

# Sensor Measurements For Diagnostic Equipment

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## Abstract

Piezoelectric sensors are widely used in accelerometers, for detecting failures in structures, and for vibration suppression systems among others. Such sensors can be manufactured in many different sizes, and packages to work in a variety of environments. The main characteristic of the piezoelectric material that allows for this effect is the conversion of mechanical to electrical energy. That is, when a piezoelectric material is subjected to a mechanical stimulus, a response is produced and a conversion of mechanical to electrical energy occurs. A new pre-stressed piezoelectric bender has exhibited an improved response under the same magnitude stimulus when compared to a traditional piezoelectric bender as an actuator. Measurements performed on these new devices demonstrated that energy produced under a single mechanical strike is significant compared to a single piezoelectric slab. The objective of this study is to investigate the feasibility of using this new pre-stressed piezoelectric bender as a self-powered sensor that could be used for monitoring the health of an individual.

## Introduction

Piezoelectric materials have been studied for several years to be applied as effective sensors [1-4]. There are many sensors today that incorporate a multitude of piezoelectric technologies including single crystal, piezoceramic and piezopolymer films. The application requirements typically dictate the type of piezoelectric technology that can be applied. This study has taken advantage of a newly developed pre-stressed device that has demonstrated significant electrical output when compared to conventional piezoelectric devices. By harvesting the energy output of these new devices and redirecting the energy to generate a signal through a known medium, it may be possible to achieve a signal-sensor relationship that could be applied as an aid in monitoring and individual's health [5-9]. The primary objective of this study was to determine the feasibility of using a pre-stressed device as a self-powered sensor. Results have been obtained for the impedance, capacitance, phase angle and electromechanical coupling of several composite laminates to be considered as potential sensors.

## Experimental Set-up

In order to test the capabilities of a pre-stressed piezoelectric wafer, several tests were performed using high-density piezoelectric ceramic, PZT 5A equivalent, manufactured by CTS Wireless. The ceramic had a surface area of 3 in by 0.5 in and varying thickness. Fifty-six devices manufactured by Dominion Resources consisted of 1 top layer of aluminum 0.001 in thick, a 0.015 in thick PZT layer, and a 0.010 in thick stainless steel type 304 bottom using the polyimide SI<sup>TM</sup> as an adhesive. Impedance, phase angle, capacitance, and electromechanical coupling factor  $Q$  were measured at a range of frequencies between 100 Hz and 10 kHz using an impedance analyzer (model HP4194A) with a voltage source of  $1V_{rms}$ . Each device was x-rayed immediately following fabrication using a Philips xray machine (model MGC 30/MCN 167). To ensure uniformity, the total thickness of each device was measured using calipers along the length of the device and the result averaged. Dome height, defined as the arc height obtained as a result of pre-stressing, was determined using a non contact laser NAIS, (model ANR5232). The elements were tested for displacement performance under loading at a quasi-static frequency (5 Hz) at voltages up to 800 Volts peak to peak using the same non-contact laser described above, a signal generator (HP 33120A), a TREK power amplifier (model PDZ70-2-L-CE), a LeCroy 500 MHz Oscilloscope (model 9350L), and a data acquisition system (National Instruments) controlled with a PC using LabView<sup>®</sup> software.

The layer configuration for the devices utilized was chosen based on previous studies [10]. The results of the previous study states that a “steel thickness ratios of 0.280 to 0.375 seem to give the largest, most reliable displacements for any given voltage,” at 1 Hz and no load. The ratio for this set of tests was 0.31, which falls within that range as seen in Figure 1.

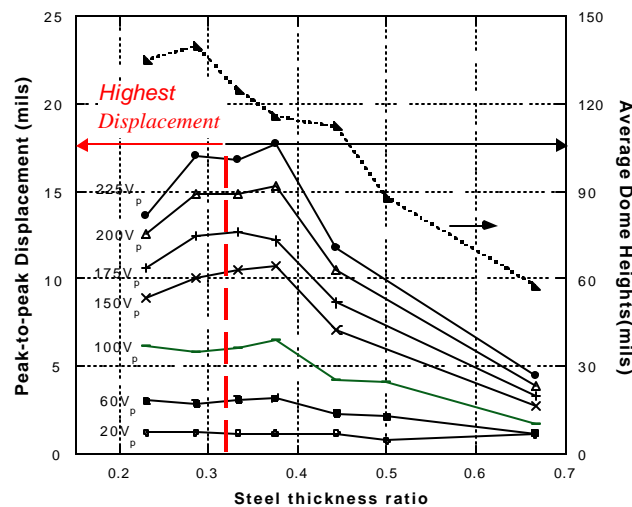


Figure 1- Change in Maximum Displacement for Various Thickness Ratios at 1 Hz No-Load [10]

## Results

All the devices manufactured were x-rayed in an effort to identify elements that had cracks. A typical cracked element can be seen in Figure 2. By visual inspection of the x-rays, the cracked devices were easily identified. This approach could be a useful tool for quality assurance on the production of pre-stressed benders.

