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EFFECT OF FREQUENCY AND RESISTANCE BY TEMPERATURE VARIATION ON LEAD ZIRCONATE TITANATE PIEZOELECTRIC CERAMICS DISC

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Lead Zirconate Titanate (PZT) piezoelectric ceramics disc has been analyzed for its output peak- to-peak voltage between a temperature range at variable frequencies and resistances. The temperature range selected was between 70ºC-160ºC. The aim was to determine the real time output peak-to-peak voltage across the thin PZT disc for its reliability analysis at the aforesaid stated conditions. Temperature sensitivity with respect to resistance and frequency was observed. The results indicate that the drop in peak-to-peak voltage was higher at high values of frequencies and resistances. The real time monitoring of PZT disc between 70^{o}C-160^{o}C temperature ranges did not show significant variation in voltage at particular resistance. Insensitivity at this particular temperature range makes these PZT disc reliable for the designing of micro-electromechanical systems within said operating conditions.

Keywords: PZT disc, Frequency, Resistance, Temperature and Peak-to-peak voltage

1. Introduction

Lead Zirconate Titanate (PZT) material is one of the important class of piezoelectric, ferroelectric and pyroelectric materials [1]. Several authors have reported the effect of heating rate. For practical applications, however, the temperature rise at high input power levels should be taken into consideration and studied earlier. Previously the work has been carried out by investigating the influence of resonant driving at various power levels on the performance of commercial piezoelectric ceramics rings. It was observed that degradation in the piezoelectric properties of the rings occurs by relatively high power resonant driving, and the de-aging effect of the temperature was found responsible for it [2]. 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, and then shifts back due to the effects of aging which results in current oscillation [3]. Piezoelectric resonators have been used for frequency control and timing applications in many electronic products. Analysis of aging of piezoelectric crystal resonators have been analyzed under various conditions [4]. Effect of temperature and frequency of dielectric and ferroelectric properties of PZT thin films have been studied by E. B. Araujo and J. A. Eiras [5]. They reported the effect of temperature and frequency on dielectric and ferroelectric properties of PZT thin films. Earlier the effect of heating rate of PZT has been observed by Mohiddon and Yadav [6]. They observed that the effect of heating rate on the extent of phase formation of double doped PZT. They also found the effect of heating rate on dielectric and pyroelectric properties of PZT. The temperature dependence of the dielectric constant at various frequencies shows that the dielectric constant varies with both temperature and frequency. Modifications of PZT ceramic including the effect of dopants and preparation methods have been studied earlier to determine the optimum processing conditions for PZT ceramic [7]. By considering the above, there was a scope to investigate the effect of temperature on the thin piezoelectric disc. In present research, thin PZT disc has been investigated in real time for a specific temperature range to observe the change in peak-to-peak voltage at different resistances and frequencies.

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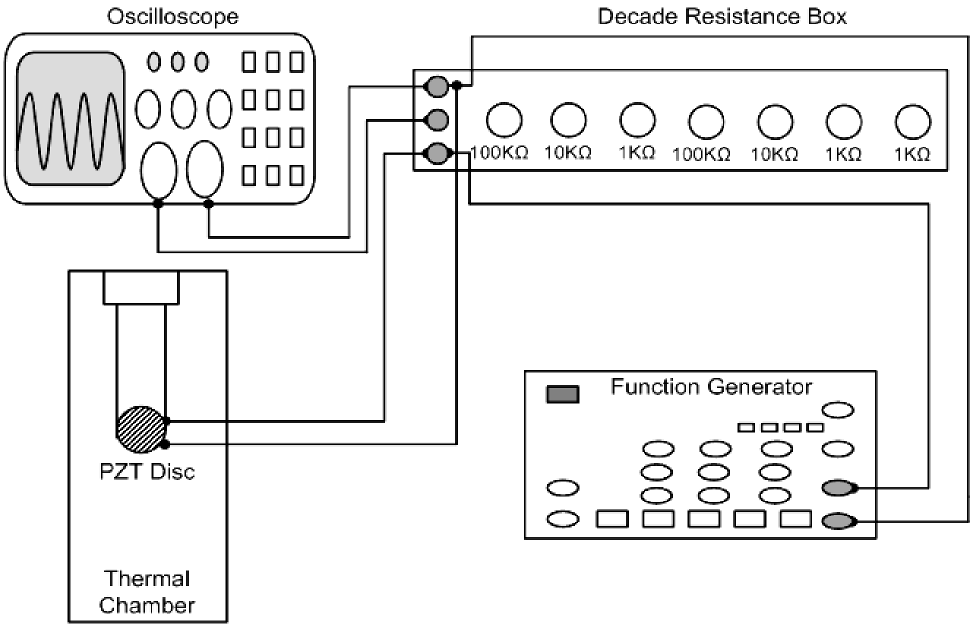

