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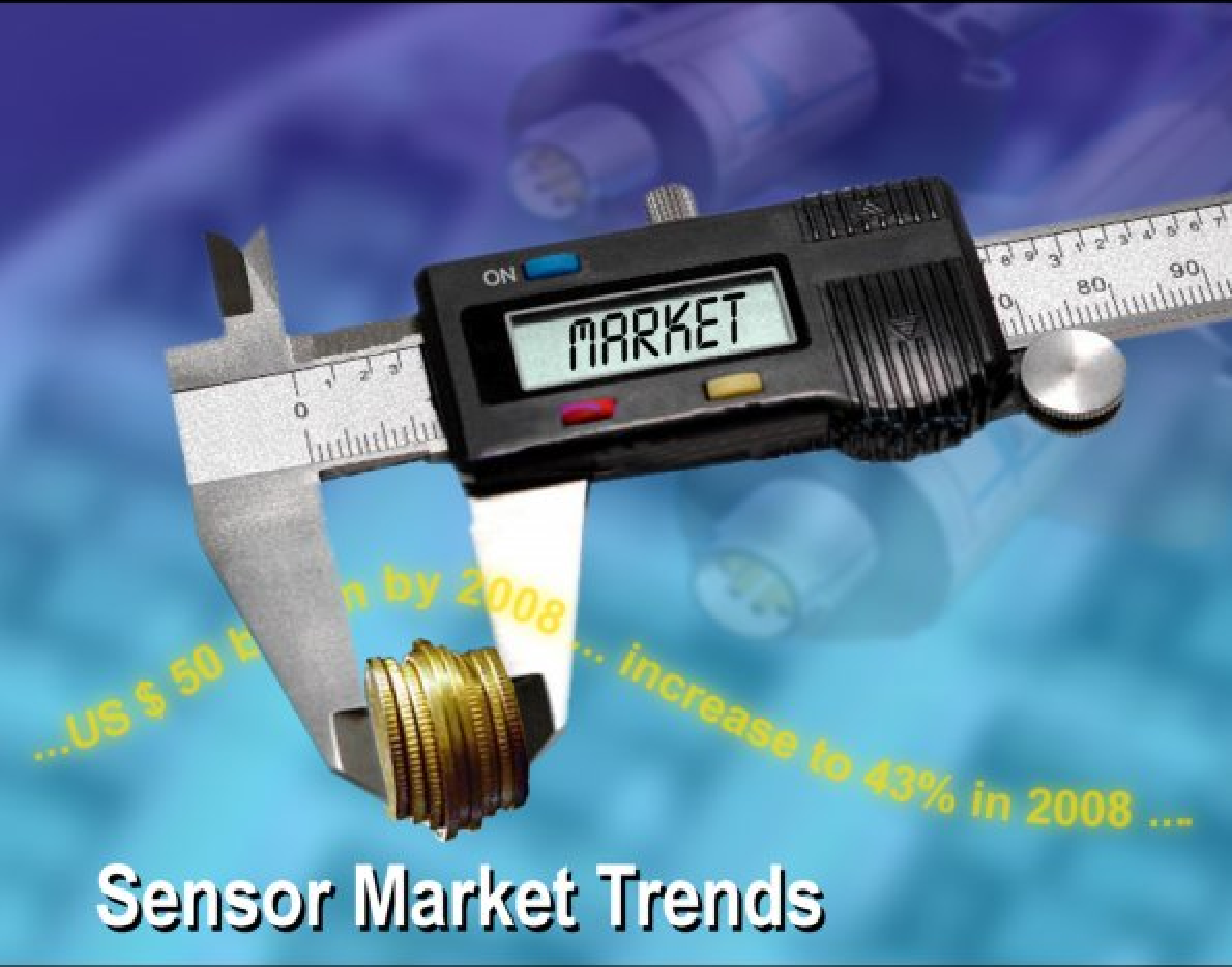

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Characterization Technique of an Excited Solid-State Piezoelectric Transformer as a Function of Transient Time

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Abstract: A technique describing voltage transformation of a transiently oscillating Piezoelectric Transformer (PT) has been reported. The first part is dealing with determination of input and output voltage of PT at resonance using Pico scope; a computer based oscilloscope. It was found that, as time goes, the output voltage of the PT fluctuated due to frequency aging; therefore a second part of experimental set-up was needed to record transformation ratio as a function of transient time. To do that, Computer 2 was connected to DMM1 and DMM2, for the purpose of measuring the voltage transformation, in additional to that, Lab view program was installed in Computer 2 and used to calculate voltage ratio as a function of transient time. In this technique, caution was taken when interpreting results from resonance (110.50 kHz) relative to PT operating in frequency (kHz) range between ($109 \subseteq 110.50 \subseteq 114$) as a function of transient time.

