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Characterization of a Small Electro-Mechanical Contact Using LDV Measurement Techniques

Kelsey M Johnson

Vibration and Acoustic Simulation – Org 1521
Sandia National Laboratories

Albuquerque, NM 87185

ABSTRACT

Numerically modeling chatter behavior of small electrical components embedded within larger components is challenging. Reduced order models (ROMs) have been developed to assess these components' chatter behavior in vibration and shock environments. These ROMs require experimental validation to instill confidence that these components meet their performance requirements. While achieving conservative results, experimental validation is required, especially considering that the ROMs neglect the viscous damping effects of the fluid that surrounds these particular components within their system. Dynamic ring-down data of the electrical receptacles in air will be explored and will be assessed as to whether that data provides a validation data set for this ROM. Additional data will be examined in which dynamic ring-down data was taken on the receptacle while submerged in an oil, resulting in a unique experimental setup that should prove as a proof of concept for this type of testing on small components in unique environments.

Keywords: LDV, Experimental Methods, Modal Testing

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INTRODUCTION

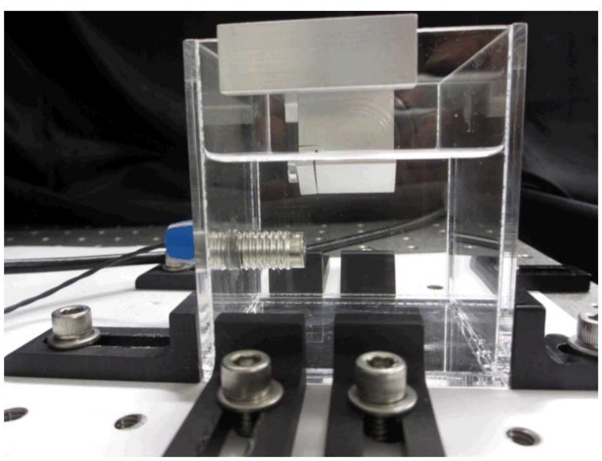
This report will explore the setup and results of an experiment conducted by Johnson [1] that aimed to provide a model validation data set for a chatter predicting ROM developed by Lacayo and Brake [2]. This particular model is of a small electrical assembly made up of a cylindrical pin and a bifurcated receptacle. The ROM models the receptacle as two pre-loaded leaf-springs in the shape of a tuning fork. There is added complexity to this assembly, as there is a viscous fluid filling the entire enclosure. The ROM currently neglects those effects of fluid damping on the system.

This experiment focused solely on the modal characteristics of the receptacle. This allowed for a simplified test that could still provide useful data for the modelers as well as proof of concept for the experimental setup. First, dynamic ring-down data of the bifurcated receptacle was measured in air to validate and instill confidence in the current state of modeling for the system. Then, the same test was performed in a relatively large volume of fluid to observe the damping effects on the receptacle.

The conditions of this particular sub-assembly lead to a unique experimental setup. First, the size of the electrical receptacle had to be taken into account. It is important to validate models of such small components as small-scale effects, such as friction and effective mass, can be large contributors and are challenging to model correctly. This small size leads to unconventional actuation and measurement techniques so as to not mass-load the test article. Second, the experimental setup had to accommodate the fluid found around the system, as viscous damping will affect the modal characteristics of the receptacle. The fluid also creates a challenge with the actuation and measurement of the test article. The methods employed for this experiment needed to be able to survive in a fluid environment. The techniques used during this test as well as the challenges associated with them will be explored further.

EXPERIMENTAL SETUP

With the unique test boundary conditions, the setup pictured below was developed. This fixture creates a clamped boundary condition for the receptacle while suspending it in a tank made of plexiglass.



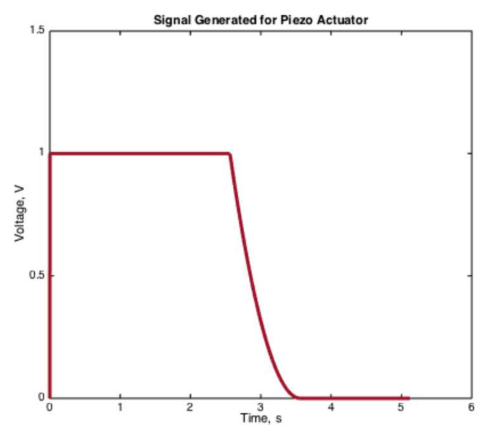


Figure 1: Test Fixture with fluid [1].

Figure 2: Voltage Signal for Actuator [1]

The actuation of the test article was provided by an Encapsulated PICMA® Stack Piezo Actuator made by Physik Instrumente [3], which is tolerant of fluid environments. This method was chosen over other non-contact actuation methods, such as ultrasonic, as the least invasive way to excite the test article without exciting the surrounding fluid excessively. The actuator had a custom voltage signal applied to excite the part while pulling away slowly after actuation so as to not affect the measurement of the test article. This signal is depicted in Figure 2.

