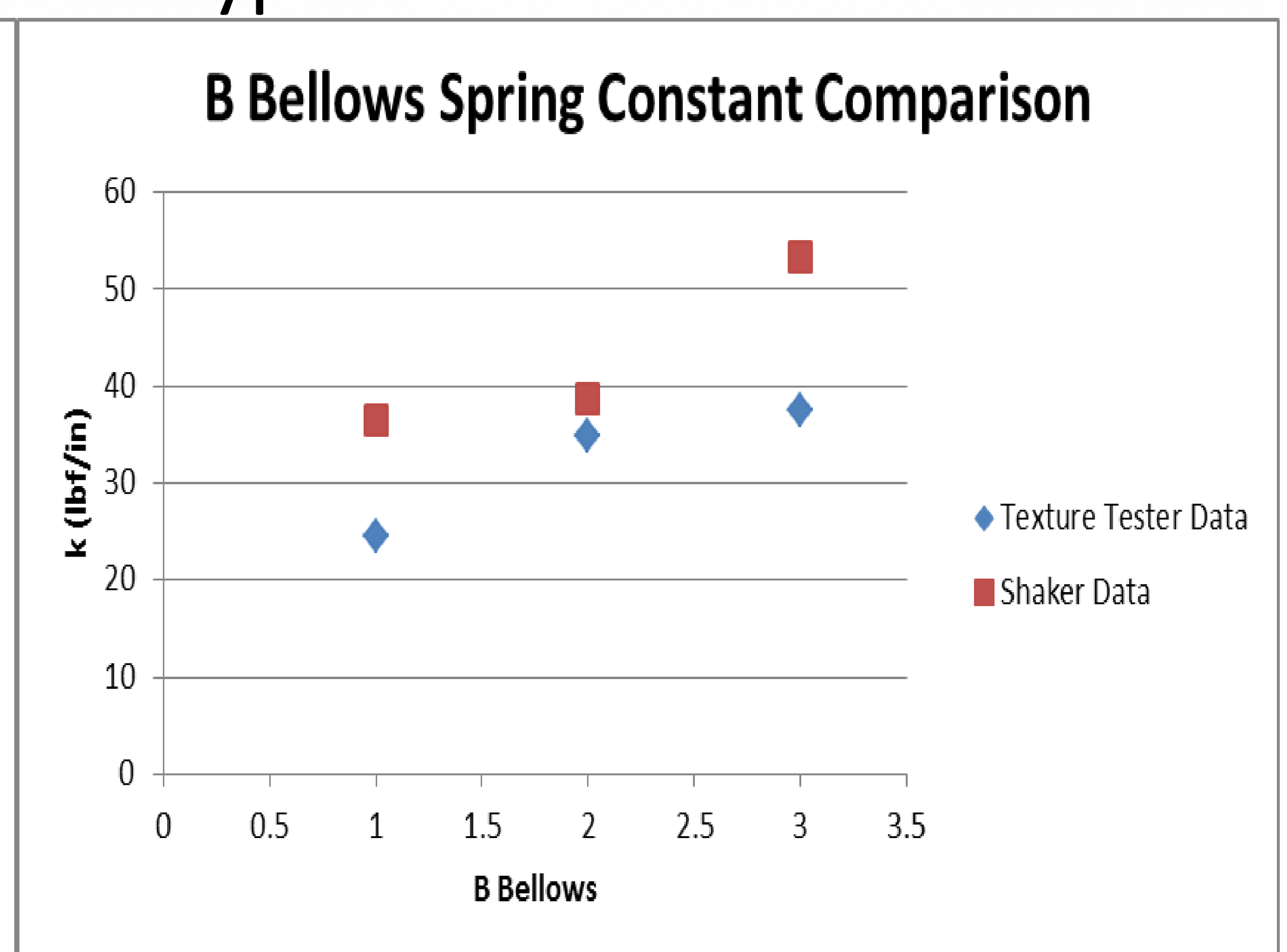
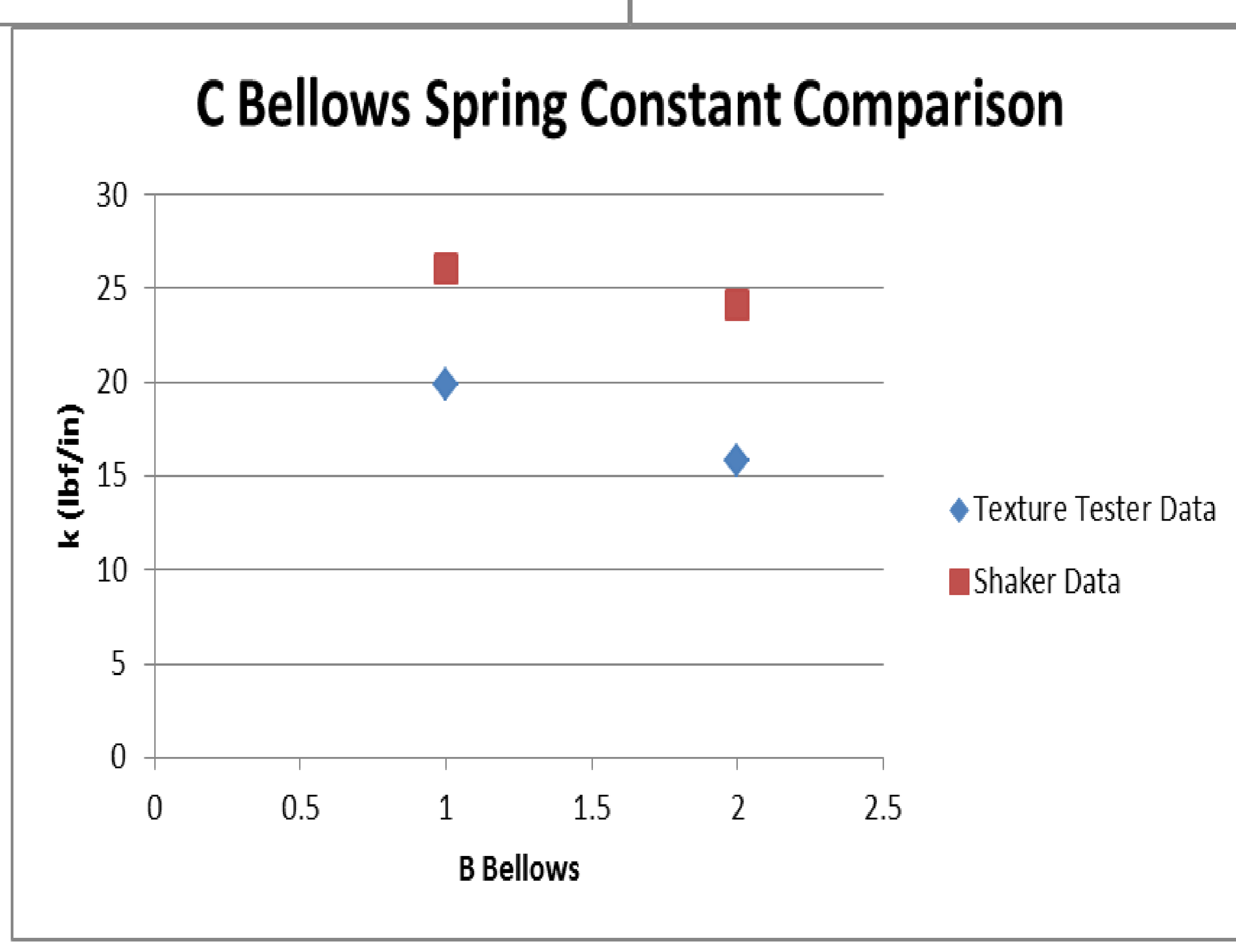
# Results

