# Experimental Determination of Effect of Variable Resistance on Lead Zirconate Titanate (PZT-5A4E) under various Thermal and Frequency Conditions

Hassan Elahi[1]; RiffatAsim Pasha[2]; Asif Israr[1]; M. Zubair Khan[1]
[1]Institute of Space Technology, Islamabad, Pakistan.
[2]University of Engineering and Technology, Taxila, Punjab, Pakistan.
*hassanelahi_uet@yahoo.com, asim.pasha@uettaxila.edu.pk, asif.israr@ist.edu.pk, m.zubair@ist.edu.pk*

*Date Received: September 7, 2014; November 26, 2014*

***Abstract:*** *A specially designed apparatus and circuit working on the principle of inverse piezoelectricity due to the effect of polarization was used to find the relationship between resistance and peak to peak voltage of Lead Zirconate Titanate (PZT-5A4E) by shocking it at variable frequencies and at variable resistances under various thermal conditions within Curie temperature limit using equivalent circuit method. It was found that by increasing temperature, peak to peak voltage increases and similarly by increasing frequency, peak to peak voltage decreases and with the increase in resistance peak to peak voltage decreases.*

***Keywords***: *PZT5A4E; Resistance; Electromechanical Interaction; Frequency; Thermal Conditions.*

## I. INTRODUCTION

Piezoelectric materials have a crystalline structure having the ability to convert mechanical strain energy into electrical charge and on the other hand applied electrical potential into mechanical strain. This characteristic provides these materials the ability to absorb mechanical energy from their surroundings, normally vibration, and transform it into electrical energy that can be used to power other devices. Piezoelectric materials can be considered to mass of minute crystallites (domains). The macroscopic behaviour of the crystal differs from that of individual crystallites, due to orientation of such crystallites [1]. The technique to convert mechanical input to electric output by the help of piezoelectric vibrator was developed in 1947 by Bond, W.L [2].Giannakopoulos, A. and S. Suresh determined that the electric voltage generated by piezoelectric material depends on its boundary conditions as well as on its electrical conductivity [3]. Jiang, C. and Y. Cheung proposed a three phase model for piezoelectric material [4]. Magneto-electric voltage increases with increase in temperature [5].Kim, C.-S., S.-K. Kim, and S.Y. Lee determined the piezoelectric and dielectric values of newly doped piezoelectric materials at different calcination and sintering temperatures [6]. Piazza, G., et al. experimentally showed that piezoelectric material has central frequency on which voltage is tunable and it depends on a critical value at which material resonates [7]. Zhang, S., et al. developed piezoelectric material for high power applications and high temperature applications [8]. Moure, A., A. Castro, and L. Pardo showed trends and behavior of a piezoelectric material as a ceramic at different temperatures [9]. Okayasu, M., K. Sato, and Y. Kusaba, experimentally analyzed the domains of Lead ZirconateTitanate during loading and unloading conditions [10].

## II. MATERIAL

The material of the specimen utilized during this research work is Lead ZirconateTitanate that shows a marked piezoelectric effect compared to other ferroelectric properties. It is widely used in polycrystalline (ceramic) form with very high piezoelectric coupling. Lead zirconatetitanate shows a much greater piezoelectricity effect than quartz. These can readily be fabricated into variety of shapes and sizes and therefore can be tailored to a particular application. The description and dimensions of the specimen are provided in Table I and the properties of parent specimen are provided in Table II.

**Table I Description of specimen (PZT-5A4E Single Layer Disks)**

| Composition | Trade | (Dimension) | | Part No |
|---|---|---|---|---|
| | | Diameter | Thickness | |
| Lead ZirconateTitanate | PiezoSystems Inc. | 12.7mm | 0.191mm | T107-A4E-273 |

