

Characterization of Different types of High Performance THUNDER[®] Actuators

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ABSTRACT

THUNDER[™] technology introduces a versatile new family of rugged, robust, reliable piezoelectric actuators and sensors. Because of their pre-stressed composite structure, these powerful yet lightweight devices exhibit unprecedented performance in a durable, solid state package. Both sensors and actuators can be manufactured in a variety of adaptable geometries – squares, rectangles and disks – from several millimeters to many centimeters in size. Wide bandwidth performance can be achieved and maintained even in harsh chemical and temperature environments.

Based on an invention patented by NASA, THUNDER[™] is an emerging, enabling technology that holds the promise of significant advancements in numerous “smart” applications. Development of these applications for smart materials and structures requires extensive characterization of a variety of THUNDER[™] devices in a range of configurations. This comprehensive characterization effort is especially challenging because of the extraordinary flexibility and range of motion demonstrated by THUNDER[™] devices, even under significant load.

This paper will discuss important new work in the ongoing program of THUNDER[™] device characterization. The program includes not only development of the characterization process, but also design and manufacture of the test and measurement equipment necessary to conduct meaningful and reliable testing on these unique, high performance devices. Results will be presented on characterization of two configurations of THUNDER[™] devices, including a circular and a rectangular model of different sizes constructed of varying materials. Data will be offered for a number of key performance characteristics, including displacement, block force, plus displacement vs. voltage and displacement vs. force.

KEYWORDS: Piezoelectric, actuators, sensor, displacement, force

1. INTRODUCTION

Solid State Actuators made with piezoelectric materials have evolved greatly in the last decade. The most commonly known piezoelectric actuators are unimorphs¹, bimorphs¹, MOONIES², RAINBOW³⁻⁷, CRESCENT⁸, and THUNDER⁹⁻²³. THUNDER[™] is a composite of materials which include a PZT (of any particular type), an adhesive (LaRC-SI)^{24, 25}, and metallic layers (stainless steel, aluminum, brass, copper, etc.). The manufacturing process of this type of actuator involves heating the composite at high temperatures (325°C), and then cooling it to room temperature. The resulting curved composite is a rugged device whose displacement and force capabilities have been enhanced when compared to a ceramic alone.

There are several factors that affect the final performance of a THUNDER[™] device either under load or under no-load. Among the most significant parameters are geometry, number and type of layers of metal, curing temperature, thickness ratio of active to inactive layers, holding mechanism, frequency, and voltage. Because of the many variables that dictate the final performance characteristics of a THUNDER[™] actuator, evaluation of its properties is a complex problem. The evaluation of a particular actuator is dictated by its intended application. In order to obtain a general knowledge of the actuator, this paper attempts to describe results obtained for two types of THUNDER[™] actuators under specific boundary conditions.

2. EXPERIMENTAL SETUP

Testing of the THUNDER[™] piezoelectric devices was conducted through a data acquisition system. It consisted of a Hewlett Packard 3325A Synthesizer/Function Generator with IEEE interface which provided a sinusoidal low amplitude waveform. This signal was amplified 100 times through the use of two Trek High-voltage Power Supply/Amplifier units-- Model 50/750 and Model P0674 which provided power to the THUNDER actuator. Displacement of the actuator was then monitored using a Dual Channel Angstrom Resolver for displacements below 0.0254cm, and a Nais Micro Laser Sensor

LM10 for displacements below 4.0cm. All test equipment was controlled and monitored using LabVIEW™ through a data acquisition card and an IEEE interface card.

The computer set the parameters for the signal generator, frequency (1 Hz), and voltage which is amplified 100 times through the amplifier to power the device. The laser monitored the displacement at one center point of the device. Two types of devices were measured, a circular device of 3.175 cm in diameter and a total thickness of 0.048 cm, and a rectangular piece 7.62 x 5.08 x 0.079 cm. Both pieces have a top aluminum layer, an adhesive (LaRC-SI), a PZT wafer (Motorola 3195HD), adhesive, and a bottom stainless steel layer. Table 1 presents the dimensions of each layer for the model designated 5C, and Table 2 presents dimensions for the model designated 6R. Each one of the actuators was mounted on specially designed fixtures which contained the device without restraining its movement. Figure 1 shows the fixture used for measuring model 5C with the circular device held in three locations using spring-loaders spacers. Figure 2 shows the fixture used for measuring model 6R, a rectangular piece as it was measured on a simply-supported (pin-guided) fixture.