Keywords: Drift frequencies; Voltage transformation; Transient time; LabView programming; PT; Piezoelectric Transformer; Ascending voltage; Descending voltage; Pico scope; Computer based oscilloscope; Voltage differential probe; GPIB card

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1. Introduction

A rapid technique of determining the resonance frequency of a Piezoelectric Transformer (PT) or sensor [1,2] is by exciting it with an interrogation frequency, and then analyzing the output parameters of the sensor. PT is comparable to quartz crystal resonator, PZT transducers, and other sensors that measure physical parameters by tracking the sensor resonance frequency as a function of the environmental parameter of interest. While steady-state frequency measurements enable precise determination of resonance frequency they are inherently time consuming or relatively expensive requiring instruments such as a spectrum analyzer and other techniques as reported earlier in [3-10]. In this work the author is describing a characterization technique using an excited PT as Device Under Test (DUT), this technique has proved to be very accurate and can be applied to any kind of oscillating piezoelectric sensor [11-16], with characteristic drift frequencies corresponding to their transient time. The described technique in this paper has a measurement resolution of 109 -114 kHz, a value ultimately limited by the behavior of the PT itself, with a measurement time of more than 3600 seconds.

The prototype PT was ordered as per customized design from APCI, a piezoelectric manufacturer in USA, the cost of production of the single disk PT was approximately $180. The PT was then mounted inside Teflon insulations ready for electrical characterization. A frequency below the ant resonance, at Y is approximately114.20 kHz, (See Figure 1) was used to excite the PT, this frequency caused the PT to mechanically oscillate; in turn, the oscillations in the PT generated a continually amplified signal voltage that was detected by using Pico scope and digital multimeters, as the frequency of the excited PT tends to drift toward resonance (109.50 kHz). While this technique has been demonstrated to be useful for determining a transiently oscillating PT, with proper modification, this technique could be used to determine other sensor platforms, for example, surface acoustic wave sensors, where information can be obtained from the drift frequencies of a transiently excited sensor in a few decimal above it's ant resonant frequency.

2. Theory

In analyzing material using the resonance method, the piezoelectric constants are usually determined with greater accuracy from high voltage transducers at any particular resonance frequency as reported earlier in [17-19]. The piezoelectric element vibrates most efficiently when excited at resonance, a point where it converts most of its electrical energy input into mechanical energy [20]. The pattern of PT responses is depicted in Figure 1.

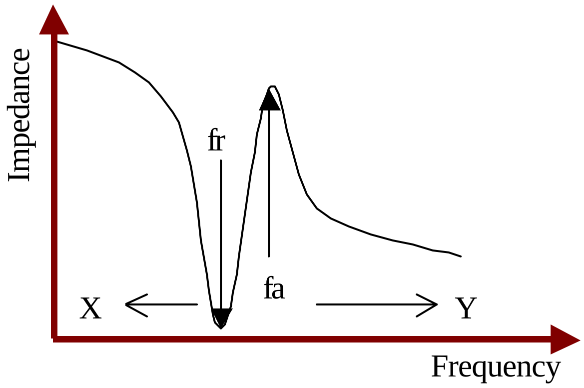

Fig. 1. General curve of impedance versus frequency of a piezoelectric device excited very close to resonance frequency (fr) between X and Y.

As the frequency from the signal generator is tuned to the frequency Y very close to ant resonant of PT, the device oscillations will first approach a frequency at which impedance is higher (ant resonance) or frequency of maximum impedance as denoted as fa. This maximum impedance frequency approaches the resonance frequency, fr, the frequency at which impedance is very small in the driving circuit, approximately to that of device oscillations. The signal voltage values for minimum impedance frequency, fr, and maximum impedance frequency, fa, can be scanned as the sensor oscillate freely due to a single excitation frequency at any point Y very close to fa. In this paper, the author has described a sophisticated experimental technique, and voltage transformation of an excited PT at Y = 114.20 kHz. The changes in drift frequencies and amplified output sine voltages were recorded directly to their corresponding transient time as the PT oscillates.

