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PERFORMANCE CHARACTERISTICS MODEL OF A THIN LEAD ZIRCONATE TITANATE DISC UNDER DIFFERENT CONDITIONS

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In the present work a thin lead zirconate titanate (PZT) piezoelectric ceramics disc investigated for its sensitivity in performance at two different temperatures for different frequencies and at a series of resistance bands. The peak-peak voltage has been considered as its output functioning parameter at different conditions. Real time data was collected by connecting the prescribed circuitry and behavior of material investigated for ten consecutive resistance bands. The disc was found highly sensitive to the selected range of frequencies and resistances as compared with temperature sensitivity. Experimental results have been used to develop a mathematical model by considering the ten consecutive resistance bands for two referenced temperatures. An exponential behavior has been noted which indicated the change at higher values of resistance bands. The behavior of the material was founded with the stated frequencies and resistance bands at room temperature and at 160^0C.

Keywords : Frequency, Resistance, Peak-Peak Voltage, PZT, Temperature

1. Introduction

Piezoelectric materials are extensively used in various sophisticated applications, where sensitivity plays a significant role. Thermal stresses experienced by materials normally depend on rate of heating or cooling, therefore, it becomes more important to investigate such smart materials for their sensitive applications before using in any instrument.

Lead Zirconate titanate (PZT) Ceramics materials are widely used in various applications such as micro sensors, actuators, resonators and vibrators. The function of these smart materials very much depends on various conditions such as change in frequency, resistance and temperature. These variables may affect the output performance of the instrument in which they are used and considered highly sensitive in this regard.

Reliability of instruments is important and researches have been carried out on PZT and $BaTiO_3$ (Barium titanate) thin films. Piezoelectric coefficients are temperature dependent in PZT film. This change may result in variation in output signals. A frequency response measurement has been used to measure the sensitivity of piezoelectric devices [1].

The effect of temperature and frequency on dielectric and ferroelectric properties of PZT thin films has been investigated [2]. Aging mechanisms and high frequency mode of piezoelectric resonator have been studied, for which deformation behavior under thermal loading has been described [3]. Piezoelectrics have been investigated for their thermoelectric behavior and various governing equations for thermal affects have been described [4]. Panda et al. showed that thermal stresses are sensitive to the thickness of the samples. Therefore, earlier they recommended to use various samples of the same thickness to get reliable results [5]. Thermal fatigue methods including quenching [6] and repeated heating method have been described earlier [7].

Piezoelectric ceramics under electric fields becomes non linear due to domain effects. The effect of power on the rise of temperature of piezoelectric materials is also an observed phenomenon. Degradation of lead zirconate titanate piezoelectric ceramics due to high power resonant driving has been investigated by Chen et al. [8]. They observed that PZT was stable below a certain resonant power. If a sample resonates

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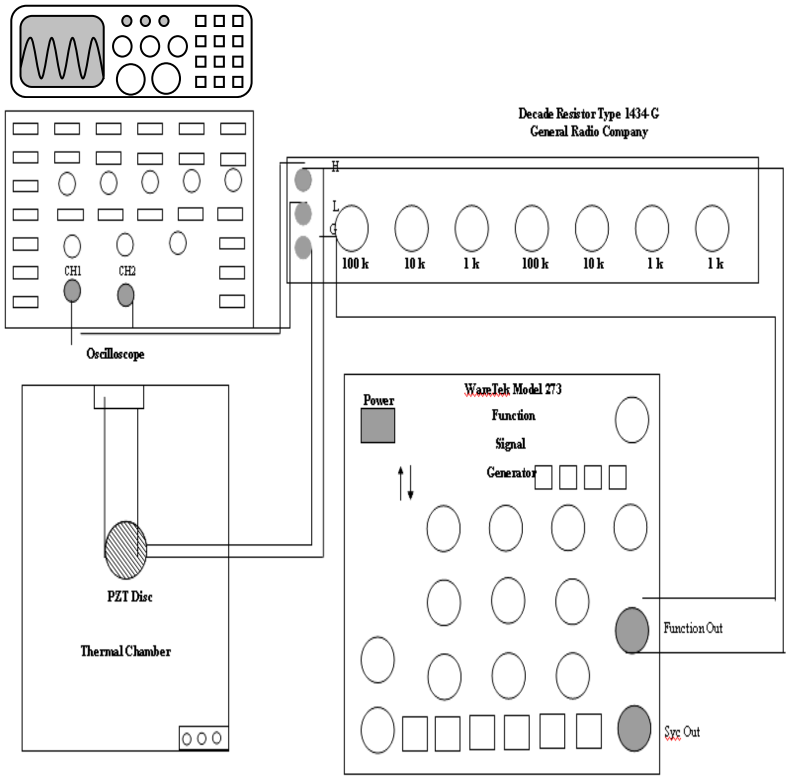