Force measurements were accomplished using the device shown in Figure 3 in combination with the mechanisms shown in Figures 1 and 2. The force gage was used for loads above 22.24 N where the displacement was expected to be smaller than the maximum traveled allowed by the gage. For smaller loads and quasi-static operation, a weight was attached to the device using the fixture shown on Figure 4. In this manner force and displacement could be recorded. Free displacement was measured for cantilever and simply supported, and displacement under a load was measured for simply supported pieces only. Each model consisted of a ten-device sample to investigate consistency and repeatability between pieces. The LabVIEW program recorded each measured point after taking 100 samples and averaging the sample point four times.

Table 1. Description of a THUNDER 5C model

Layers for Model 5C :Diameter 3.175 cm	Thickness (mm)
Aluminum Alloy 2024 – perforated	0.0254
LaRC-SI	0.0381
PZT – 3195 HD	0.1905 ± 0.0127
LaRC-SI	0.0381
Stainless Steel 302	0.1524
Total Measured Thickness	0.48 ± 0.015

Table 2. Description of a THUNDER 6R model

Layers for Model 6R :7.62x5.08x0.079 cm	Thickness (mm)
Aluminum Alloy 2024 – perforated	0.0254
LaRC-SI	0.0381
PZT – 3195 HD	0.381± 0.0254
LaRC-SI	0.0381
Stainless Steel 302	0.2540
Total Measured Thickness	0.762 ± 0.028

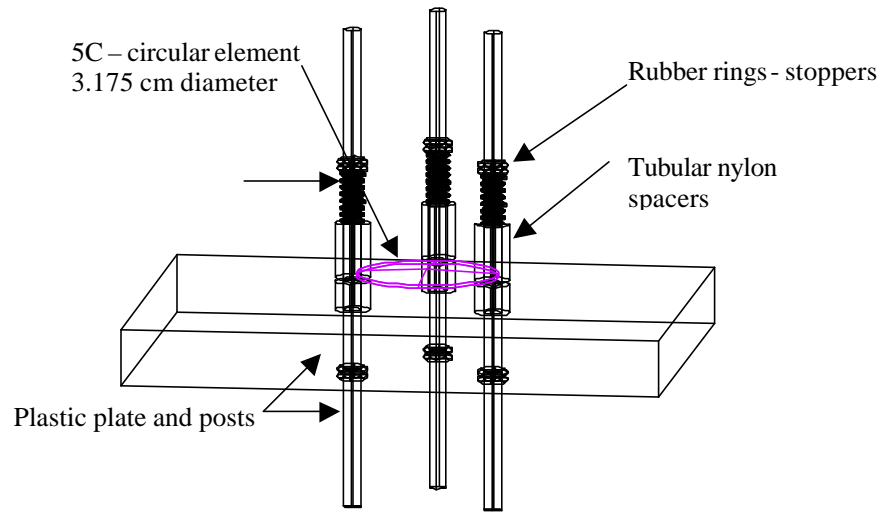


Figure 1. Schematic Of Holding Mechanism For Measuring Device For Circular Pieces.

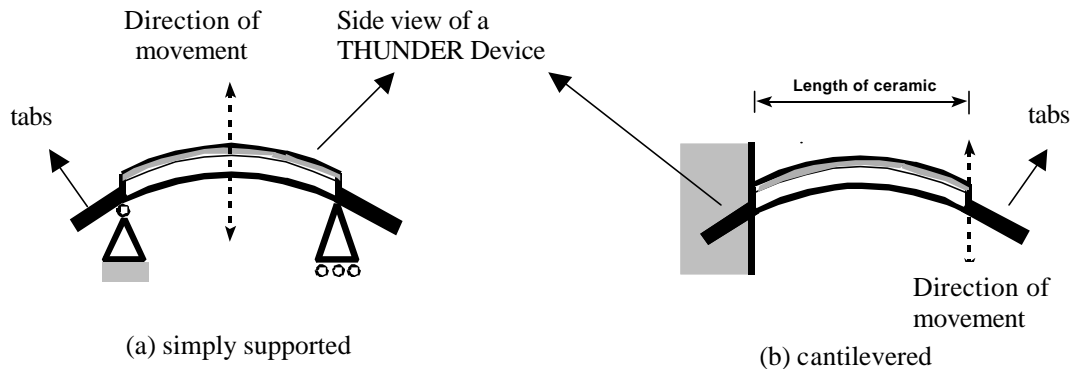


Figure 2. Schematic Of Holding Mechanisms For A Rectangular Piece, THUNDER™ Model 6R