Figure 1. Experimental setup for determination of peak-to-peak voltage at variable temperature, resistances and frequency.

2. Experimentation

Lead zirconate titanate piezoelectric ceramics disc (supplied by Piezo Systems Inc. USA) with nickel electrodes on its major faces, 0.19mm thick and 12.7mm in diameter was used for the experimentation. Electric wires were soldered by using compatible solder and flux. Disc mounted in a thermal chamber was directly monitored for its surrounding temperature. The experimental arrangement, showing the circuitry is described in Figure 1.

A function signal generator was used for the excitation of piezo disc at various frequencies. The disc was excited at 50, 100, 150, & 200 Hz. The decade resistor was used for applying range of resistances (0, 1, 10, 100, & 1000KΩ). The voltage change at particular frequency and resistance was measured by oscilloscope. The voltage across channel-1 and channel-2 of the oscilloscope were kept constant at 2V and 5V respectively. Experimentation was conducted for the temperature ranging from70^{0}C to 160^{0}C. A comparative study has been carried out to observe the sensitivity of the PZT disc at the stated variable conditions.

3. Results and Discussions

Experimental data was tabulated in Tables 1 to 4 for the disc under variable temperature ranges at various resistances and frequencies. Table 1 indicates that at 50 Hz, the output voltages remain almost same from 0 to 10KΩ. The reasonable decrease in peak-to-peak voltage was observed at 100 and 1000 KΩ. The same pattern has been observed at frequencies of 100, 150 and 200 Hz as indicated in Table 2, Tables 3 and 4 respectively. The experimental data described in aforementioned tables indicates that the frequency has also affecting the output performance of the thin PZT disc at variable conditions. In Table 4, a decrease in peak-to-peak voltage at 100 KΩ at 200 Hz is observed with respect to change in temperature, which is a different trend in comparison to other resistances. The results show that peak-to-peak voltage is almost independent of temperature in this particular range, however a considerable effect was obtained at higher values of resistances. The results were validated by repeating the experimentation at a particular condition. Percentage decreases in peak-to-peak voltage at various frequencies w.r.t. resistances between a specific temperature changes have been analyzed and represented in Table 5. It is observed that the maximum change for this particular temperature range is at 100 Hz and 1000 KΩ which is 11.11% decrease from the original value.

Table 1. Change in Peak-to-Peak Voltage at 50 Hz Frequency Input.

Temperature ^{0}C	Peak-to-Peak Voltages at Various Resistance Values				
	0 KΩ	1 KΩ	10 KΩ	100 KΩ	1000 KΩ
70	10.2	10.1	10.1	8.64	2.32
80	10.2	10.1	10.1	8.56	2.32
90	10.2	10.1	10.1	8.56	2.32
100	10.2	10.1	10.1	8.56	2.24
110	10.2	10.1	10.1	8.48	2.24
120	10.2	10.1	10.1	8.48	2.24
130	10.2	10.1	10.1	8.40	2.16
140	10.2	10.1	10.1	8.40	2.16
150	10.2	10.1	10.1	8.40	2.16
160	10.2	10.1	10.1	8.16	2.08

Table 2. Change in Peak-to-Peak Voltage at 100 Hz Frequency Input.