**Table 2. Parent Specimen Properties**

| Sr. No. | Description | Notation | Value | Units |
|---|---|---|---|---|
| Piezoelectric Properties | | | | |
| 1 | Relative Dielectric Constant @1KHz | $K^T_3$ | 1800 | |
| 2 | Piezoelectric strain coefficient | $d_{33}$<br>$d_{31}$ | 390 x$10^{-12}$<br>-190 x $10^{-12}$ | Meters/Volt |
| 3 | Piezoelectric voltage coefficient | $g_{33}$<br>$g_{31}$ | 24 x $10^{-3}$<br>-11.6 x $10^{-3}$ | Volt meters/Newton |
| 4 | Coupling coefficient | $K_{33}$<br>$k_{31}$ | 0.72<br>0.32 | |
| 5 | Polarization field | $E_p$ | 2 x $10^6$ | Volts /meter |
| 6 | Initial depolarization field | $E_c$ | 5 x $10^5$ | Volts/meter |
| Mechanical Properties | | | | |
| 7 | Density | ρ | 7800 | Kg/meter$^3$ |
| 8 | Elastic modules | $Y^E_3$<br>$Y^E_1$ | 5.2 x $10^{10}$<br>6.6 x $10^{10}$ | Newtons/meter$^2$ |
| Thermal Properties | | | | |
| 9 | Thermal expansion coefficient | | ~ 4 x $10^{-6}$ | Meters/meter $^o$C |
| 10 | Curie Temperature | | 350 | $^o$C |

## III. EXPERIMENTAL SETUP

Experimental setup was designed in such a way that load cell is fixed on a base of mild steel iron sheet and piezoelectric ring shaped specimen with nut and bolt on a load cell in such a way that it's lower and upper both sides face copper electrodes acting as anode and cathode. Mica sheet was utilized for electrical and thermal insulation between electrodes and load cell. Heat filament element was utilized in the circuit for on spot heating and temperature was observed with the help of temperature gun. Lead ZirconateTitanate (PZT-5A4E) specimen was then thermally shocked with the help of function generator at various frequencies and resistances which were varied using decade resistor box. The response is analysed on digital oscilloscope at different temperatures. Experimental setup and overall circuit diagram are shown in Fig. 1 and Fig. 2 respectively.