3. Experimental Set-up

The PT was mounted between Teflon insulation using four screws labeled as a, b, c, and d. The screws were used to support the top and bottom Teflon insulations as shown in Figure 2 (a). In this figure screw number 1 is an input electrode attached to the ringside of the disk, which is labeled as number 5. This screw passes though the upper Teflon insulation number 4, to make a contact with platinum electrode coated on the surface of the disk. Screw number 2 was used as output terminal and connected to the platinum electrode (dot side) through the center of the upper Teflon cover, number 4. The third screw was inserted to the center of the bottom full-face electrode or screw number 3 via Teflon cover number 6; this screw was used as ground electrode for both input and output screw terminals.

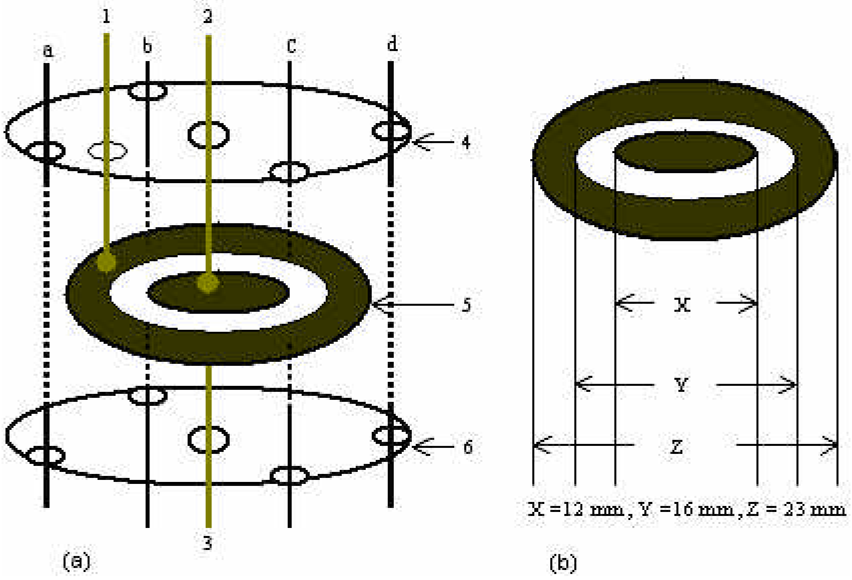

Fig. 2. In drawing labeled (a) is the mounting of PT inside the Teflon insulation showing screw terminals for input and output through upper and bottom Teflon. The diagram labeled as (b) is the parameters of disk PT marked as X, Y, and Z.

In Figure 2 (b) is a diagram showing the diameters of the disk, X is the dot electrode that is 8 mm, Y, is the diameter of both dot and unelectroded region which is 12 mm, and Z is the diameter of the disk which is 23 mm. The picture in Figure 2 (c) is showing the top and bottom view of mounting positions of the PT.

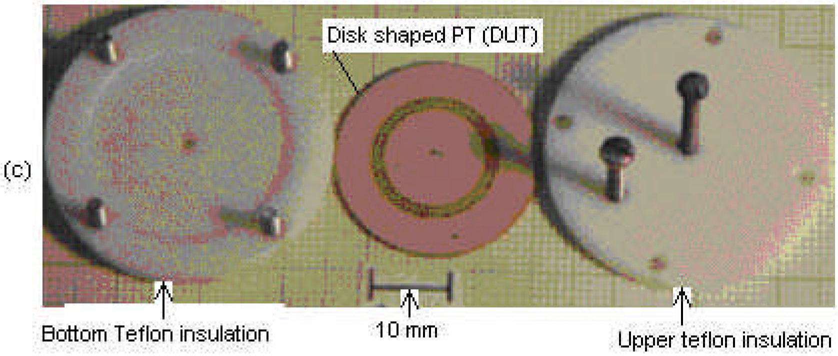

Fig. 2 (c). A picture showing the side view of both top and bottom Teflon insulations, which supports the PT.