Figure1. Schematic diagram of Experimental Arrangement for measuring Peak-Peak Voltage with respect to Frequency and Resistance at Room Temperature (20 ^{0}C) and at 160 ^{0}C.

continuously for a long period at high resonate power, its temperature rises. The change in temperature may cause a serious degradation. Frequency is one of the important parameters which influences the output performance of such smart materials. Earlier a study of ferroelectric properties of the oscillator model of PZT-22 has been carried out [9]. The investigation shows that the permittivity dispersion at two different frequencies. Effect of frequency and resistance by temperature variation on PZT disc have been investigated which indicates that drop in peak-peak voltage was higher at high values of frequency and resistance [10]. Earlier the ring shaped PZT piezoelectric vibrators are driven by electric field with a fixed frequency of slightly less than the resonance to form an oscillating current and it is noted that resonance frequency of PZT ring shifts in the direction of low frequency under a high electric field due to the heat produced by dissipation power [11].

In the present work the effect of temperature on thin PZT discs have been investigated with respect to change in frequency and resistance for peak-peak voltage as its functional output performance parameter. Frequency and resistance are the parameters which influence the properties of piezoelectric materials at variable temperature conditions. Therefore, there was a scope of work to investigate such behaviors of thin PZT disc. By considering the extensive data available under such condition and by developing a mathematical model it is determined that how these parameters influence the characteristics of PZT disc at room temperature (20^{0}C) and at a temperature 160^{0}C well below the curie temperature of PZT specimen.

2. Experimentation

A lead zirconate titanate piezoelectric ceramics disc provided by Piezo system Inc., with nickel electrodes on its major faces, 0.19 mm thick and 12.7 mm in diameter was used for its performance analysis. Electric wires were soldered by using compatible solder and flux. The disc was mounted in a thermal chamber alongwith a thermocouple for measuring the surrounding temperature of the disc. A schematic diagram of the experimental arrangement, showing the circuitry is described in Figure 1.

Table 1. Difference in Voltage for each 100K Ohms Band at Room Temperature.

Frequency(Hz)	50Hz	100Hz	150Hz	200Hz	300Hz
Resistance(KΩ)	Pk-Pk(ΔV)	Pk-Pk(ΔV)	Pk-Pk(ΔV)	Pk-Pk(ΔV)	Pk-Pk(ΔV)
1-100	1.4	2.36	3.64	4.36	5.72
100-200	1.52	2.24	2.4	2.32	1.92
200-300	1.2	1.36	1.04	1.04	0.72
300-400	0.96	0.8	0.8	0.48	0.4
400-500	0.64	0.56	0.4	0.32	0.24
500-600	0.56	0.4	0.24	0.24	0.16
600-700	0.48	0.24	0.16	0.16	0.08
700-800	0.32	0.24	0.16	0.08	0.08
800-900	0.24	0.16	0.16	0.08	0
900-1000	0.16	0.16	0.08	0.08	0

Table 2. Difference in Voltage for each 100K Ohms Band at 160 ^{0}C.