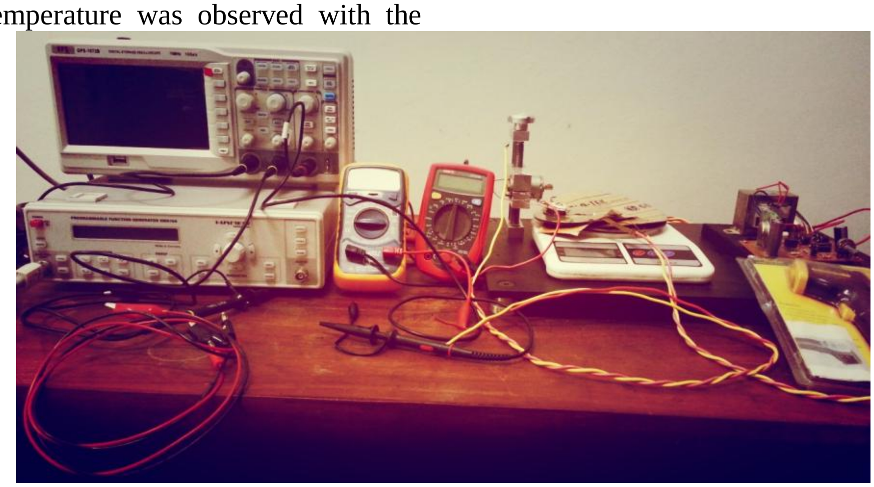

**Fig.1 Experimental Setup**

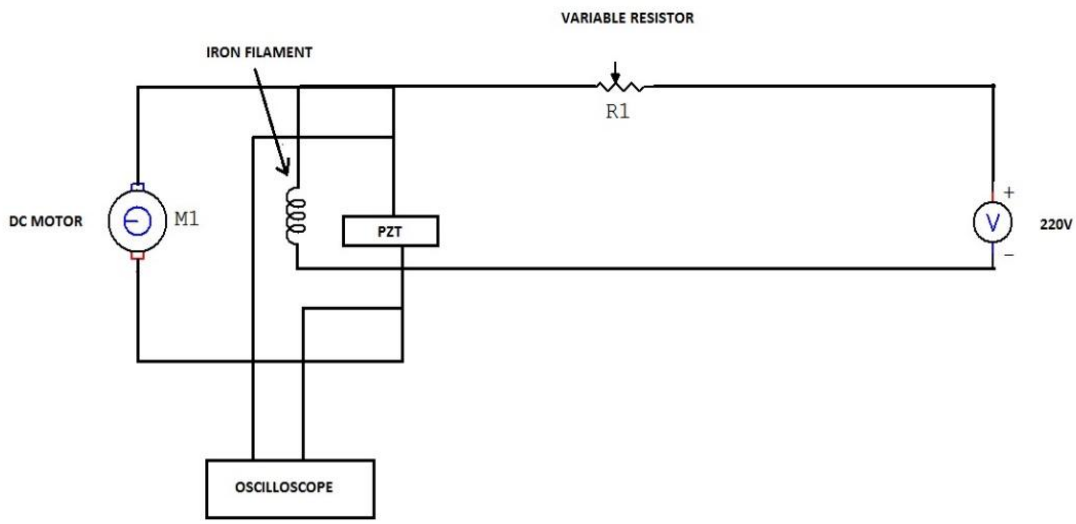


**Fig.2 Overall circuit diagram for the experimental setup**

## IV. RESULTS AND DISCUSSIONS

During the experimentation it is observed that by increasing temperature, the peak to peak voltage increases but by increasing frequency the output peak to peak voltage decreases. For maximum results optimization has to be done by increasing temperature, decreasing resistance, and decreasing frequency. Experimentation is performed at temperatures varying from 20 °C to 200 °C temperature, resistance varies from 0 KOhm to 200 KOhm, and frequency ranges from 20 Hz to 200Hz. The results obtained are shown in the graphs below:

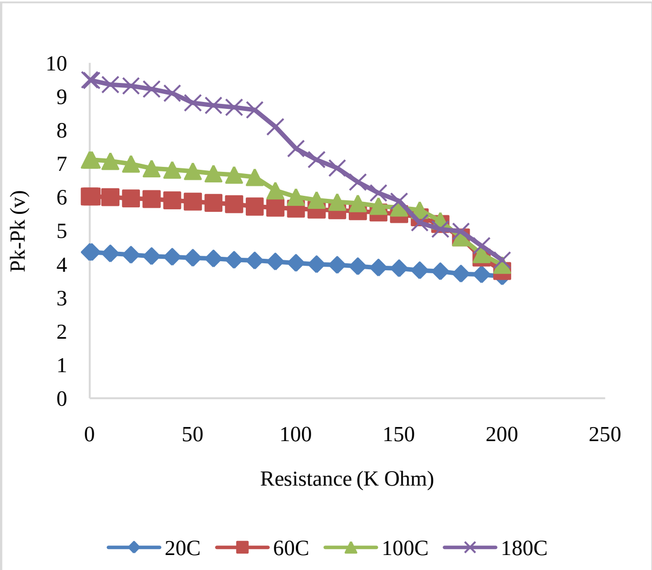


Fig. 3 Resistance vs. Pk-Pk voltage at 50 Hz Frequency & Variable Temperature

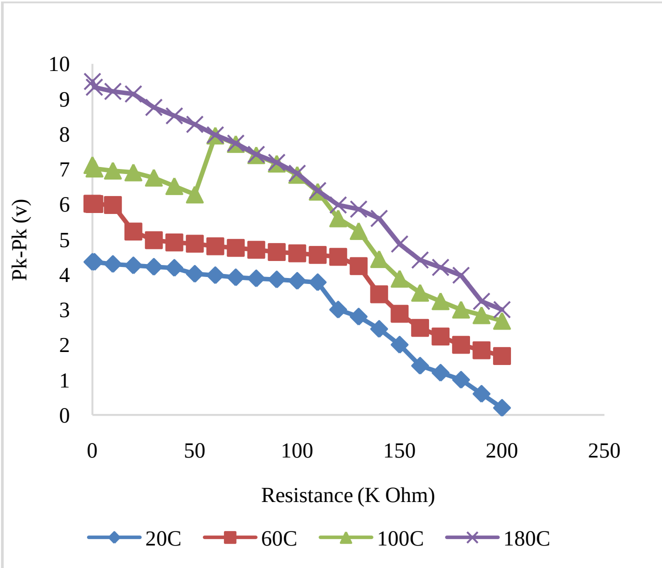


Fig. 4 Resistance vs. Pk-Pk voltage at 100 Hz Frequency & Variable Temperature

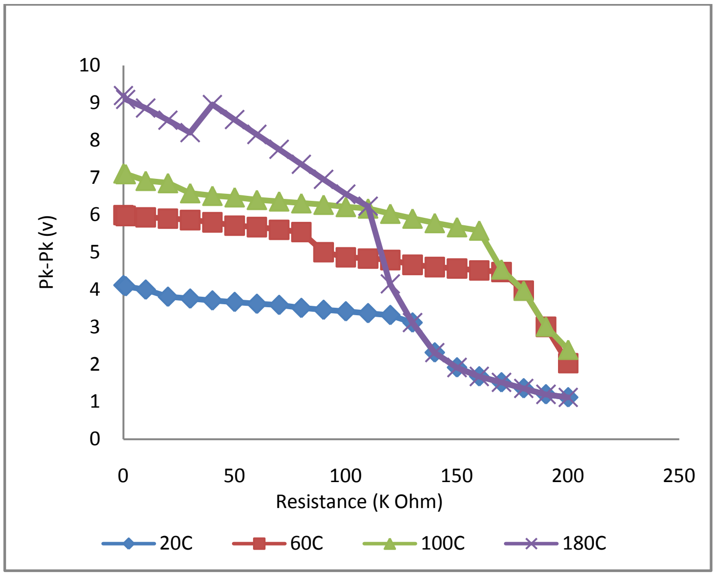


Fig. 5 Resistance vs. Pk-Pk voltage at 150 Hz Frequency & Variable Temperature

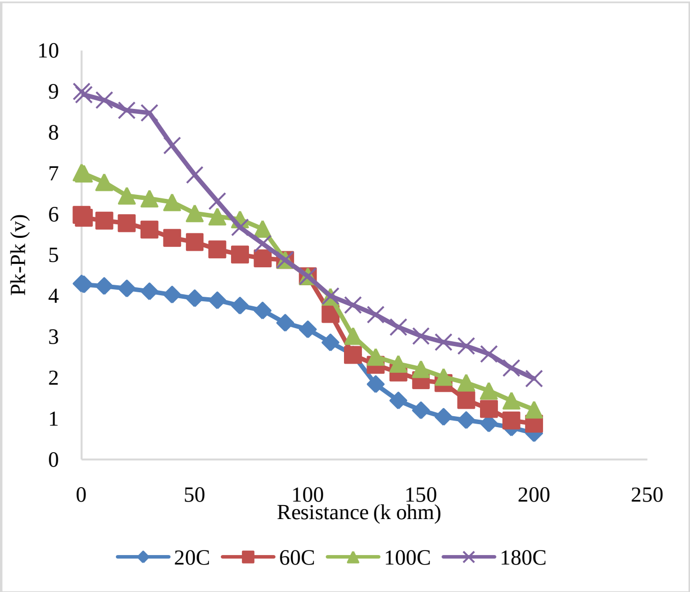


Fig. 6 Resistance vs. Pk-Pk Voltage at variable temperature and 250 hertz frequency