A laser doppler vibrometer is a common method for measuring the responses of test articles that cannot be mass-loaded by accelerometers. For this experiment, a Polytec PSV-400 one dimensional system was used. A close-up module was added to aid in focusing on the small receptacle. Plexiglass was chosen as the container so that the alpha angle to the normal part surface wouldn't be dramatically affected. The different test setups between air and added fluid changed the position of the laser heads slightly, but it was simple to attain a good focus on the points regardless. Using Polytec's proprietary software, the voltage signal was supplied to the actuator and was timed with the measurement scans of each point.

The fluid used in the test setup is a XIAMETER® PMX-200 silicon oil with two different viscosities of 10cs and 20cs [4][5]. Varying the viscosity of the oil was intended to give insight as to the effects of that viscosity on the part dynamics. This also gives more data for modelers as to the differences between the part being surrounded by varying oils as well as air.

TESTING AND RESULTS

As mentioned above, the Polytec software would supply the actuation signal to the piezoelectric actuator. Fifteen measurement points were created on one tine of the bifurcated receptacle. This was done to maximize the measurement surface area, but sacrificed measurement data from the second tine. The Polytec software produced fast Fourier transform (FFT) data for each of the setups— one in air, one in 10cs oil, and the last in 20 cs oil, as seen in figures 3 through 5, respectively. These FFTs aren't quite right, as an input force measurement is required to get a proper transfer function. This is due to a challenge with the actuation method used. The displacement of the actuator is 14μm ± 10%. Without a more complex test fixture, it is nearly impossible to get the actuator positioned to the part within that displacement value. The actuation provided is technically the fluid, including the air, being displaced by the actuator. This fluid movement is what excited the part enough for measurements to be taken by the LDV. Figures 6 and 7 display the measurement results from the LDV of the first and second bending modes in air. All figures are referenced from Johnson's results [1].

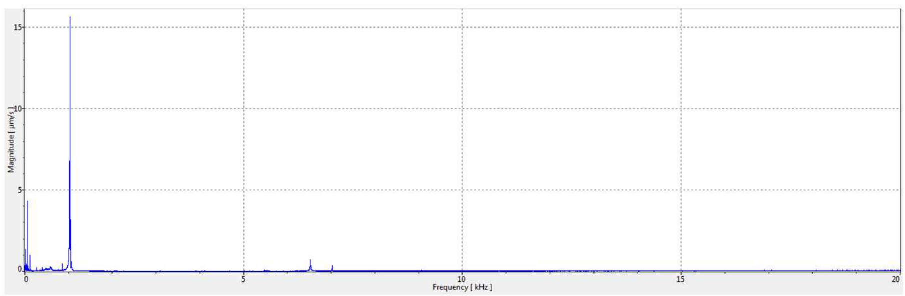


Figure 3: Frequency contact of electrical contact in air [1]

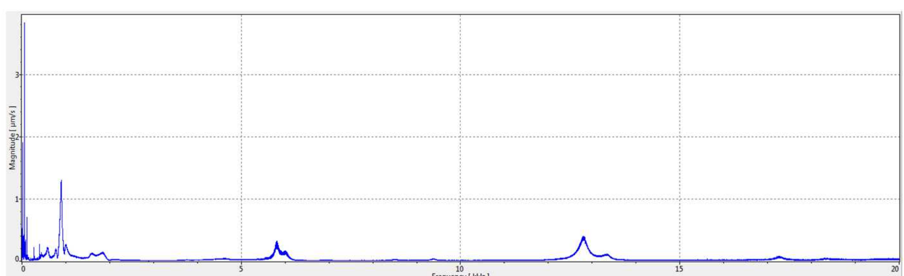


Figure 4:Frequency contact of electrical contact in 10cs oil [1]

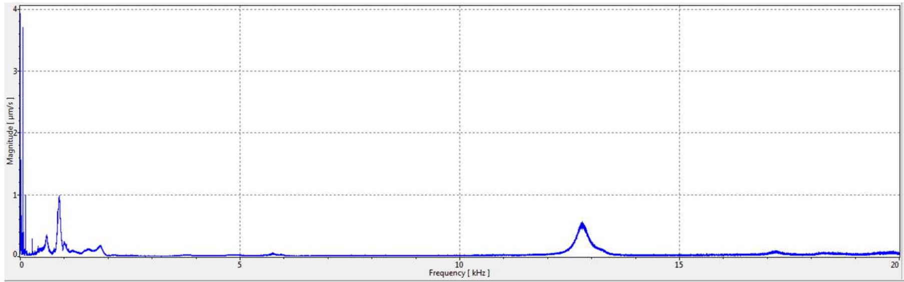
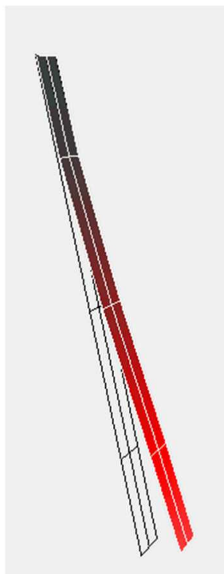


