Effect of temperature and loading on output voltage of lead zirconate titanate (PZT-5A) piezoelectric energy harvester

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Abstract. Energy harvesting is the process of acquiring energy from the external sources and then further used to drive any system. Piezoelectric material was operated at various temperature but the characterization of the material mostly performed at room temperature. The depolarization in piezoelectric material occurs when the material is heated to its curie temperature and when mechanical stresses are high to disturb the properties of the material. The aim of this paper is to study the performance of lead zirconate titanate (PZT-5A) piezoelectric material under various temperatures and loading conditions. The output voltage of piezoelectric material decreases with increase of temperature. It was found that output voltage from the harvester increases when loading increases while its temperature decreases.

1. Introduction
Piezoelectric materials are an inventive step used for energy harvesting. Energy harvesting system uses piezoelectric materials where distortions produced by different resources are directly transformed to electrical voltage through piezoelectric effect. With the ever increasing energy needs, extracting and manipulating more and more energy sources has become a need of the day. There are two types of energy harvesting schemes macro scale and micro scale energy harvesting. Piezoelectric energy harvesting schemes comes under the category of micro scale energy harvesting scheme [1]. The first application of piezoelectricity appeared in sonar in which quartz crystals was used to produce ultrasonic waves during World War I [2]. Piezoelectric materials generate electrical voltage when mechanical stress is applied known as direct effect of piezoelectric. The inverse piezoelectric effect is the ability of a material to produce mechanical distortion when electric field is applied. The energy harvesting by using piezoelectric material uses direct piezoelectric effect. The direct piezoelectric effect was discovered in 1880 by Pierre and Jacques Curie in various naturally occurring substances including Quartz and Rochelle salt [3]. If piezoelectric materials are heated to a threshold temperature, the crystal pulsations may be so strong that domains become chaotic and element become completely depolarized. This critical temperature is called Curie temperature [4]. Salem Saadon and Othman Sidek in 2011 presented a review about vibration based piezoelectric energy harvesting technology which is carried out by researcher during the last three years [5]. Seon-Bae Kim et al. studied the behavior of piezoelectric materials at various thermal conditions. The output power at different temperature has been predicted by the change of piezoelectric coupling coefficient. He showed that output power decrease with increase of temperature [6]. Poorna Mane et al. studied the effect of temperature, pressure, frequency, and load resistance on the energy harvesting prospective of the device. The output voltage and power were calculated as 108V and 11641μW at 20°C, 275.8kPa,
Our aim in this paper was to determine the effect of temperature and loading on output voltage of lead zirconate titanate (PZT-5A) piezoelectric material at 5 Hz frequency.

2. Material
In this research work a rectangular lead zirconate titanate (PZT-5A) specimen was selected for required experimentation. Lead zirconate titanate (PZT) is a perovskite ceramic material that shows marked piezoelectric effect. It can be prepared by using different methods e.g. sputtering and jet molding etc. It is a pyro-electric material that generates voltage when temperature changes so that’s why it is also used as a temperature sensor. It can be classified into two groups hard and soft PZT depend upon the mechanical and electrical characteristic. It can be used to make ultrasonic transducer and ceramic capacitor. It can be used in sonar technology, surgical instruments and ultrasonic bending and welding because of its high permittivity, large coupling factor, high Curie temperature and high charge coefficient [11]. The modeling dimensions of specimen are given in Table 1 and properties of the specimen as given by supplier are given in Table 2.

### Table 1. Dimension of specimen

| Composition | Trade | Part No. | Dimension (mm) |
|-------------|-------|----------|----------------|
| PZT-5A | Piezo system Inc. | T107-A4E | L=20, W=10, T=5 |