Temperature ^{0}C	Peak-to-Peak Voltages at Various Resistance Values				
	0 KΩ	1 KΩ	10 KΩ	100 KΩ	1000 KΩ
70	10.3	10.2	10.1	7.52	1.44
80	10.3	10.2	10.1	7.44	1.44
90	10.3	10.2	10.1	7.44	1.44
100	10.3	10.2	10.1	7.36	1.44
110	10.3	10.2	10.1	7.28	1.36
120	10.3	10.2	10.1	7.28	1.36
130	10.3	10.2	10.1	7.28	1.36
140	10.3	10.2	10.1	7.28	1.36
150	10.3	10.2	10.1	7.12	1.36
160	10.3	10.2	10.1	7.04	1.28

Table 3. Change in Peak-to-Peak Voltage at 150 Hz Frequency Input.

Temperature ^{0}C	Peak-to-Peak Voltages at Various Resistance Values				
	0 KΩ	1 KΩ	10 KΩ	100 KΩ	1000 KΩ
70	10.2	10.2	10	6.24	1.04
80	10.2	10.2	10	6.16	1.04
90	10.2	10.2	10	6.16	1.04
100	10.2	10.2	10	6.08	1.04
110	10.2	10.2	10	6.00	1.04
120	10.2	10.2	10	6.00	1.04
130	10.2	10.2	10	5.92	1.04
140	10.2	10.2	10	5.92	0.96
150	10.2	10.2	10	5.76	0.96
160	10.2	10.2	10	5.76	0.96

Table 4. Change in Peak-to-Peak Voltage at 200 Hz Frequency Input.

Temperature ^{0}C	Peak-to-Peak Voltages at Various Resistance Values				
	0 KΩ	1 KΩ	10 KΩ	100 KΩ	1000 KΩ
70	10.2	10.1	9.92	5.2	0.88
80	10.2	10.1	9.92	5.2	0.88
90	10.2	10.1	9.92	5.2	0.8
100	10.2	10.1	9.92	5.2	0.8
110	10.2	10.1	9.92	5.04	0.8
120	10.2	10.1	9.92	5.04	0.8
130	10.2	10.1	9.84	4.96	0.8
140	10.2	10.1	9.84	4.88	0.8
150	10.2	10.1	9.84	4.8	0.8
160	10.2	10.1	9.84	4.72	0.8

Table 5. %age Decrease in Peak-to-Peak Voltage at Various Frequencies wrt Resistances.

Frequency	Resistances				
	0 KΩ	1 KΩ	10 KΩ	100 KΩ	1000 KΩ
50 Hz	0	0	0	5.55%	10.34%
100 Hz	0	0	0	6.38%	11.11%
150 Hz	0	0	0	7.69%	7.69%
200 Hz	0	0	0.80%	9.23%	9.09%

Figure 2 indicates the effect of temperature on the peak-to-peak voltage at variable frequencies at 0K**Ω** resistance**,** peak-to-peak voltage found no change at this particular frequency. For the selected temperature range, i.e., value of voltage remained 10.2 volts at 50, 150 and 200 Hz for temperature range 70^{0}C to 160^{0}C, and remained 10.3 volts at 100 Hz for the whole range of temperature change. This constant behavior of peak-to-peak voltage shows the reliability of thin PZT disc between the selected temperature ranges. This temperature does not affect the domain and dipole moment of the PZT disc.

Figure 3 describes the values obtained at 1KΩ and it also shows the same trend as for 0 KΩ value and no remarkable change occurred at this resistance. Values of peak-to-peak voltage remained 10.1 volt at 50Hz and 200Hz, whereas a slight increase observed at 100Hz and 150Hz i.e, 10.2 volts with a temperature change. The importance of this work is due to its real time determination at a particular range of temperature change. No remarkable change in peak-to-peak voltage has been observed for resistance at 1KΩ.