Frequency(Hz)	50Hz	100Hz	150Hz	200Hz	300Hz
Resistance(KΩ)	Pk-Pk(V)	Pk-Pk(V)	Pk-Pk(V)	Pk-Pk(V)	Pk-Pk(V)
1-100	1.88	3.4	4.6	5.56	6.84
100-200	1.84	2.32	2.24	2	1.52
200-300	1.36	1.2	0.96	0.72	0.48
300-400	0.96	0.72	0.56	0.4	0.32
400-500	0.64	0.4	0.24	0.32	0.08
500-600	0.4	0.32	0.24	0.08	0.16
600-700	0.4	0.16	0.16	0.08	0.08
700-800	0.32	0.16	0.16	0.08	0
800-900	0.16	0.16	0.08	0.16	0
900-1000	0.24	0.08	0	0.08	0.08

A WaveTek Model FG-273 function signal generator of Kenwood was used for the excitation of piezo disc at various frequencies. The disc was excited at 50,100,150,200 & 300 Hz. A decade resistor type 1434-G of General Radio Company was used for applying a very long range of resistances (0-1000KΩ). Peak-Peak voltages were measured by Tektronix TDS 210 oscilloscope. The voltage across channel-1 and channel-2 of the oscilloscope were kept constant at 5V and 2V respectively.

Experimentation was done at two temperatures 20^{0}C and 160^{0}C. A comparative study has been carried out to observe the sensitivity of the PZT disc at the stated variable conditions. For the reliability of results three discs for each phase was examined under the prescribed conditions.

3. Results and Discussion

3.1. At Room Temperature

PZT disc was excited at the frequencies as listed in Tables 1 and 2. At a particular frequency, variable resistances were applied and output peak-peak voltage across the specimen was recorded. With five selected frequencies, a maximum voltage 10.2 volt was observed at 0 kΩ resistance. By increasing the resistance value the output voltage started decreasing. This decrease in voltage is frequency dependant and this drop in voltage with respect to resistance is more at higher frequencies. For example, at 100 kΩ and 50 Hz, the voltage was 8.8 volts and for the same value of resistance at 300 Hz, the voltage observed was 4.48 volts. This indicates that PZT disc is very much sensitive to frequency change. The overall trend for the selected range is shown in Figure 2.

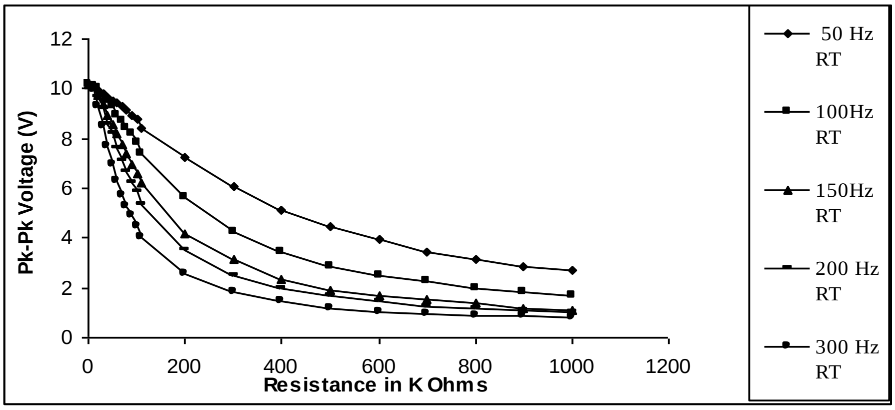

Figure 2. Effect of resistance on Pk-Pk voltage various frequencies at Room temperature.