### Table 2. Specimen properties as provided by supplier (PIEZO SYSTEM INC, USA)

| Sr. No. | Description                              | Notation | Value       | Units      |
|---------|------------------------------------------|----------|-------------|------------|
| 1       | Density                                  | P        | 7750        | Kg/m³      |
| 2       | Mechanical Quality factor                | Qᵣ       | 80          |            |
| 3       | Piezoelectric voltage coefficient        | g₃₃      | 24 × 10⁻³   | Vm/N       |
| 4       | Piezoelectric strain coefficient         | d₃₃      | 374× 10⁻¹²  | m/volt     |
|         |                                          | d₃₁      | -17× 10⁻¹²  |            |
| 5       | Dielectric constant                      | εᵣ       | 1.504× 10⁻⁸ | F/m        |
| 6       | Elastic compliance constant              | S₁₁ₑ     | 16.4× 10⁻¹² | m²/N       |
| 7       | Initial depolarization field             | Eᵣ       | 5× 10⁵      | V/m        |
| 8       | Polarization field                       | Eᵢ       | 2× 10⁶      | V/m        |
| 9       | Curie temperature                        |          | 350         | °C         |
| 10      | Thermal expansion coefficient            |          | -4× 10⁶     | Meters/meter °C |

### 3. Experimental setup
For the sake of experimentation, a setup was designed in such a way that load cell is fixed on a base of mild steel iron sheet. A 12V dc motor with a cam shaft mounted by a screw mechanism was used to provide alternating loading conditions. The rectangular specimen was fixed with nut and bolts on a load cell in such a way that it’s lower and upper both sides faces copper electrodes. These electrodes acted as cathode and anode. The schematic diagram of specimen is as shown in Figure 1. The mechanical load was applied on the top surface via screw mechanism and function generator was used.
to electrically shock the specimen at 5Hz frequency. The arbitrary function generator was used to generate a series of sinusoidal signals. An energy harvesting circuit or ac to dc converter was used to convert ac voltage into dc voltage as shown in Figure 2. For electrical and thermal insulation mica sheet was used which is resistant to both electrical and thermal conductivity. For on spot heating we used heating filament in a circuit and temperature gun was used to monitor surface temperature. The voltage response is investigated on digital oscilloscope at different temperatures and loading conditions. The experimental setup used for energy harvesting is as shown in Figure 3.

4. Results and discussion
Figure 4 shows that on increasing the temperature at different loading conditions the output voltage decreases accordingly. Vary the temperature up to 350°C to checkout its response on oscilloscope at different loading conditions. It is observed that temperature at 20°C does not influence the output voltage at different loading conditions which shows that the every transducer made from this type of material may be successfully used up to this temperature. When the temperature is between 50°C and 300°C the properties of Piezoelectric ring changes due to depolarization effect and the output voltage decreases. At temperature 350°C they degrade very rapidly and tending to zero. The maximum dc voltage of 5.93V was obtained at 30N, 5Hz frequency and 20°C temperature. So it is highly applicable to use piezoelectric material at low temperature and maximum loading conditions.
Figure 4. Effect of temperature on Peak dc voltage at 5Hz frequency and different loading conditions

Figure 5. Effect of loading on Peak dc voltage at 5Hz frequency and different temperature conditions

Figure 5 shows the linear relationship between load and output voltage at different temperature conditions. The data indicate that temperature has negative effect on the output voltage. It is observed that temperature at 50°C, 100°C, 150°C, 200°C and 250°C present a significant decrease in voltage due to depolarization effect at variable loading conditions. The maximum voltage of 6.67V was obtained at 36N, 50°C and 5Hz frequency. It was seen that output voltage increases when the load increases and temperature decreases.

5. Conclusions
The behavior and performance of lead zirconate titanate (PZT-5A) piezoelectric material was investigated as a function of environment temperature and different loading condition. The output voltage of the material decreases with the increase of temperature. Following conclusions are obtained from this research work:

I. It was found that temperature up to 20°C does not influence the output voltage. When temperature increases at different loading conditions the output voltage decreases.

II. The output voltage of piezoelectric material increases when loading increases and temperature decreases.

III. It is determined that lead zirconate titanate (PZT-5A) piezoelectric material perform well below Curie temperature. So it is highly applicable to use this type of material at low temperature and for greater loading conditions.

6. Acknowledgments
This project was funded by University of Engineering & Technology Taxila, Pakistan. My deep gratitude goes to my M.Sc. supervisor, Professor Dr. Riffat Asim Pasha for his supervision, continuous support, encouragement, research approach and expertise in this research work.

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