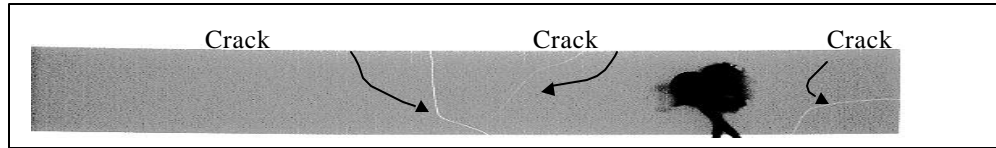


Figure 2- X-Ray Sample of a Cracked Piece

Next, parameters relevant to the physical properties of the devices were measured. These parameters included total thickness and dome height. The total thickness of the devices was measured along the centerline of the length of the element on three different places, and the results averaged. The average thickness was  $32.2 \pm 3.1$  mils (1 mil = 0.001 in), and the dome height of the device was measured as  $172.4 \pm 12.2$  mils. These values give an indirect measurement of the adhesive line thickness as well as a parameter used to predict performance. Note that the dome height value measured for these samples is higher than the one predicted by Figure 1 (~110 mils). This may be due to differences in manufacturing techniques as well as the adhesive thickness line, which in this case was approximately 3 mils per layer.

Using the impedance analyzer, impedance, phase, capacitance, and Q were measured for a range of frequencies. These measurements are necessary to document the mechanical and electrical parameters that may be necessary to classify this bender as a sensor. The results showed the cracked pieces have a distinct different trend for all the parameters measured in the sample shown in Figure 3 parts a through d. The trend shows that the devices, even with cracks present can work properly and that structural changes, i.e. one piece attached to a structure or a person, can be seen on the “signature” of any of these parameters measured.