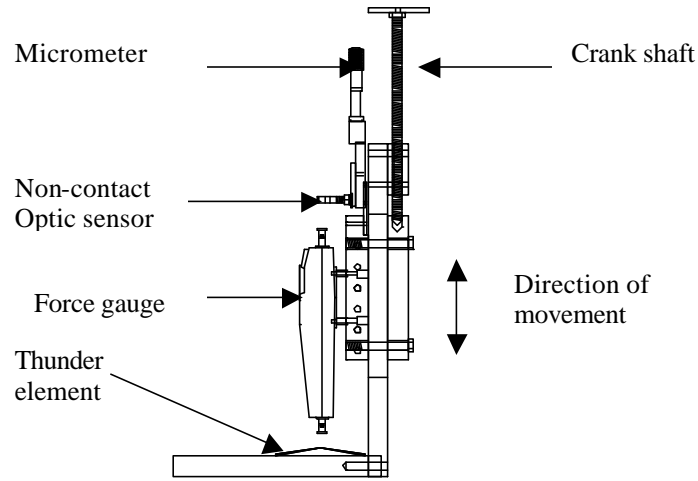


Figure 3. Force Measuring Device for Loads Above 22.24N

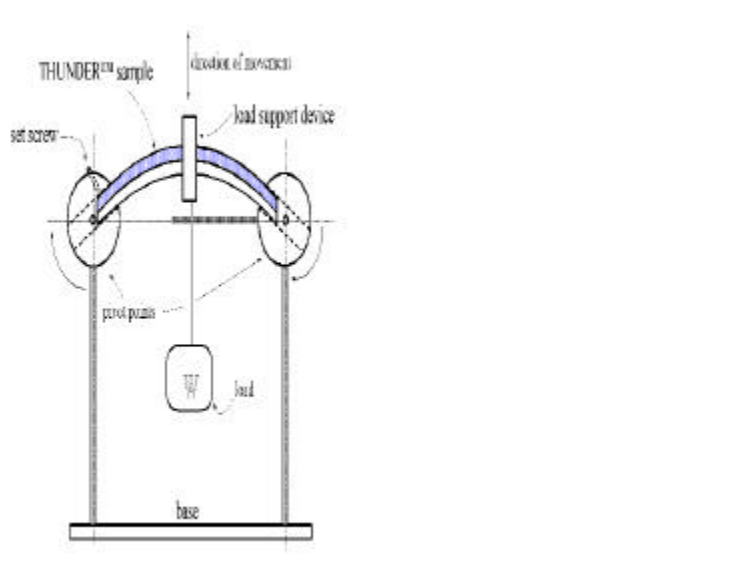


Figure 4. Force Measurements Device for Below Loads 22.24N

3. RESULTS

Displacement measurements were performed on model 5C pieces at 1, and 60 Hz with load and no-load. Figure 5 shows the average free displacement vs different voltages of 10 pieces. The maximum voltage used was 450 Volts peak-to-peak, since any higher voltages depolarize the samples. The limit on voltage was determined experimentally on all pieces, and it was set to 24 V/cm of the piezoceramic thickness. Notice that the spread of the data maybe due to variations on thickness of the materials used in the manufacture of THUNDER™ (see Table 1 for details).