In order to perform test, the signal generator terminals were connected to screw 1 and screw 3, see screw positions in Figure 2 (a), and tuned to a frequency very close to the ant-resonance frequency, *fa* = 114 kHz, of the PT. The input signals were applied directly to the ring electrode of the disk from the signal generator; the input parameters were then recorded directly from the frequency counter, Pico scope, digital multimeter 1 or DMM1, and computer 1. The output signal voltages were measured from the dot electrode and the full-face bottom electrode (common electrode) by using the Pico scope, computer 2, and digital multimeter 2 or DMM2 as shown in Figure 3.

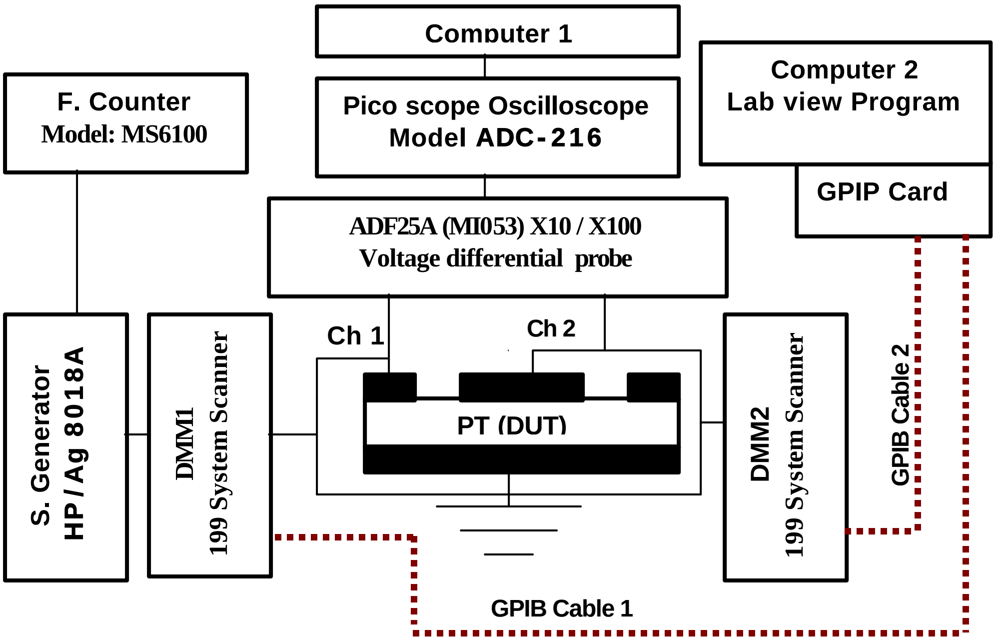

Fig. 3. Set-up for characterization of an excited PT; voltage transformation as a function of resonant frequency, drift frequencies, and transient time.

For this case, the signal generator was then set to few decimals higher than that of the PT, this was a controlled input sine voltage (8.0 RMS Voltage) set to vibrate at 114.20 kHz, an excitation frequency which was higher in few digits (0.20 kHz) very close to the ant resonant frequency of the PT. After the PT was interrogated by using 114.20 kHz, it continued to oscillate freely in frequency range less than that of fa; as time goes it produced an amplified signal voltage, and the drift frequencies shifted toward the center frequency, fr, as the PT continues to oscillate. This effect caused a maximum amplified voltage of transiently excited PT with higher output signal voltage observed at the center frequency.

The experimental results of this PT were reported within the frequency range (X ⊆ fr ⊆ fa ⊆ Y), where X=109 kHz, was the lower frequency to the left of resonance curve, the maximum output signal voltage was observed at resonance (fr = 110.50 kHz).

The transformation ratio was then calculated automatically; using output to input voltage ratio parameters recorded using DMM 1 and DMM 2; connected to Computer 2 through GPIB card 1 and GPIB card 2. To test the exact transient time stability of the PT, a computer controlled Lab view program was made and installed in Computer 2. This program was used to calculate the transformation ratio of the PT as a function of transient time. The block diagram in Figure 4 is showing the program used to calculate voltage transformation as a function of transient time.