Figure 5: Frequency contact of electrical contact in 20cs oil [1]



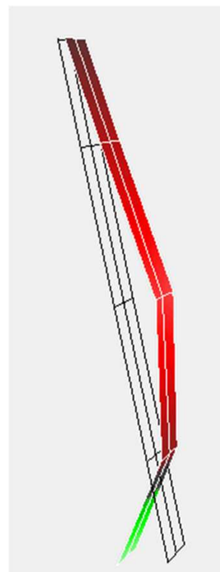


Figure 6: First bending mode in air [1]   *Figure 7: Second bending mode in air [1]*

To process the time history data, Johnson used the Short Time Fourier Transform (STFT) method developed by Kuether at Sandia National Laboratories. In short, this method takes the instantaneous frequency and damping as well as the amplitude of the time history signal in short windows around the frequencies of interest. Using the estimated FFT from Polytec's measurements, Johnson was able to estimate the frequency locations of the modes of interest. Then, modal data was processed using the STFT method, which was more mathematically exact than Polytec's estimation. The settings used by Johnson for the STFT method can be found in [1].

First, we'll examine the results of the first bending modes of the system in the three different test configurations. Figures 8 and 9 show the Polytec measured FFT of the first bending mode in air and the STFT results. As mentioned before, the receptacle is bifurcated. This means that there will be an in-phase and an out-of-phase mode for every mode of interest. Theoretically, these modes should have the same frequency, but once losses are taken into account, it is expected that these in-phase and out-of-phase modes will be slightly separated. The first mode data for 10cs and 20cs oil is shown in Figures 10/11 and 12/13, respectively.

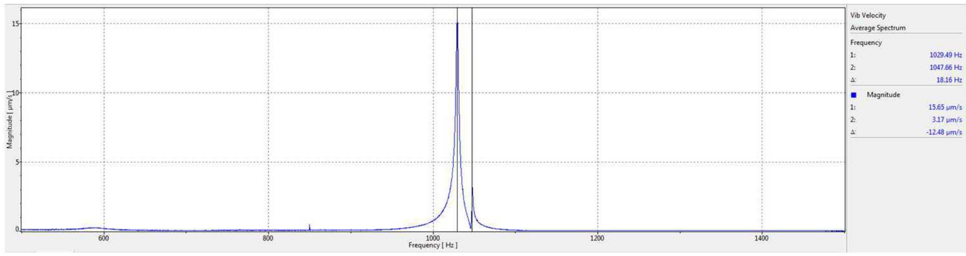


Figure 8: Test in air - First Bending Mode [1]