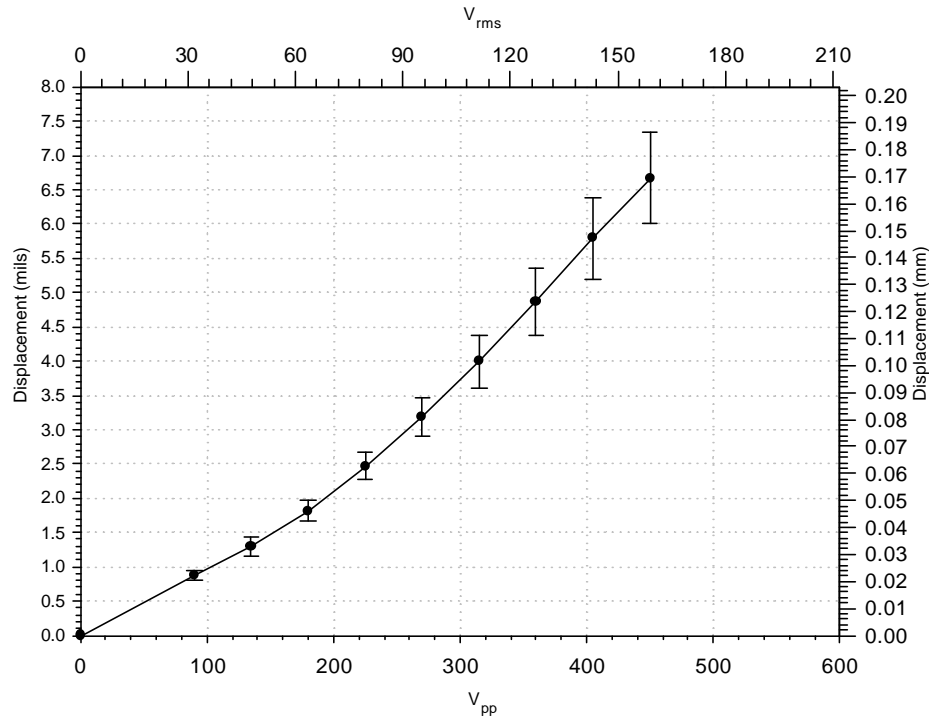


Figure 5. Simply-Supported Displacement Vs. Voltage Under No Load At 1 Hz For a THUNDER Device Model 5C

The maximum displacement is 0.17 mm under no-load, and there seems to be a quadratic relationship between voltage and displacement under no-load. Such trend can be explained due to the geometric shape of these particular pieces. The 5C model does not have a spherical shape but domed which makes the piece unstable under no-load. Hence, measurements with a load were performed at different voltages. Figure 6 shows the results of displacement vs force at different voltages.

Results for small loads have been eliminated due to inconsistencies on the result. As mentioned before, small loads require a different measurement mechanism because of the travel range of the force gage used was too small to accommodate for such high displacements. The method of attaching weight also is difficult to implement on circular pieces. A more meaningful result for circular pieces would be pressure, so that the force is distributed over the entire surface of the model. For larger loads, the force gage produces repeatable results.

Blocking force was defined as the force needed to reach a peak displacement less than 10% of the piezoceramic thickness. In all these cases, the maximum load that the force gage could apply was 133N. Applying such high forces sometimes may cause micro-cracks on the piece, and therefore is considered as the maximum value that the pieces can withstand without using a plate to distribute the forces. In an application, smaller point or line forces should always be used. THUNDER™ pieces can be powered with line current (120 V_{rms} and 60 Hz). Because of the inertia forces involved on attaching a weight at these frequencies, the force gage was used for larger loads. Note that the same trend obtained at 1 Hz is obtained. These results indicate that the response of a THUNDER element is independent of frequency for values below its natural or mechanical resonance.

The same measurements were performed on the 6R Model. The main difference is the versatility of a rectangular piece; that is, more modes of operation exist with such geometry. Furthermore, this piece consists of a stronger composite since the ceramic thickness is twice as much as the 5C Model. First, cantilevered measurements were made of 10 samples of this particular model using the clamping method shown in Figure 2b. Again the same trend observed on the Model 5C can be seen on Figure 8. There is a non-linear behavior between displacement and voltage. It is important to point out that the displacement was measured only at the mid-point across the width of the piece. Since the piece has a slight dome across its width, the real movement of the piece is in three dimensions.