Figure 4 indicates that the values remains same at 50 and 100 Hz (i.e., 10.1 volts), whereas values observed at 150 Hz was 10 volts. A different trend observed at frequency 200 Hz where the peak-to-peak shows a minor decrease (i.e from 9.92V to 9.84) at temperature 130^{0}C. But still we can say that temperature for a particular frequencies dose not effecting too much for the performance response of thin PZT disc. This small change in voltage shows the reliability of that particular disc as the selected temperature is within the curie temperature of the PZT disc.

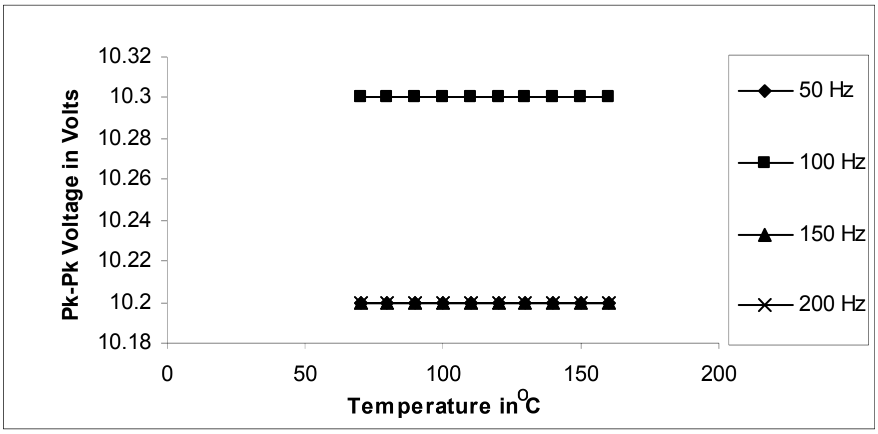

Figure 2. Effect of temperature on peak-to-peak voltage at resistance 0KΩ and at various frequencies.

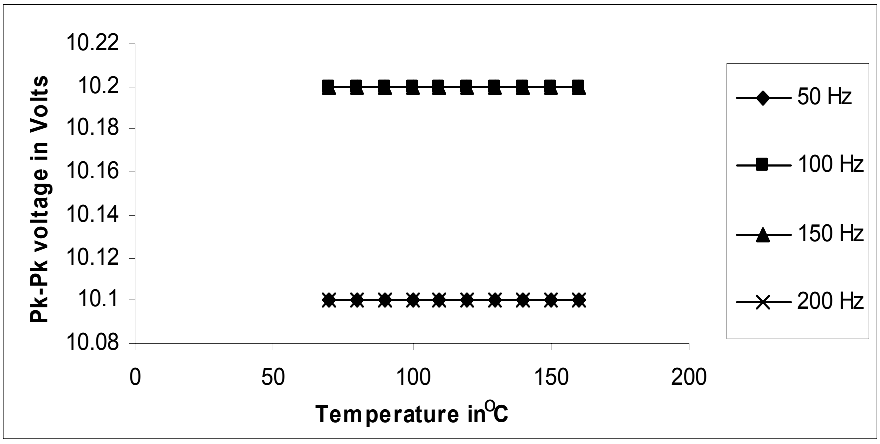

Figure 3. Effect of temperature on peak-to-peak voltage at resistance 1 KΩ and at various frequencies.