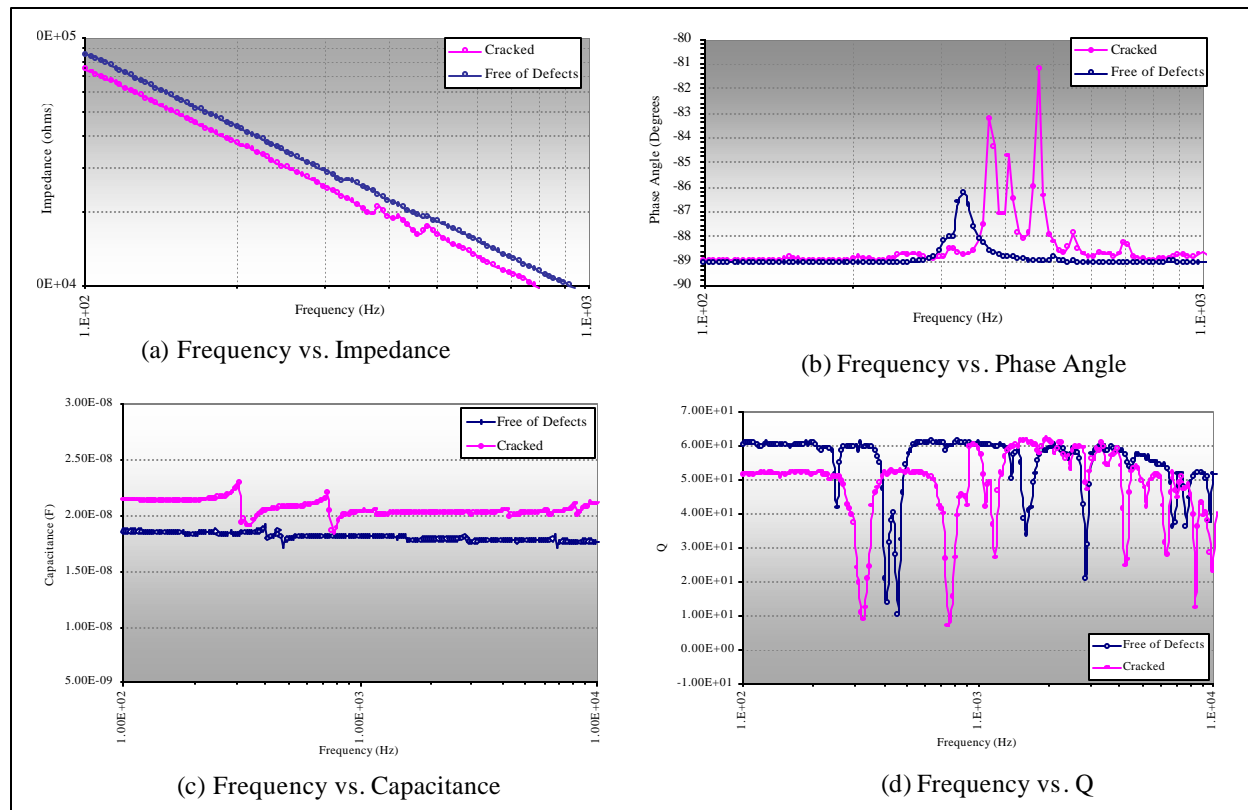


Figure 3- Impedance, Phase Angle, Capacitance and Q vs. Frequency

To fully characterize the performance of this device, displacement was also measured at 5 Hz and with a load of 76 grams, which would be the equivalent to the force applied in later tests to measure the produced energy. This load was applied through a lever arm (See Schematic in Figure 4) and displacement was then monitored at different voltages. The resulting loops shown in figure 4 show that maximum displacement under an AC field is not one peak value but several. This result shows that maximum displacement can be achieved with a lower DC voltage than with a sinusoidal AC field. This is a very important factor to consider when designing applications, and can also be of advantage when testing the energy produced by a single stroke vs. a continuous stroke. Also note that the driving fields used on this piece were much higher than conventional fields (87 Volts/mil). This was possible due to the poling conditions of these samples (90 V/mil).

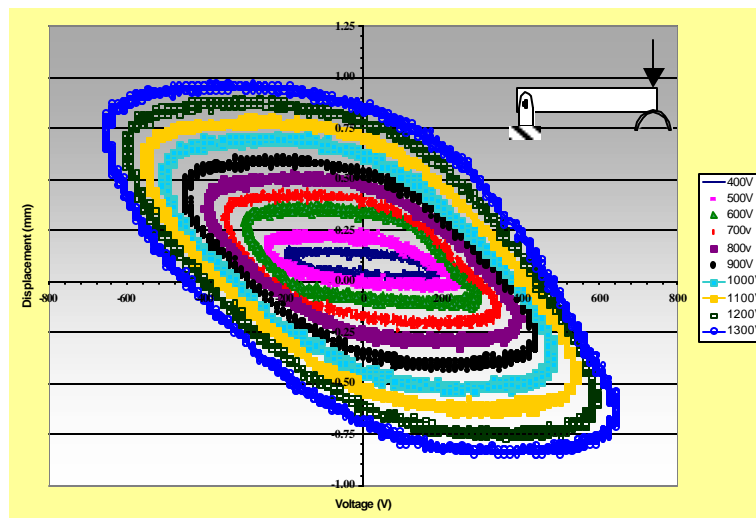


Figure 4- Typical Voltage Displacement Loop

The next stage of measurements of the devices to be used as sensors consists of applying a mechanical stroke of the magnitude shown here. A shaker will be utilized to apply a controlled vibration and the voltage produced measured using different resistance values. These values will be calculated from the impedance curves measured in this study to ensure impedance matching and to avoid energy losses. It has been shown in previous studies [5-9] that impedance matching is a factor to be considered when measuring “energy produced” through a mechanical action. These set of measurements are in progress.

## Summary and Conclusions

Measurements were performed on pre-stressed piezoelectric benders designed for actuation. The measurements included electrical and mechanical properties as well as displacement performance under a load. These data is to become the baseline data for the second stage of these experiments, which consist of measuring the “energy produced” by the elements when under mechanical action. The results so far have shown several tools that can be used to ensure that the devices produced are free of defects either through the use of x-rays or by measuring electrical parameters. Most importantly, it has shown that electrical parameters could be used as a diagnosis tool to diagnose changes on structures.

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