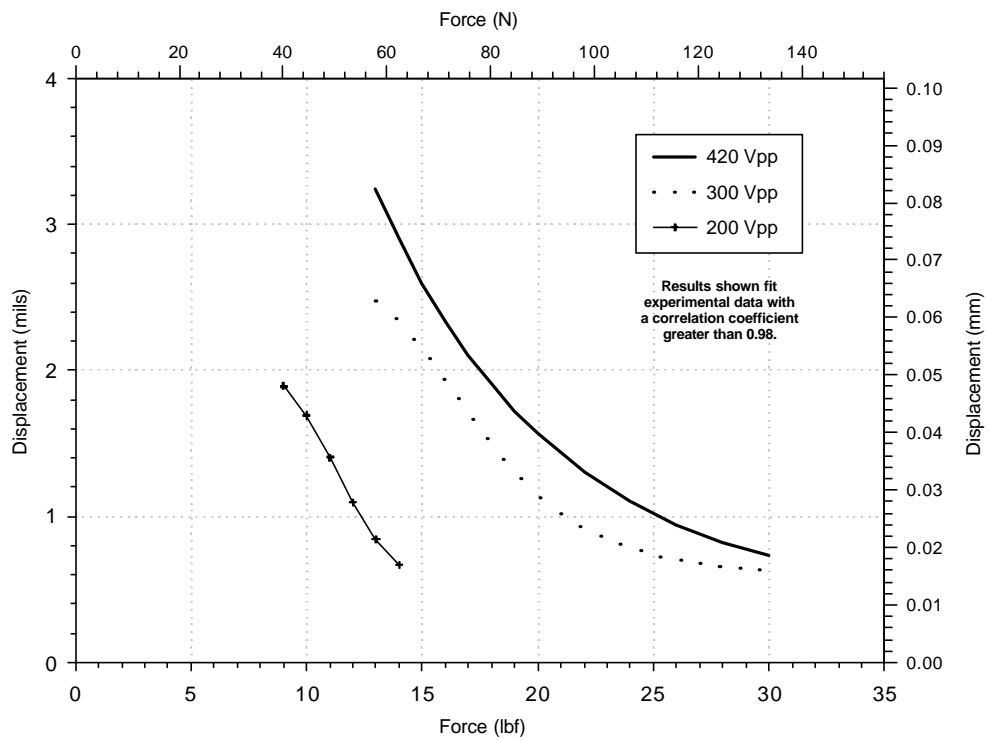


Figure 6. Displacement vs Voltage Under Load at 1 Hz for a THUNDER Device Model 5C