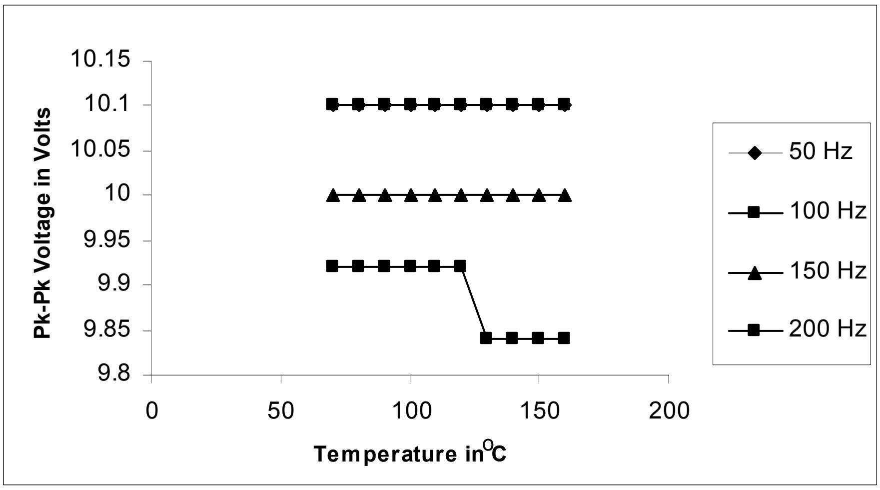

Figure 4. Effect of temperature on peak-to-peak voltage at resistance 10 KΩ and at various frequencies.

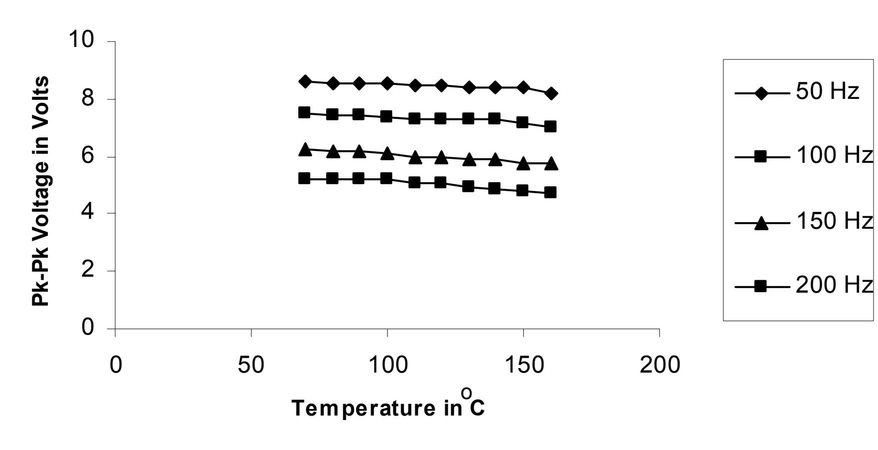

Figure 5. Effect of temperature on peak-to-peak voltage at resistance 100 KΩ and at various frequencies.

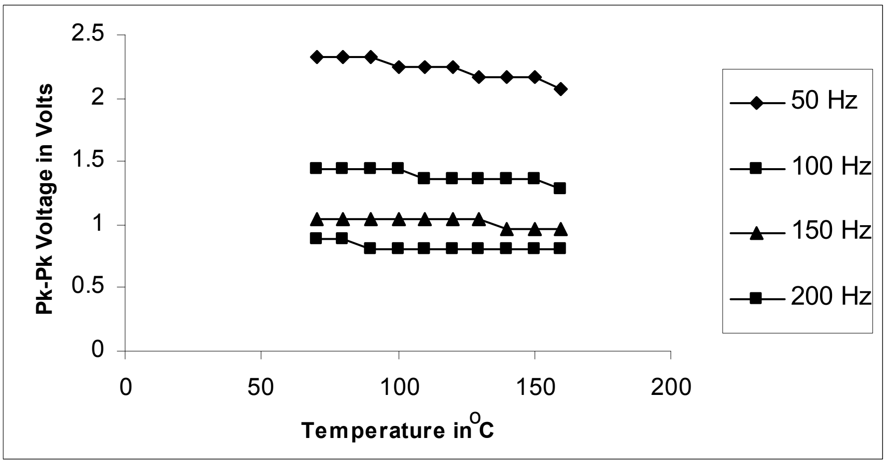

Figure 6. Effect of temperature on peak-to-peak voltage at resistance 1000 KΩ and at various frequencies.