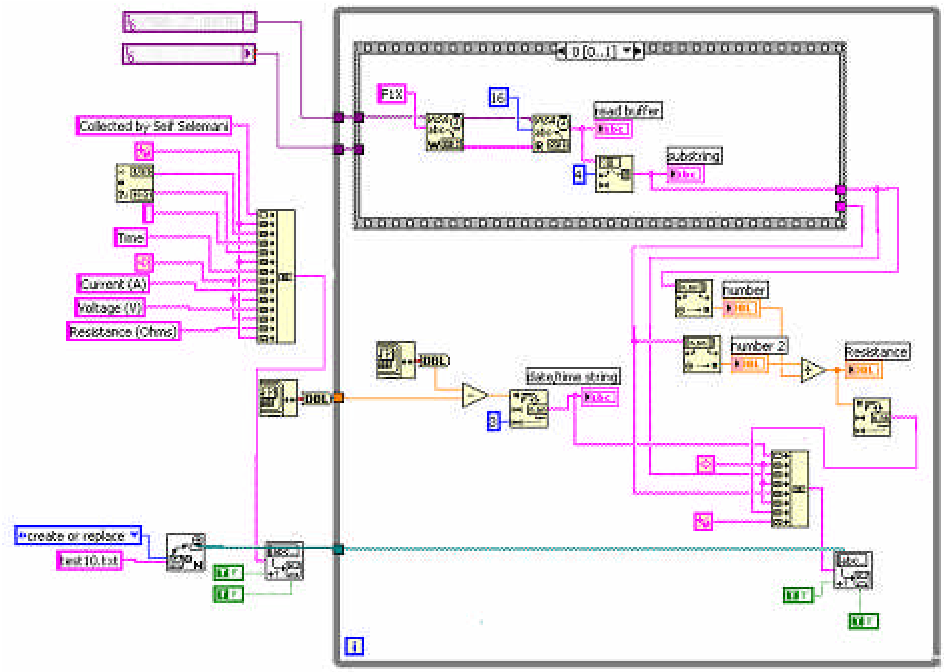

Fig. 4. The block diagram showing lab view program used to read data from Digital Multimeter 1 (DMM1) and Digital Multimeter 2 (DMM2), this program was then used to calculate the transformation ratio as a function of time of an excited Piezoelectric Transformer (PT).

In this program, Digital multimeter 1 or DMM 1 was programmed to read input voltage while DMM 2 was programmed to read output voltage. The block labeled as number 1 tracked voltage parameters of DMM1 and that labeled as number 2 tracked voltage parameters of DMM 2. The ratio of DMM 2 to DMM 1 gave the voltage transformation ratio as a function of time. A file was created to read and display voltages from DMM 1 as input voltage (V in), and DMM 2 as output Voltage (V out). The collected data had output voltage (V out), input Voltage (V in) and Voltage transformation ratio (V out / V in). These data were then put into Microsoft excel to derive the curve showing voltage transformation as a function of transient time and drift frequencies.

4. Results and Discussions

The voltage transformation of a continually oscillating PT has been presented in two parts; the first part has been reported as transformation ratio of the PT at resonance only, the second part has been reported as transformation ratio of the PT due to drifting frequencies in between 114 kHz and 109 kHz as a function of transient time. The first part of the results is shown in Figure 5, the curve indicated by green line is the output voltage (160 V), while blue line indicates the input voltage (8.0 V).