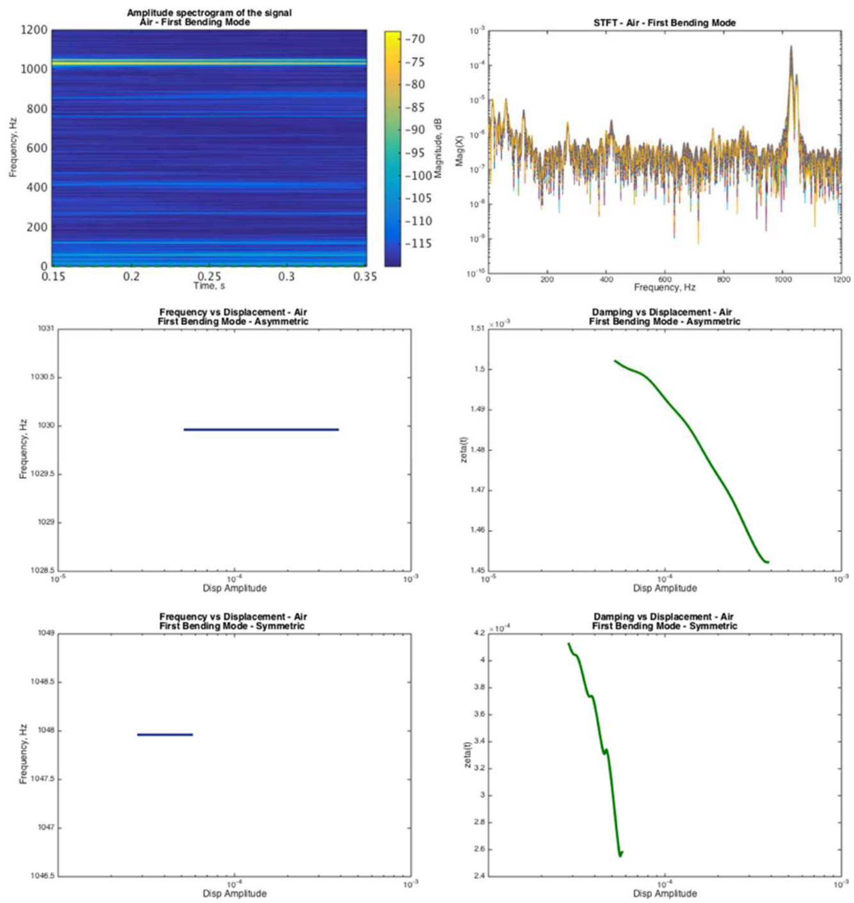


Figure 9: Test in air - First bending mode STFT Data [1]

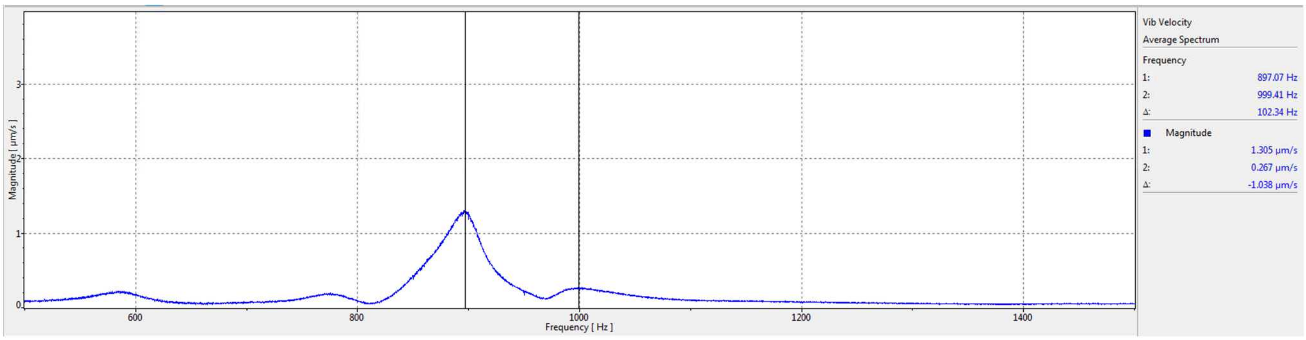


Figure 10: Test in 10cs Oil - First Bending Mode [1]