Findings showed that the respective bellows types possessed similar spring constant and resonance values and fell within the ranges given by the bellows manufacturer catalog. However, there were discrepancies between the spring constant determined from the Shaker and Texture Tester experiments. The results from the Shaker consistently gave higher values than the Texture Tester. Further tests are being conducted to gain more understanding of why this is. The results also showed how the spring mass damping systems varied with different bellows types.



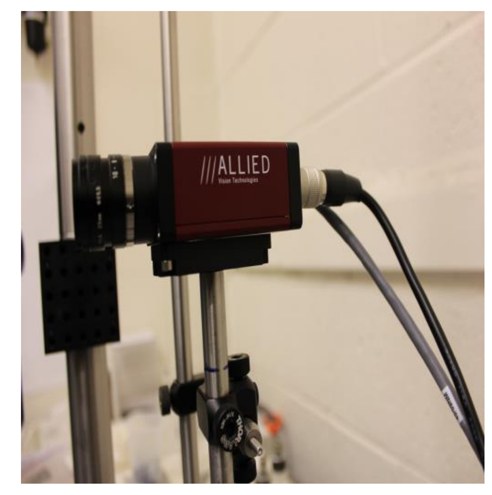



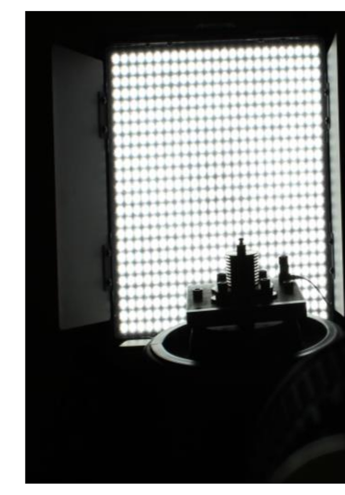



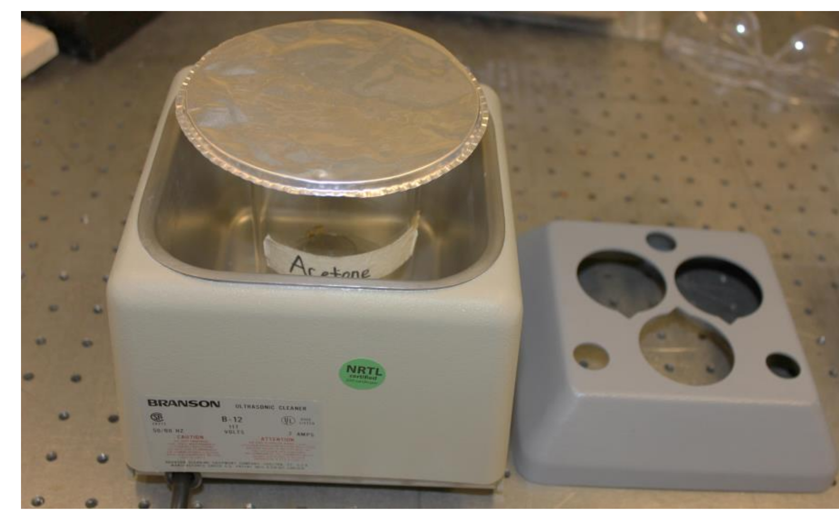

# Discussion

<u>Importance of Work:</u>

More bellows tests will be conducted in the future and the work done will allow for faster testing and data analysis. There is now documentation for all of the processes, and the data analysis can now be completed in a significantly smaller amount of time. Testing done on the bellows will help in future experiments by providing a guide for which bellows, based on its characteristics, should be used as a simulated bubble to test the spring mass damping system. On a broader scope, the work being done to understand the relationship between bellows, bubbles, and liquid systems, will provide insight for developing Launch Accelerometers.







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