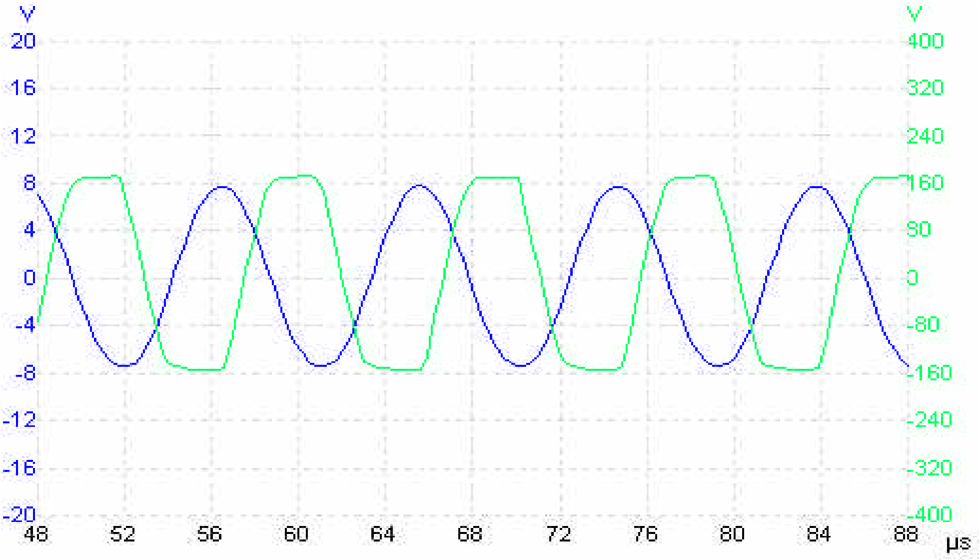

Fig. 5. The input and output voltages as displayed on Pico scope oscilloscope screen when the PT was excited at 110.5 kHz. The green line shows the output voltage (160 V) while the blue line shows input voltage (8.0 V).

The behavior of signal voltage of this PT seemed to be unstable, and decreased rapidly as frequency tends to drift from 110.50 kHz to 109 kHz due to dielectric and mechanical losses of the PT. In Figure 6 (a) and Figure 6 (b), is the curve, which shows transformation ratio as a function of drift frequencies. The curves were obtained by plotting the data point of RMS voltages against drift frequencies; these data were obtained by direct reading and taking data from the computer based oscilloscope or Pico scope. Then, the stopwatch was used to record the variation of transient time as voltage transformation changes. The data of voltage transformation against drift frequencies were then plotted with their respective time starting from 51 seconds to 5117 seconds.

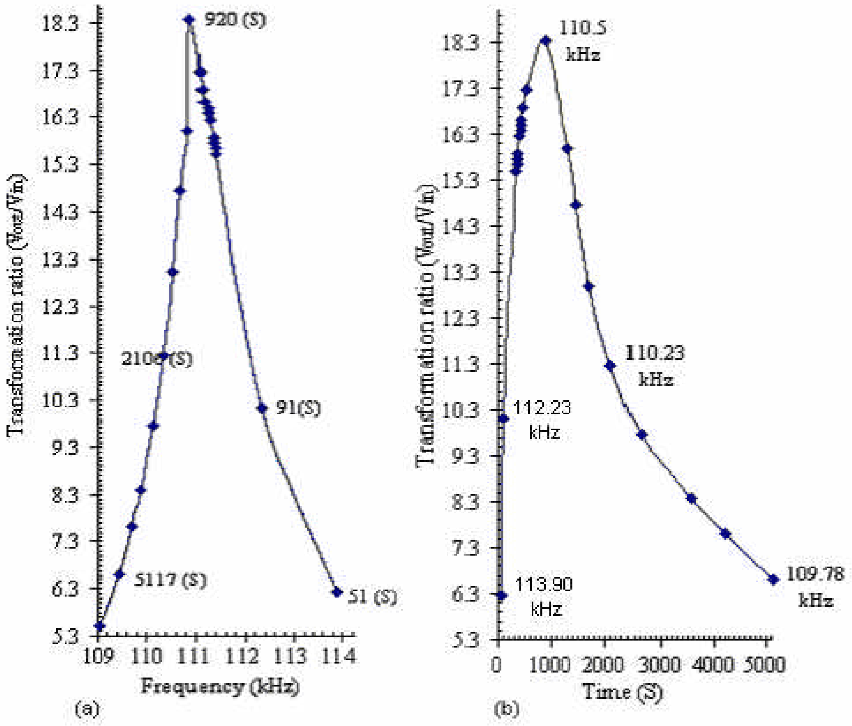

Fig. 6. The voltage transformation of the PT as a function of drift frequencies and time; In Figure 6 (a) is voltage transformation as a function of frequencies while Figure 6 (b) represents voltage transformation as a function of transient time.

The voltage transformation in Figure 6 (a) showed that at 51 seconds the voltage transformation was 6.30 at 113.90 kHz. The voltage transformation of this PT continued to increase until it reached resonance at 110.50 kHz after 920 seconds, at this point the voltage transformation was at its maximum peak (18.30) and saturated. The data taken after 5117 seconds have shown that after voltage transformation reached saturation at (110.50 kHz), the frequencies of the PT continued to drift toward left, and transformation ratio decreased to 6.30 at 109. 40 kHz. Figure 6 (b) is showing the reverse path of drift frequencies of results shown in Figure 6 (a) because the voltage transformation increased from (114 kHz) toward resonance (110.50 kHz). Any initial excitation frequency that is lower than resonance (110.50 kHz) had caused descending voltage transformation away from resonance, which varied with drift frequencies, for example, the voltage transformation decreased from 11.30 to 6.3 when frequency shifted from 110.23 kHz to 109.78 kHz at 2100 seconds and 5117 seconds; respectively. The voltage transformation has shown an ascending behavior when the PT was excited with frequency higher than resonance, for example, the voltage transformation increased from 6.30 to 10.30 when the drift frequency of the PT shifted from 113.90 kHz to 112.23 kHz; respectively.