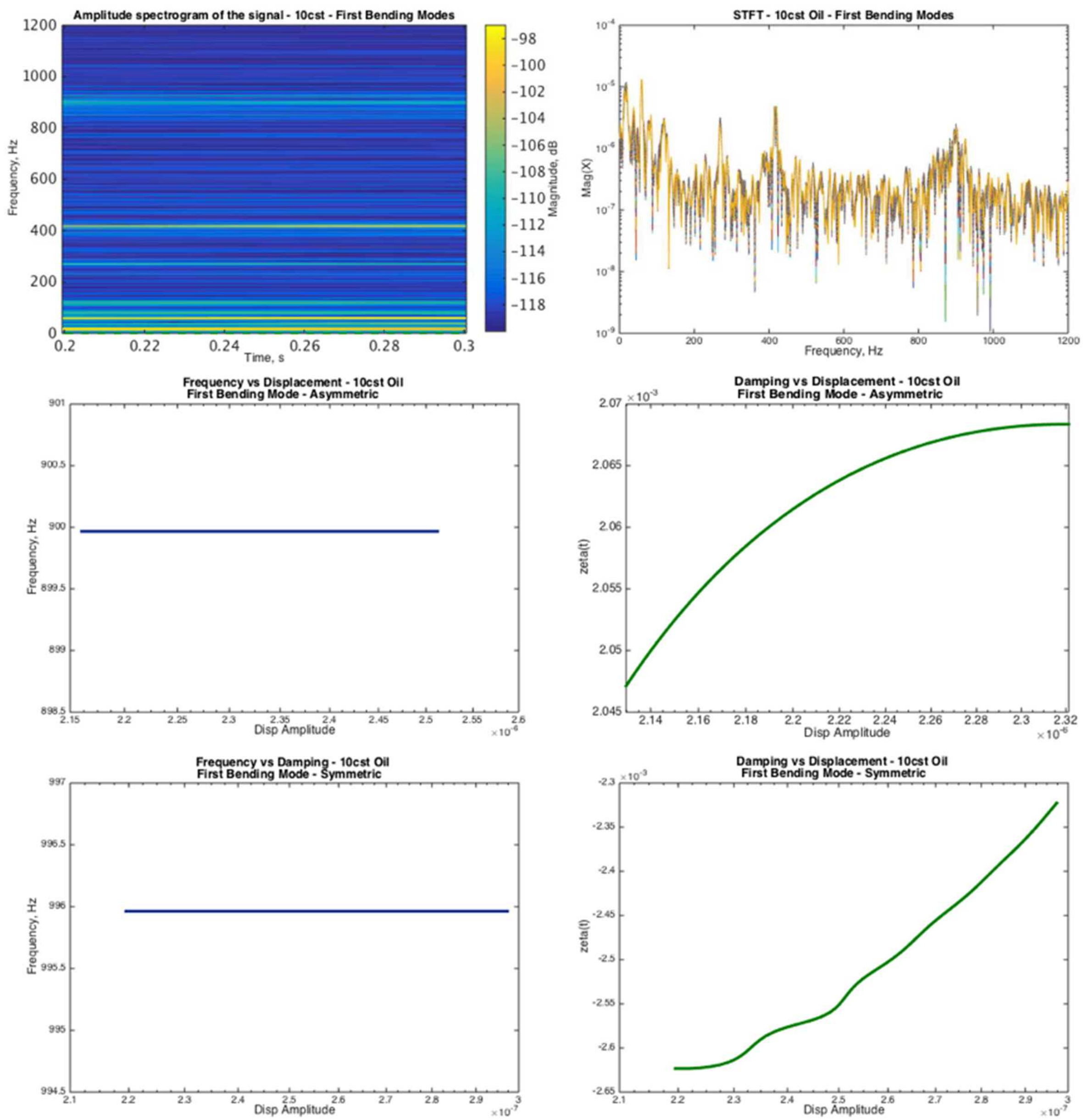


Figure 11: Test in 10cs oil - First Bending Mode STFT Data [1]

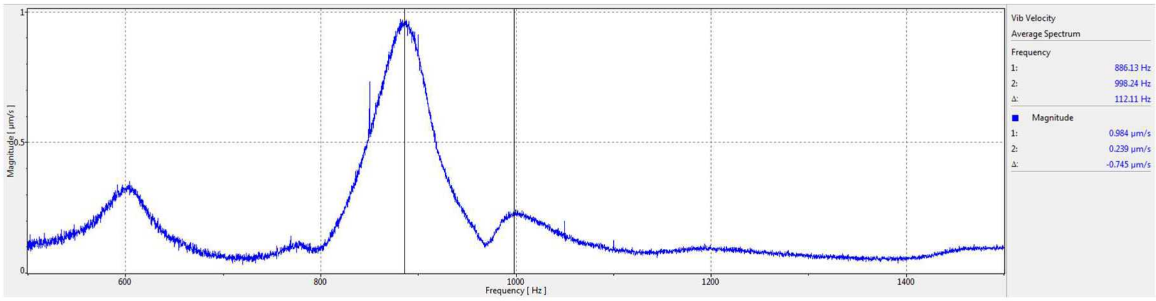


Figure 12: Test in 20cs Oil - First Bending Mode [1]