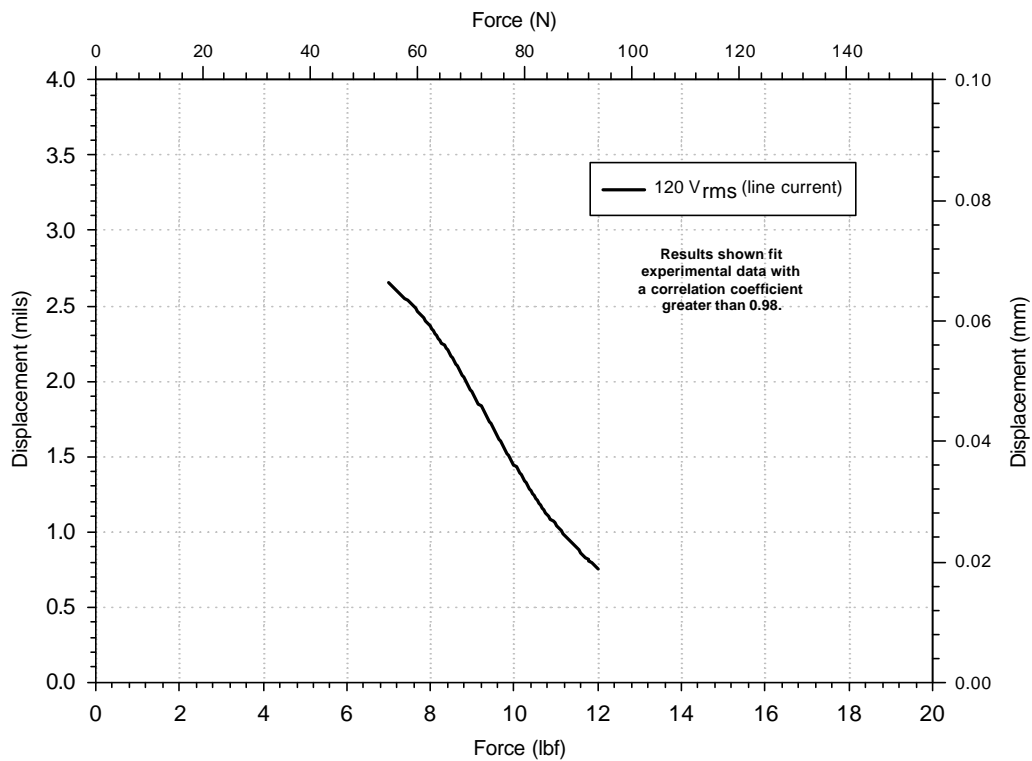


Figure 7. Displacement vs Force Simply Supported at 60 Hz Under Load for a THUNDER Model 5C

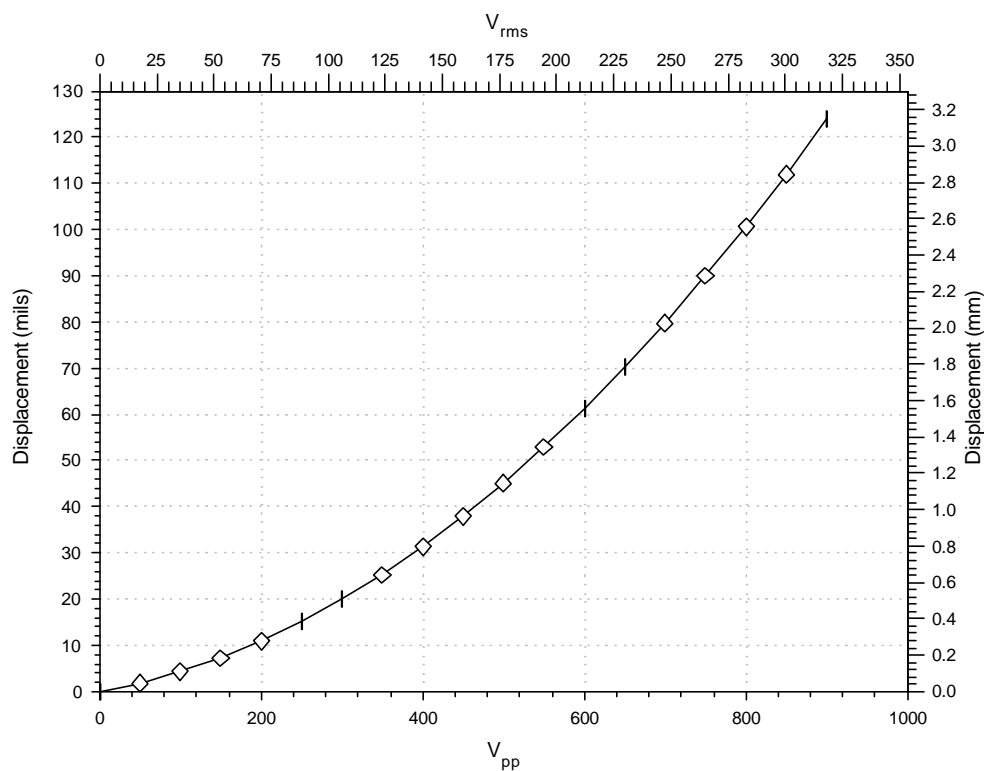


Figure 8. Cantilevered Displacement vs Voltage Under No-Load at 1 Hz for THUNDER model 6R