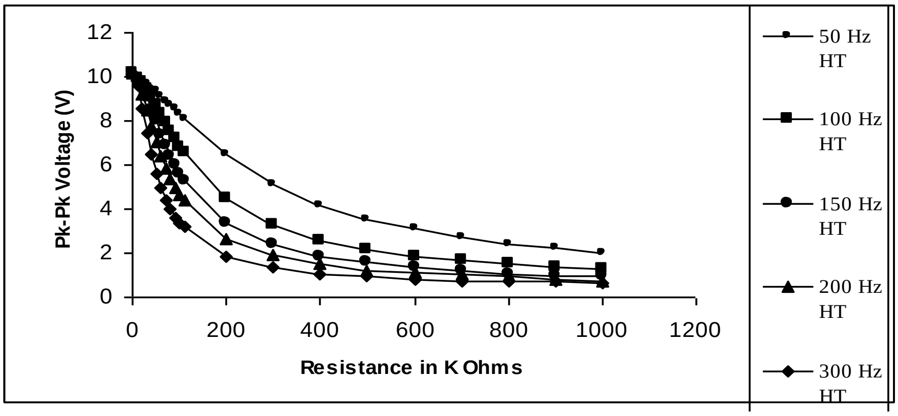

Figure 3. Effect of resistance on Pk-Pk voltage for various frequencies at 160 ^{0}C.

The difference of output voltage for each 100 kΩ resistance band was also variable for each band even at the same frequency. For example at 50 Hz, and 1-100KΩ resistance band the value was 1.4 volt, but this value was continuously decreasing for each band and it was found 0.16 volts for 900-1000 kΩ band.

3.2. At 160^{0}C

Piezoelectric disc was also analyzed to observe the effect of temperature at different resistance bands. The disc was mounted in a thermal chamber at 160^{0}C. Peak-peak voltage was recorded against resistance and frequency. The behavior of output voltage was observed by keeping the reference temperature for few minutes. It was observed that there was no change on peak-peak voltage with time. Noticeable changes in values were observed by changing the frequency and resistance, Figure 3 indicates the behavior of thin PZT disc for this specific condition. Overall drop in voltage was more as compared to room temperature condition. For example at this temperature, the Pk-Pk voltage from 10KΩ - 1000KΩ and at 50 Hz changes from 10V to 2V respectively. At room temperature with the same conditions the drop in voltage was 10.1V to 2.72V. This indicates that temperature is affecting the output response of PZT disc. This small change in voltage may be considered as a significant change in sensors and other sophisticated applications, therefore, cannot be ignored in modeling of such smart instruments. Higher the frequency, the higher is the difference in voltage from lower to high value of resistance.

There was no change in output voltage at each frequency at 0 kΩ resistance and it remains constant as 10.2 volt at room temperature as well as at 160^{0}C. A threshold value was 10 K Ω beyond which the values starts to change. The value for the output voltage at 50 Hz and at 10 K Ω was 10 volts. This value decreased to 2 volts at 1000 kΩ, i.e 80% decrease. The decrease in the value was

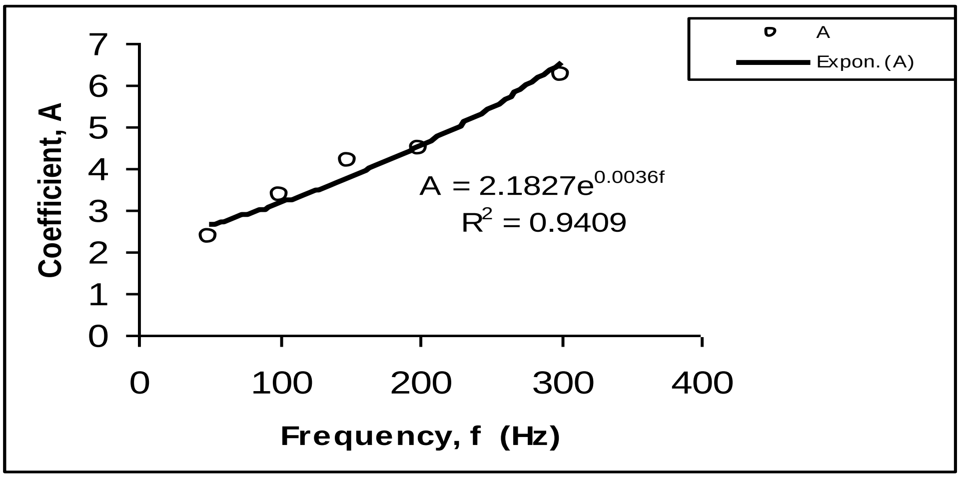

Figure 4. A trend for the Coefficient, A against Frequencies at Room Temperature.