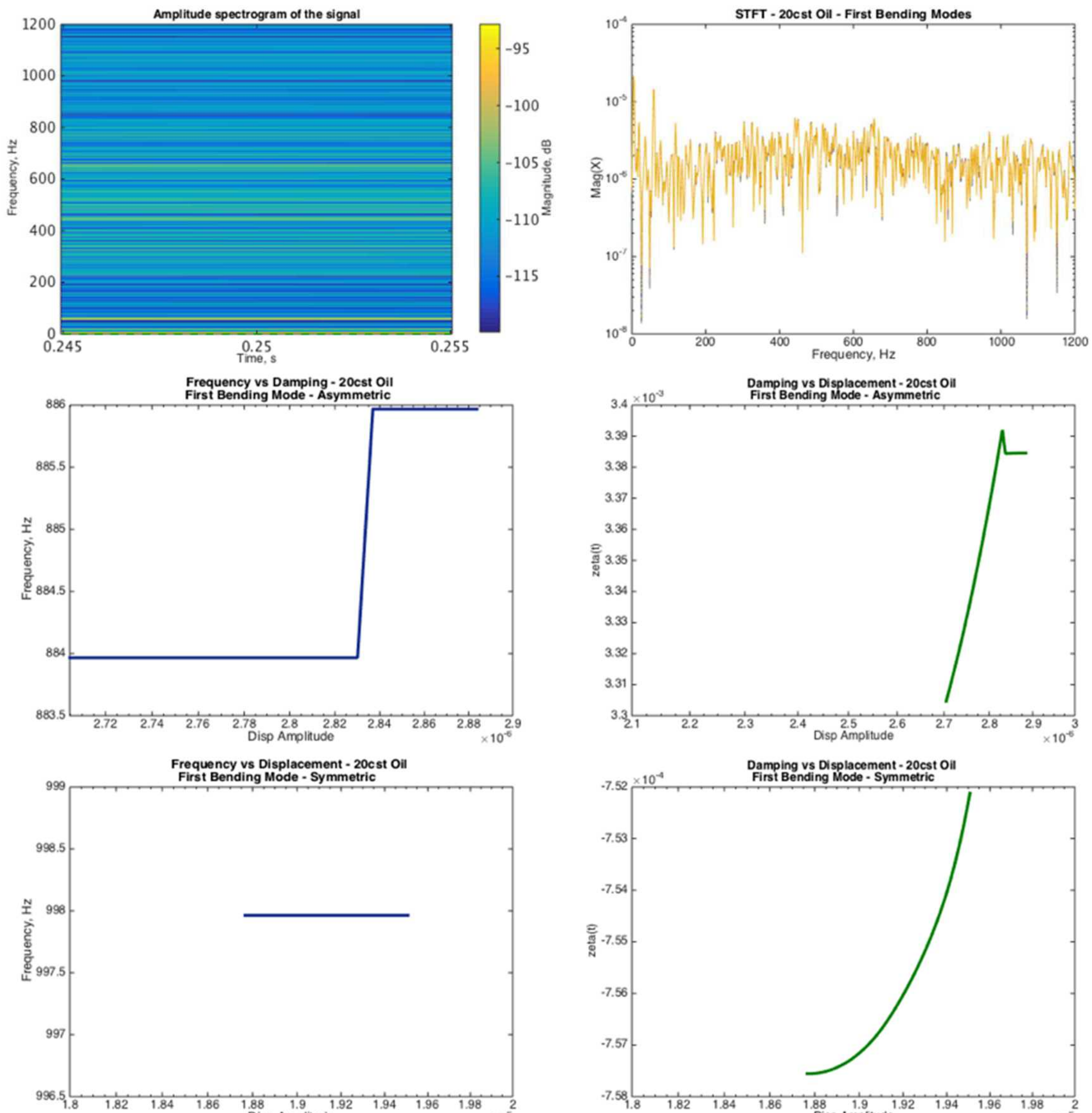


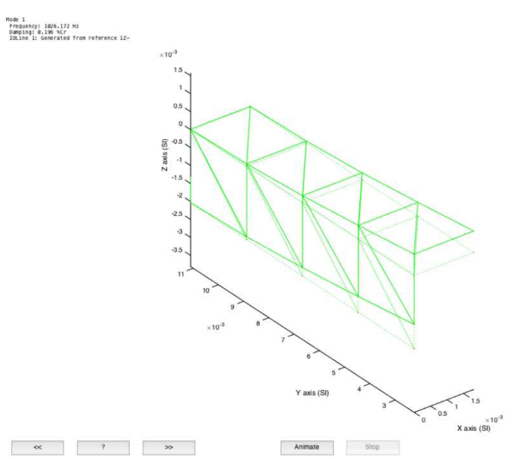
Figure 13: Test in 20cs oil - First Bending Mode STFT Data [1]

To summarize the above data, Table 1 shows the frequency and damping data extracted from each first bending mode in the above tests. This comparison shows that with increasing viscosity, the frequency separation between the in-phase and out-of-phase complimentary modes also increases as well as an overall frequency softening of the first modes. There were challenges with the STFT code processing the data with the added oil, described by Johnson. *"With increasing oil viscosity,* *there is an increase in the measurement noise, which is most obvious in the spectrogram and STFT of the 20cst data. The code is also having difficulty finding the first in-phase bending mode frequency peak. This is likely due to the displacements being damped by the oil as well as the oil movement continuing past the actuation signal, causing more actuation in various directions. There are also more fixture modes measured in oil than in air. Again, this is likely due to fluid movement during the measurements."[1]*

Table 1: STFT Extracted Frequency and Damping for First Bending Modes [1]

	AIR (IN-PHASE)	AIR (OUT-OF-PHASE)	10CST (IN-PHASE)	10CST (OUT-OF-PHASE)	20CST (IN-PHASE)	20CST (OUT-OF-PHASE)
FREQUENCY	1030.00 Hz	1048.00 Hz	899.97 Hz	995.96 Hz	884.17 Hz	997.96 Hz
DAMPING (ʒ)	0.0015	0.0003477	0.0021	0.0019	0.0034	0.0007557