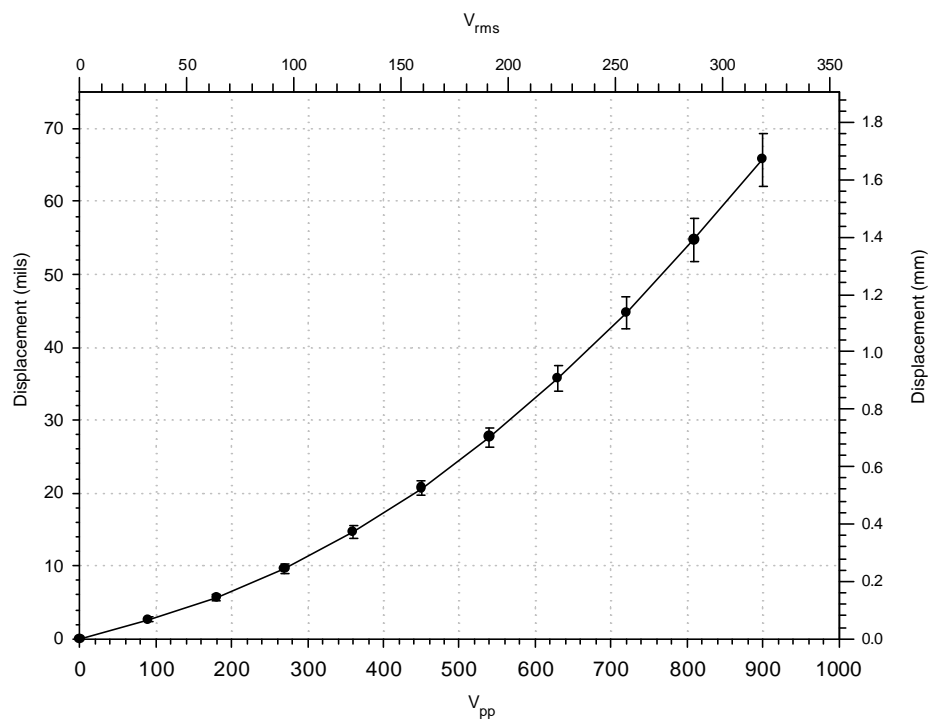


Figure 9. Simply-Supported Displacement vs. Voltage Under No-Load at 1 Hz for THUNDER model 6R

The next condition to be tested using this model is presented in Figure 9. The piece here is simply supported and the same non-linear trend is observed. The advantage of using this type of device is ease of adapting it to any structure type. Also note that the scatter is much smaller on this model than the circular one (5C). On both cases, Figures 8 and 9 the maximum voltage applied was 900 Volts peak-to-peak, with a peak displacement for simply supported of 1.651 mm and for cantilevers is 3.2 mm (cantilevered displacement approximately double the simply supported one).

Figure 10 shows the results of the displacement obtained when the piece is under a pre-load at different voltage levels in a quasi-static mode (1 Hz). Measurements were stopped when the displacement of the element became 10% of the piezo ceramic thickness used on this particular model (0.0381 mm), or when the maximum load of 133 Newtons was attained. When applying such large pre-loads distributed along a line across the width of the sample, reversed curvature is obtained. Cracking is possible under these conditions, especially if the mounting does not allow the element to move (configurations such as pin-pin).

Finally, Figure 11 shows the results obtained for displacement under a load using line current. The same effect observed with the 5C model is noted here. That is, the same exponential decay trend is obtained indicating that the displacement under load is independent of frequency (1 and 60 Hz).