frequency dependent and decreasing continuously. At 300 Hz the value at 10 K Ω was 9.6 volt, and it decreased to 0.64 volt i.e 93.33% decrease from 10 kΩ value. This means that the voltage drop at low frequency is less as compared to voltage drop at high frequency. Another interesting behavior was related to the change in pk-pk voltage by changing the resistance value. It is clear from Figure 3 that the drop in voltage is dependent on the applied frequency and resistances. Table 2 describes the change in pk-pk voltage for each 100 kΩ resistance band. At room temperature the pk-pk voltage was 1.4 V at 50 Hz and at 1-100 KΩ resistance band. For the same resistance band (1-100 kΩ) at 160^{0}C and 50 Hz, the value noted is 1.88 V. For the same resistance band at frequency 300 Hz the output value changes from 5.72V (at 20^{0}C) to 6.84V (at 160^{0}C).

The variation in peak- peak voltage at the stated conditions is thoroughly tabulated in Tables 1 and 2. The data available is by repetition of experimentation thrice for each condion and average value has been used for the development of model. Reliability in electromechanical systems is very important in the operation of electromechanical systems for its smooth functioning. The little change in variation of peak-peak voltage at particular resistance band and at two stated temperatures is due to reliability of thin PZT disc and shows its capability to function properly in this condition without distortion in properties.

3.3. Development of a Model

A mathematical model has been developed by using the data available which indicates the effect of frequency and resistance band on peak-peak voltage change (ΔV) at two different temperatures.

Data tabulated in Table 1 has been used to draw the exponential curves between resistance band number and difference in peak-peak voltage at room temperature for five selected frequencies. Pk-pk value showed a decreasing exponent trend with the increase in resistance band number. In other words , higher the resistance the less is the voltage output. Similar exponents have also been drawn for 160 ^{0}C by using the data in Table 2. By considering the coefficients A and B, other exponents were drawn against Frequency f in Hz. The coefficients A and B against these frequencies at 20^{0}C showed an increasing trend and indicated in Figures 4 and 5. Similarly the trend for the same coefficients at 160^{0}C has been shown in Figures 6 and 7. An exponential model developed indicating the effect of resistance band number (N) on peak-peak voltage at room temperature is as under,

$$\Delta V = Ae^{-BN}$$

Where

$$A = 2.18e^{0.0035f} \quad \text{and} \quad B = 0.23e^{0.003f}$$

Similarly at temperature 160^{0}C, the model has the coefficient values as under,

$$A = 2.74e^{0.003f} \text{ and } B = 0.27e^{0.003f}$$

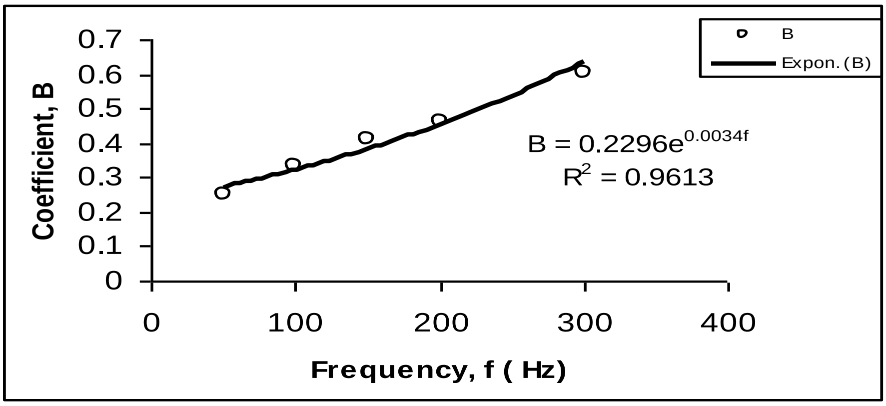

Figure 5. A trend for the Coefficient, B against Frequencies at Room Temperature.