Experimentally; it was difficulty to capture the transient time data without having a stopwatch. In order to capture transient time and voltage transformation in real time, a lab view program was installed in Computer 2 and used to capture voltage transformation as a function of time. By using this technique, it was possible to record voltage transformation as a function of time for more than 3600 seconds. The results are depicted in Figure 7. These results have shown the same voltage transformation and the same patterns as those observed in Figure 6.

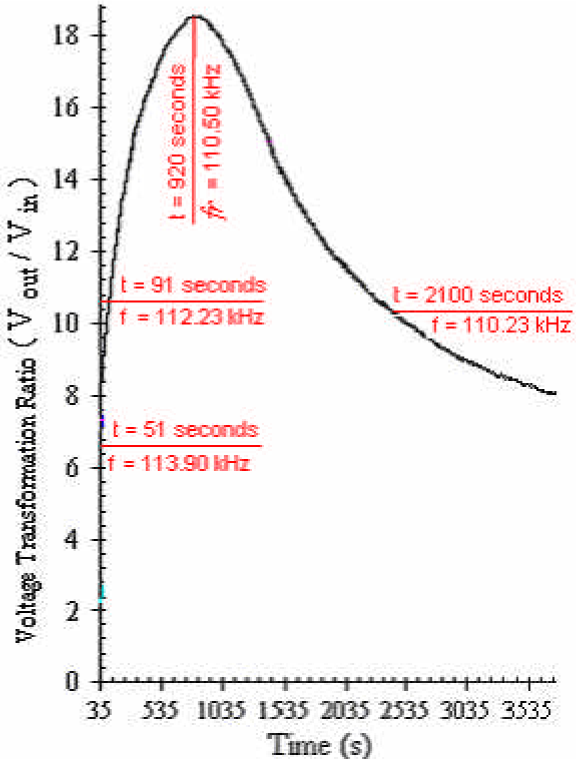

Fig. 7. Voltage transformation of a PT as a function of transient time when the PT was excited at 114.20 kHz, as the PT oscillates freely, the voltage transformation was recorded as a function of time from 35 seconds to 3600 seconds.

The voltage fluctuation came from the PT itself, e.g., from dielectric as well as the mechanical losses and temperature rise from the PT as it oscillates. The voltage behaviors caused by initial excitation or an interrogation frequency (114.20 kHz) have shown that the PT could be operated successively in more than 3600 seconds with transformation ratio higher than 6.3, at frequencies lower or higher than resonance.

5. Conclusions

The voltage transformation observed in the first part of this investigation, has indicated that resonance techniques underestimate the value of voltage transformation due to the dielectric and mechanical losses, which is a function of transient time and drift frequencies. When a PT was excited at a frequency very close to its resonance (110.50 kHz), the output signal voltage was at its maximum peak showing transformation ratio of 18.4. As the PT oscillates with time, the transformation ratio decayed exponentially as the frequency drifted toward left from 110.50 kHz to 109 kHz. In order to record this data in real time and publish the results, DMM1 and DMM2 were added to the experimental set-up and connected to computer 2 through GPIB card 1 and GPIB card 2. In additional to that the lab view program was made and installed in Computer 2.

By using this set-up, it was possible to capture and record voltage transformation ratios and frequencies of an oscillating PT as a function of transient time. It was found that when the PT was interrogated with a single frequency (114.20 kHz), the frequency drifted from right to the left. It was noted that caution should be taken when interpreting results from the resonance method for any sensor relative to PT, because, large number of piezoelectric parameters of sensors and other piezoelectric devices have been presented only at resonance, neglecting the drift frequencies and transient time dependency. In this experiment, special caution has been taken, and proven by interpreting the voltage transformation results of a PT, excited from a single interrogation frequency (114.20 kHz), the effects of transient time, and drift frequencies in voltage transformation, have been demonstrated.

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