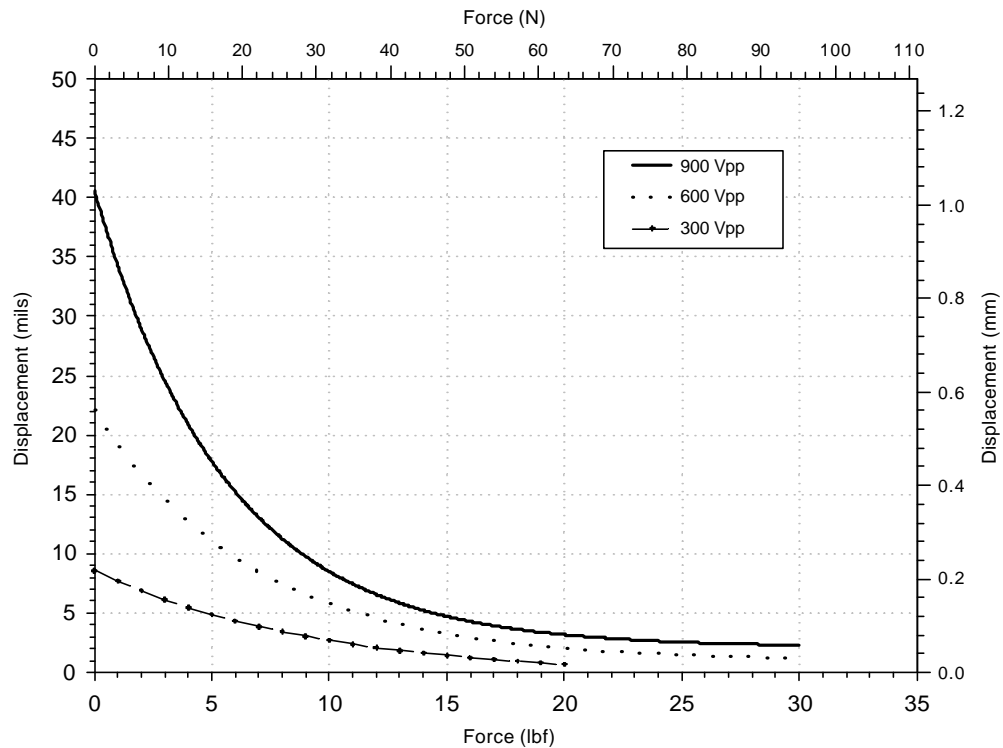


Figure 10 Force vs. Displacement at 1 Hz Under Load for a THUNDER Model 6R

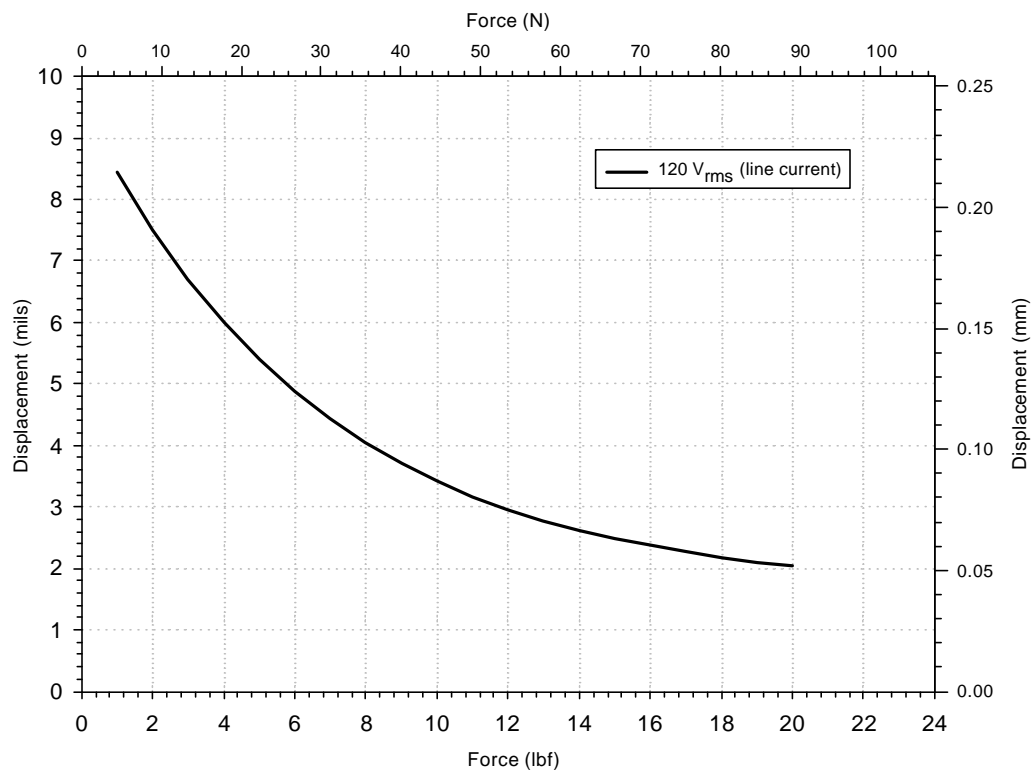


Figure 11. Force vs Displacement at Line Current Under Load for a THUNDER Model 6R

4. CONCLUSIONS

Experimental results for two types of THUNDER™ actuators (models 5C and 6R) are presented. The parameters, displacement and force were measured using various conditions such as voltages, frequencies, and clamping mechanisms. Results showed that their performance vary greatly with specific actuator design which includes geometry, number of layers, ceramic wafer thickness, adhesive, and ratio of active to inactive layer thickness. The geometrical shape of an actuator plays a crucial role in its performance. For instance, a rectangular actuator can provide larger displacement than a circular device when tested in either load or no-load conditions. Furthermore, displacement under load seemed to be independent of applied frequencies measured in this paper.

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