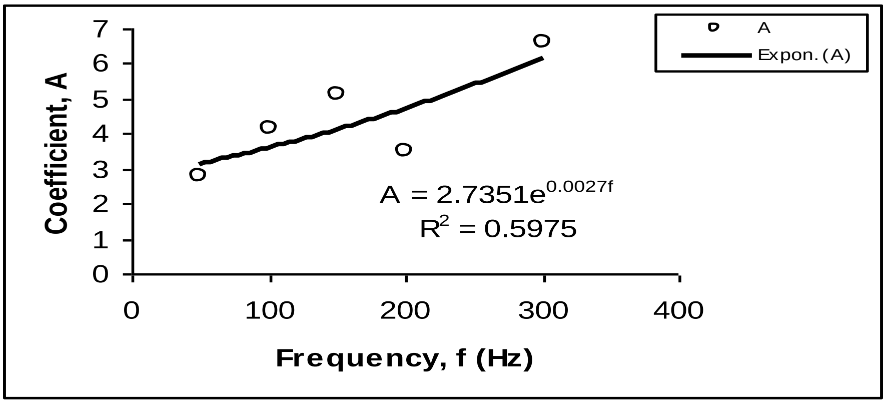

Figure 6. A trend for the Coefficient, A against Frequencies at 160^0C.

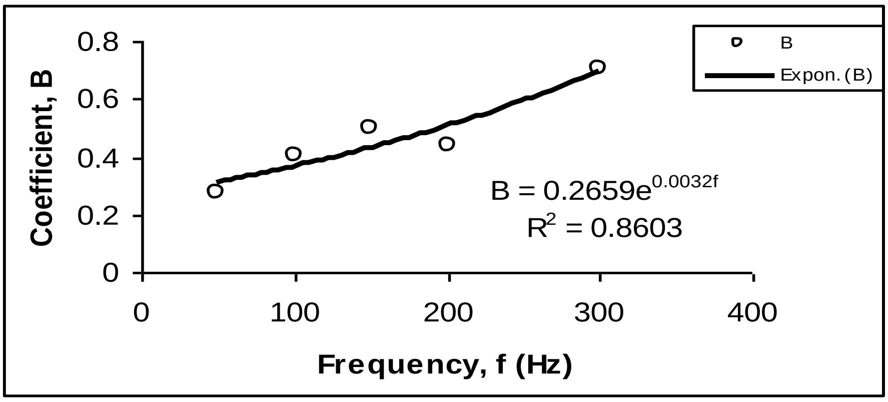

Figure 7. A trend for the Coefficient, B against Frequencies at 160^0C.

The trend for the peak-peak voltage variation Vs resistance band number is investigated. The trends shown in Figures 4 to 7 are based on the experimental data obtained. The coefficient of the model shows an increasing trend with a corresponding increasing in frequency at 20 ^{0}C. The same tendency can be seen at 160^0C, however, the data scatter is greater. The same exponential function for the evaluation of A and B have been used at room temperature and at 160^0C. It may also be noted that the coefficient A is slightly more temperature dependent than the coefficient B. No large difference in evaluation of A

& B with temperature has been detected which indicate the reliability of the thin disc at these two particular temperatures.

4. Conclusions

Thin lead zirconate titanate piezoelectric ceramics disc was analyzed for its sensitivity and it is observed that performance characteristics of thin disc were changing at different conditions the peak-peak voltage value was higher at lower frequencies but interestingly, the difference in peak-peak voltage for a particular resistance band behaved differently. At a particular resistance band and frequency for two temperatures, the change in voltage indicates that temperature also influencing the performance characteristics of thin disc. At higher frequencies, the maximum drop in voltage was observed at low resistance as compared to at low frequency drop. Another interesting behavior observed that after 400 kΩ resistances the peak-peak voltage observed is approximately constant even at higher frequencies. The model shows that PZT disc is temperature sensitive and the coefficient values are frequency dependent. It is, therefore, concluded that thin PZT disc is relatively more sensitive in resistance change as compared to temperature and frequency change. A qualitative data has been obtained which will be useful in modeling of smart instrumentation and micro electro-mechanical system using thin PZT discs.

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