Resistance plays a significant variable change in output voltage in various materials. This behavior in electronics materials like piezoelectric ceramics becomes more sensitive when used as a smart structure at variable frequencies and resistances. The behavior of output voltage with respect to temperature change is almost same as indicated in Figures 3 and 4. This behavior indicates that for low value of resistances, the PZT disc has no remarkable change in its output voltage.

In Figure 5 it is clear that peak-to-peak voltage starts decreasing with increasing the temperature. At 100 KΩ, the peak-to-peak voltage changes from 8.64 volts to 8.16 volts at frequency 50 Hz, from 7.52 volts to 7.04 volts at 100 Hz, 6.24 volts to 5.76 at 150 Hz and 5.2 volts to 4.72 volts at 200 Hz.

Figure 6 shows the output voltage trend at various frequencies and resistance at 1000 KΩ. The peak-to-peak voltage at this resistance is very low as compared with lower value of resistances. Frequency change also affecting the output performance in term of voltage output. However it is observed that for a particular frequency disc is independent of its output voltage for the subjected reference temperature range. A sharp decrease in voltage has been observed at this high value of resistance, but still for a particular frequency, the disc is independent of temperature change.

It is observed from Figures 5 and 6 that output performance has their own distinct values at a particular frequency which indicates the influence of high values of resistances on peak-to-peak voltages with respect to temperature. These changes with respect to temperature further influence the other electrical properties of the materials like impedance, dielectric constant, capacitance etc. Such effects of heating on the proprieties aforementioned have been studied earlier [6]. Earlier Georgion and Mrad studied that resistance depend on frequency and peak-to-peak voltage [8]. The change in output value with respect to resistance is the expected normal behavior of the materials which validates our present research. The temperature dependence of the dielectric constant at variable frequencies changes with temperature [9].

By considering the above discussion, it is observed that the PZT thin disc is reliable during the specific change in temperature at particular frequency and resistance. The current research work can further be explored in real time between the considered specific temperature range for the determination of the other electrical properties like dielectric constant, capacitance, impedance, permittivity etc.

4. Conclusion

The sensitivity of thin PZT disc was analyzed and it is found that disc is unaffected or least affected at lower resistances as compared to at higher resistance values. Higher is the resistance and frequency range; lower is the value for its output performance voltage. Effect of frequency and resistance is relative with change in temperature. The disc found less sensitive during change in temperature which shows its reliability for particular selected range. As a result, thin PZT disc can be used for the designing of microelectromechanical systems.

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References

[1] G. H. Haertling: Journal of American Ceramics Society **82 (**1999) 797.

[2] W. P. Chen, C. P. Chong, H. L. W. Chan and P. C. K. Liu: Journal of Materials Science and Engineering:B **99** (2003) 203.

[3] C. H. Xu, C. H. Woo, S. Q Shi and H. L. W Chan: Current oscillation of piezoelectric ceramic vibrators driven by a constant high electric field, Journal of the American Ceramics Society **88** (2005) 624.

[4] A. Asis, W. Zhang and Y. Xi. Ferroelectrics, and Frequency Control **50** (2003) 1647.

[5] E. B. Araujo and J. A. Eiras, Mater. Lett. **46** (2000) 265.

[6] M. A. Mohiddon and K. L. Yadav, Advances in Applied Ceramics **107** (2008) 310.

[7] S. Eitssayeam, U. Intatha, K. Pengpat, G. Rujiganagul, K.J.D. MacKenzie and T. Tunkasiri, Current Applied Physics **8** (2008) 266.

[8] H.M.S. Georgion and R. Ben Mrad, Mechatronics **14** (2004) 667.

[9] J-C. M' Peko. A. G. Peixoto, E. Jimenez, and L-M. G-Sager, Journal of Electro-ceramics **15** (2005) 167.