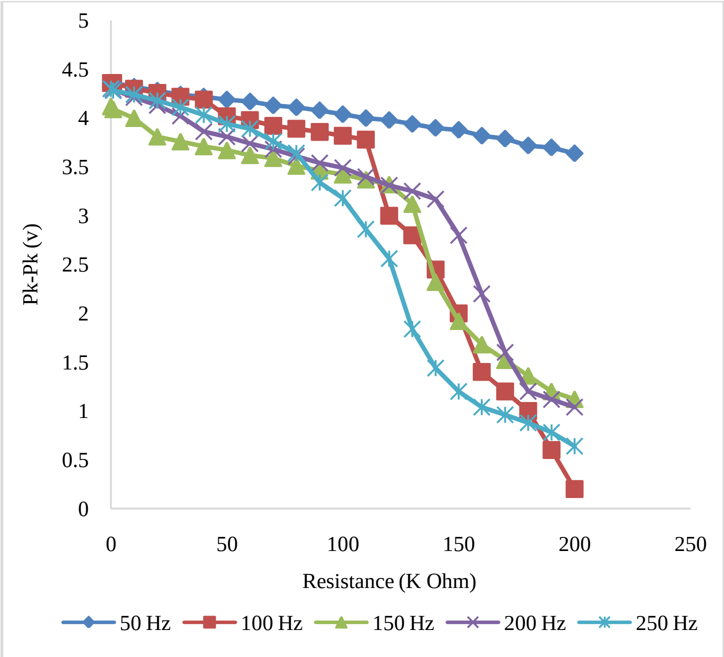


Fig. 7 Resistance vs. Pk-Pk Voltage at variable Frequency and 20 °C Temperature

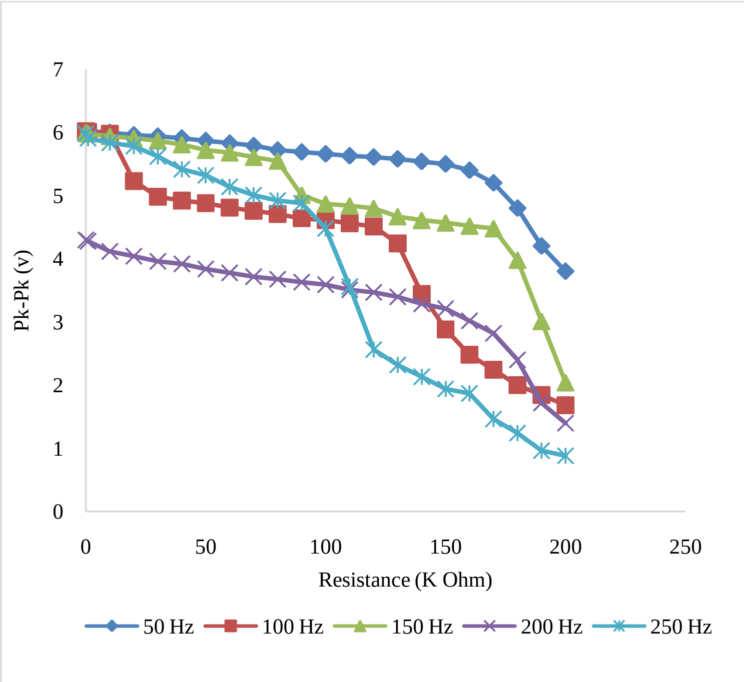


Fig. 8 Resistance vs. Pk-Pk Voltage at variable Frequency and 60 °CTemperature

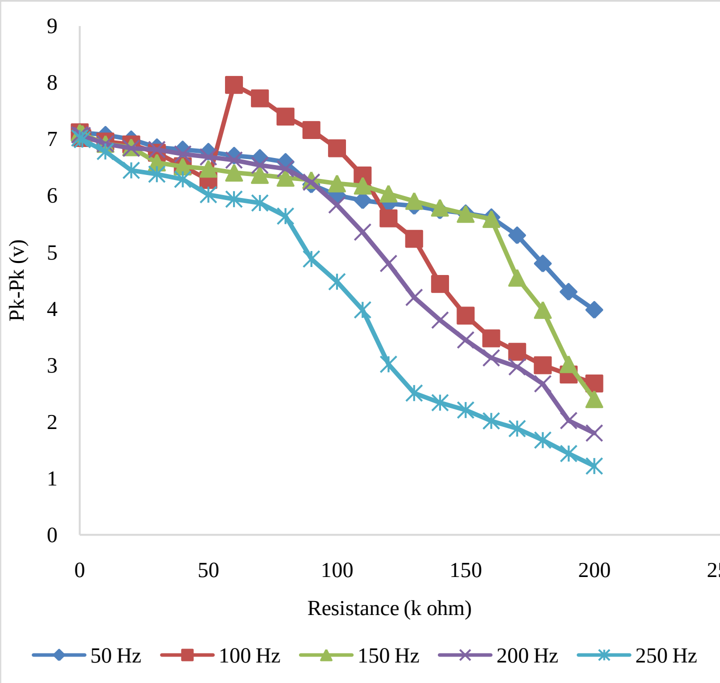


Fig. 9 Resistance vs. Pk-Pk Voltage at variable Frequency and 100 °CTemperature

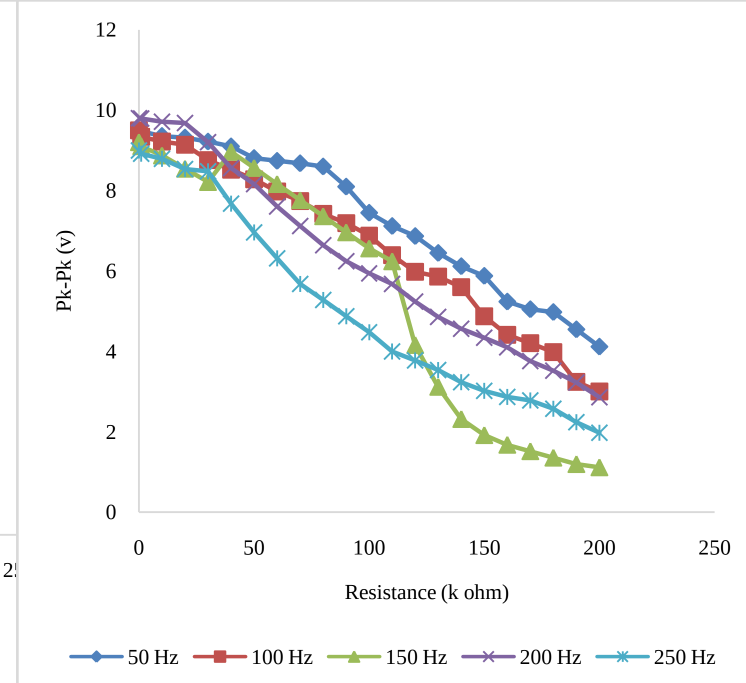


Fig. 10 Resistance vs. Pk-Pk Voltage at variable Frequency and 180 °CTemperature

## V. CONCLUSIONS

Following conclusions can be drawn from this research work:

1. By increasing temperature up to Curie temperature the peak to peak voltage of Lead ZirconateTitanate (PZT-5A4E) increases as a linear function.
2. By increasing frequency peak to peak voltage decreases linearly.
3. For best performance and maximum peak to peak voltage use PZT at 180°C temperature, 0 Ohm resistance, and 0 Hz frequency because dipolar motion of its ions is maximum at these conditions.
4. Negative linear behaviour is observed between frequency and peak to peak voltage as well as for resistance and peak to peak voltage.
5. At high resistance and frequency the motion of ions restricted so rate of polarization decreases which result in lowering of peak to peak voltage. So it is highly applicable to use Lead ZirconateTitanate (PZT-5A4E) at high temperature, low resistance and low frequency.

## REFERENCES:

[1] Liu, C., Foundation *of MEMS.* Electrical and computer Department University of Illionis at Urbana-Champaign Pearson Education International, 2006.