As mentioned in the experimental setup section, a one-dimensional LDV was used for this testing. This limited Johnson's ability to measure the responses of both tines of the receptacle together. The simultaneous response of both tines together was important to confirming the in-phase and out-of-phase modes. Two methods were used to confirm these complementary modes. Both tests were completed without the added fluid. First, the one dimensional LDV was angled to the part so as to maintain measuring the surface of the front tine of the receptacle, and also catch the inside edge of the back tine. The data was measured with Polytec software, then processed in MATLAB®. The 2D coordinates measured by the Polytec 400 were transformed to 3D coordinates manually. This transformed data was then processed through Randy Mayes Synthesize Modes and Correlate algorithm (SMAC) [6]. This algorithm is ideal for closely spaced modes, which was perfect for this particular situation of close complementary modes. The measurement point selection and processing is described more in [1]. The results from SMAC are shown in Figure 14 and 15. SMAC was able to confirm for Johnson that the in-phase mode was located at the lower frequency and the out-of-phase mode was located at the higher frequency. This makes sense, as a base deformation mode would be expected to be at a lower frequency.



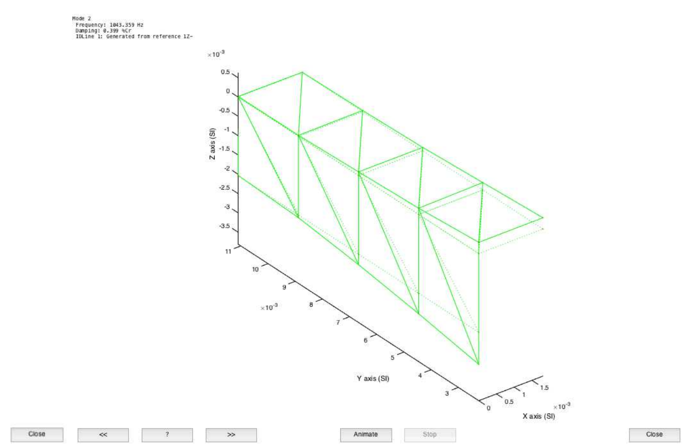


Figure14: SMAC In-Phase First Bending Mode [1] *Figure 15: SMAC Out-of-Phase First Bending Mode*

The second method used to confirm the order of the first bending modes was the use of a 3D LDV. A Polytec PSV-500 was used. With this updated technology, measurements were able to be taken along the thin side profile of the tines. This allowed for Johnson to see the measured response of both tines at once. The measured FFT can be seen in Figure 16 and the measured first bending mode FFTs can be seen in Figure 17. Figures 18 and 19 show the real-time mode shape data measured by the Polytec PSV-500. This data agrees with Mayes' SMAC method and the STFT data processed by Johnson.

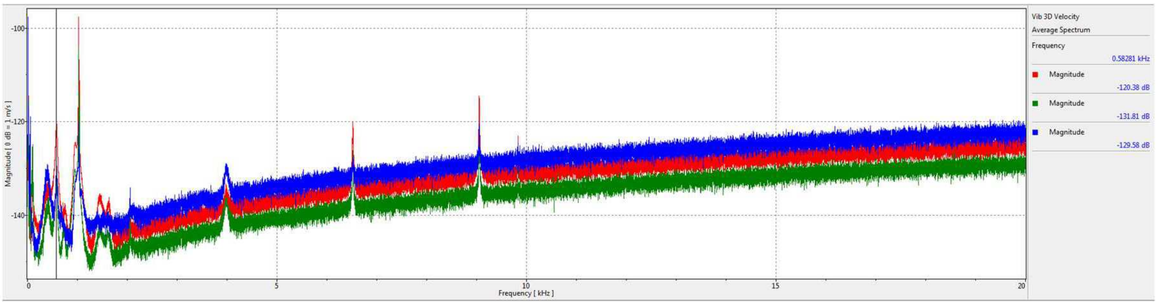


Figure 16: 3D LDV FFT Measurement [1]

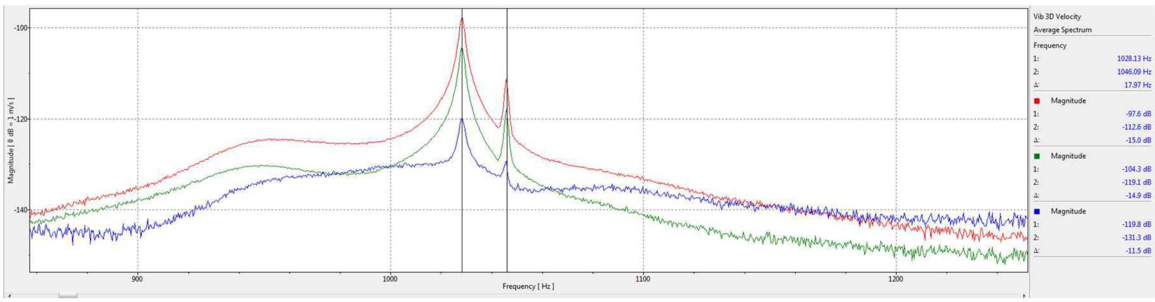


Figure 17: 3D LDV FFT First Bending Mode [1]

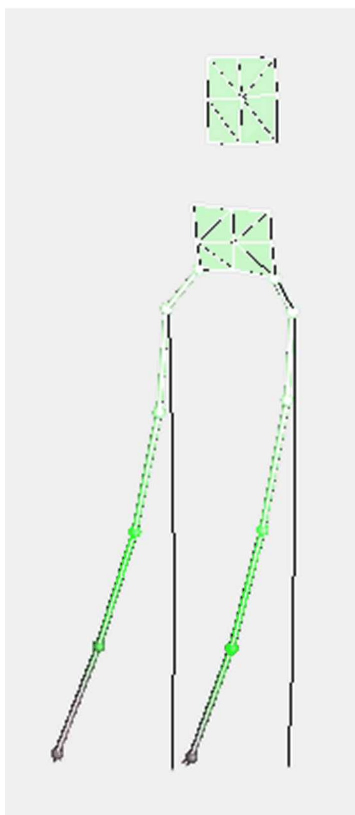


Figure 18: 3D LDV In-Phase First Bending Mode [1]

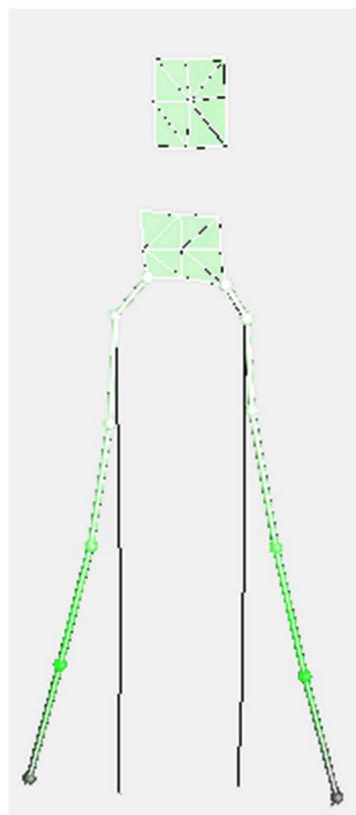


Figure 19: 3D LDV Out-of-Phase First Bending Mode [1]

MODEL VALIDATION

Lacayo and Brake employed the efforts of Blecke to create a modal model of the electrical system [7]. She used Sandia's Salinas Structural Dyanamics code for this model. Table 2 shows a comparison between the first bending modes extracted by Johnson's experiments and the first bending modes calculated by Blecke's high-fidelity model. There is error of about 20Hz (~2%) between the measured and calculated modes. Johnson states that this is likely due to fixturing within the experiment not exactly matching the fixed boundary condition of the model. There is added inherent error in the material damping model. Examining the extent that this material model variation has on the data would require a statistical study.

Table 2: Model vs Experiment - First Bending Mode [1]

	AIR – FIRST BENDING MODE (IN-PHASE)	AIR – FIRST BENDING MODE (OUT-OF-PHASE)
HIGH FIDELITY MODEL FREQUENCY	1046.20 Hz	1053.70 Hz
MEASURED FREQUENCY DATA	1030.00 Hz	1048.00 Hz
% ERROR	1.74 %	0.54 %

CONCLUSION

Experiments on small-scale components are inherently difficult. In this particular case, there was added complexity due to the viscous fluid environment. A unique test set up was developed, using the combination of LDV measurements and piezoelectric excitation to extract modal data from a small bifurcated receptacle, while also accounting for that fluid. This experiment was able to validate current modeling efforts for the receptacle in an air environment, with minimal error, as well as provide additional data for modelers to account for fluid damping effects.

Challenges with this experiment can be examined further for improvement in the test setup. A more precise fixture could aid in aligning the actuator properly so as to accurately measure the input force to the test article. In regard to the test and model comparison, the model could be changed to reflect the test setup boundary conditions as well as an improvement in the experimental clamping of the test article. The test setup could also be expanded upon to better match the entire system. Future work will include testing the full component with a clear container on a shaker, allowing for real-time chatter monitoring. This work will provide the most realistic testing environment while also being able to excite the system with the actual vibration and shock profiles that cause the chatter events. This will lead to matching recorded chatter during testing to mode shape data during those events.

Model validation is key to providing low-cost confidence in the design phase of component development. Experimental data that can point to mode shapes of interest that could possibly cause functionality issues can help designers avoid these pitfalls in the future. Once there is sufficient data to support a model and its behaviors, these models will speed up the design to manufacturing process and lead to more reliable components.

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