[2] Bond, W.L., *PIEZOELECTRIC VIBRATOS.* 1947, Google Patents.

[3] Giannakopoulos, A. and S. Suresh, *Theory of indentation of piezoelectric materials.* Acta materialia, 1999. 47(7): p. 2153-2164.

[4] Jiang, C. and Y. Cheung, *An exact solution for the three-phase piezoelectric cylinder model under antiplane shear and its applications to piezoelectric composites.* International journal of solids and structures, 2001. 38(28): p. 4777-4796.

[5] Ryu, J., et al., *Piezoelectric and magnetoelectric properties of lead zirconate titanate/Ni-ferrite particulate composites.* Journal of Electroceramics, 2001. 7(1): p. 17-24.

[6] Kim, C.-S., S.-K. Kim, and S.Y. Lee, *Piezoelectric properties of new PZT–PMWSN ceramic.* Materials Letters, 2003. 57(15): p. 2233-2237.

[7] Piazza, G., et al., *Voltage-tunable piezoelectrically-transduced single-crystal silicon micromechanical resonators.* Sensors

and Actuators A: Physical, 2004. 111(1): p. 71-78.

[8] Zhang, S., et al., *Piezoelectric materials for high power, high temperature applications.* Materials Letters, 2005. 59(27): p. 3471-3475.

[9] Moure, A., A. Castro, and L. Pardo, *Aurivillius-type ceramics, a class of high temperature piezoelectric materials: Drawbacks, advantages and trends.* Progress in Solid State Chemistry, 2009. 37(1): p. 15-39.

[10] Okayasu, M., K. Sato, and Y. Kusaba, *Domain switching characteristics of lead zirconate titanate piezoelectric ceramics during mechanical compressive loading.* Journal of the European Ceramic Society, 2011. 31(1-2): p. 129-140.