Analysis of Piezoelectric Materials for Efficient Energy Harvesting

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Abstract- *Energy is the most important issue in the world. It is true that it is not easy to override the conventional energy sources. But to meet the large energy demand we need some substitutes. The sources which provide energy in present time are going to be depleted in next 10 decades so we need alternative energy resources. Since the population is expanding at fast rate and traffic on roads has become impossible to handle, it can be taken as an opportunity to generate energy in the form of electricity from piezoelectric materials. The electric energy is generated by piezoelectric effect when the mechanical stress is applied over the piezoelectric material. Piezoelectricity is the electric charge that accumulates in certain solid material (notably crystal, certain ceramic and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. Commonly used piezoelectric material for energy harvesting is of less efficiency, so we have analyzed different materials based on their physical properties and their dimensions. The aim of this project is to find efficient piezoelectric material type to make power generation more sustainable, economical and this is done by using Simscale software.*

Keywords- piezoelectricity; Simscale software; alternative energy; power generation.

I. INTRODUCTION

Energy is the most important issue in the world. It is true that it is not easy to override the conventional energy sources. But to meet the large energy demand we need some substitutes. And due to recent environment concern issue the energy should be greener. .So it is true that we need to try to move towards harnessing the energy from the nature which can be very much potential in some respect. There are some energy which are low in energy density but can provide sufficient energy to our sensors and MEMS.

Energy harvesting has been a topic of discussion and research since three centuries. With the ever escalating and demanding energy needs, unearthing and exploiting more and more energy sources has become a day to day need. Energy harvesting is the process of deriving energy from external sources and utilized to drive the machines directly, or the energy is stored for later use. Some traditional energy harvesting schemes are solar farms, wind farms, tidal energy utilizing farms, geothermal energy farms etc.

Piezoelectric Energy Harvesting is a new and innovative step in energy harvesting. It is a challenging job to extract energy from piezoelectricity. Through this project, we will describe the basic working of a piezoelectric crystal. The proposed idea in this project is to produce higher voltages by combining energy from a number of piezoelectric crystals.

II. PRINCIPLE OF PIEZOELECTRIC CYRSTAL

The ability of certain materials to generate an electric charge in response to applied mechanical stress is called piezoelectric effect. Quartz, Rochelle salt, Topaz, Tourmaline, Cane sugar, Lead Titanate ($PbTiO_3$), Potassium Niobate ($KNbO_3$), Berlinite ($AlPO_4$), Bone, Tendon, Silk, Enamel, Dentin, Lithium Niobate ($LiNbO_3$),Barium Titanate ($BaTiO_3$) and etc are some examples of piezoelectric crystalline structures. The direct piezoelectric effect and inverse piezoelectric effect are the two types of piezoelectric effect. The direct piezoelectric effect means deriving electrical potential from material when external stress id applied and inverse piezoelectric effect means material deformation when an electric field is applied. The phenomenon will be clear from the diagram shown in Figure 1.

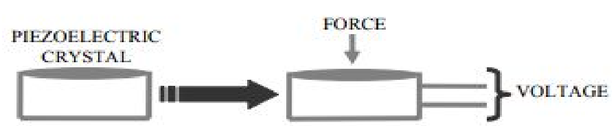

Figure 1. Principle of direct piezoelectric effect

By applying an external force to a piezoelectric material it causes the positions of the ions in the crystal lattice to modify thus induces a separation of charge that produces an electric dipole with a single axis of symmetry. The type of piezoelectric material selected for a power harvesting application can have a major influence on the harvester's functionality and performance. The commonly used piezoelectric crystal for energy harvesting applications is lead zirconate titanate, a piezoceramic, known as PZT.PZT is widely used as a power harvesting material, the piezoceramic's extremely brittle nature can withstand only limited strain over the material. Lee et al note that piezoceramics are susceptible to fatigue crack growth when subjected to high frequency cyclic loading. Another common piezoelectric material PVDF is a piezoelectric polymer that exhibits considerable flexibility when compared to PZT. Though the piezoelectric strain constant (d31) and coupling coefficient (k31) for PVDF is lower than that of PZT, PVDF is flexible, lightweight, tough, ecological properties (it does not contain lead).

Piezoelectric crystal can be arranged in series manner to achieve higher voltages and the energy obtained is stored in lithium batteries or capacitors. The optimization of piezoelectric energy is done in various ways. In this paper the experimental analysis of different type of piezoelectric structure is done by using the Simscale software and output voltage values are calculated.

III. METHODOLOGY

The input vibration is applied over the piezoelectric material which is in the form of mechanical stress which is then converted to electrical energy shown in the figure 2. A number of piezoelectric sensors are arranged in series. When the force is applied over the sensor the mechanical energy will be converted into electrical energy. This harvested energy can be utilized for many applications directly or can be stored in capacitor or battery and utilized for future usage. The most commonly used piezoelectric material for energy harvesting is PZT. But the harvested energy is of less voltage when compared to other piezoelectric materials which is discussed in the later section.

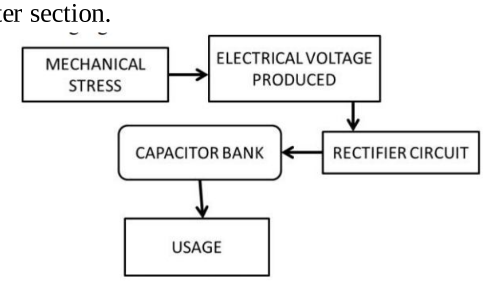

Figure 2. Flowchart for proposed methodology

IV. EXPERIMENT ANALYSIS

The simulation for material analysis of different materials is done using simscale platform. Simscale is a computer-aided engineering (CAE) software product developed by simscale GmbH. It allows Computational Fluid Dynamics ,Thermal and Finite Element Analysis simulations. It is based on cloud computing. The backend of the platform uses open source codes: FEA-Code_Aster and CalculiX and CFD-open FOAM. Here we have chosen eight materials for the output voltage analysis of piezoelectric material using simscale software. They are Barium Titanate(BaTiO3),PZT-5H,PZT-5A,PZT-4,PZT-8,Rochelle Salt, Zinc Oxide(ZnO) and PMN-PT. The CAD model for the piezoelectric crystal having dimension of X:0.04m ,Y:0.009525m and Z:0.04m is formed. In this paper we didn't consider the size and thickness of the material for efficient analysis of the material. The CAD model of the piezoelectric crystal is uploaded to the simscale for the further analysis of the material. Each material have their own specific physical properties like density, young's modulus ,poisson's ratio and Piezoelectric coefficient (d33).By applying force on the material, it produces a specific displacement which vary from material to material based on their physical properties. From the displacement produced we can calculate the voltage produced for the particular material using a formula by knowing the piezoelectric coefficient (d33).The physical properties for the different material which is used here is shown in the Table II. The simulated result shown here are for applied force of 50N towards Y-axis having fixed support on the top of the material used. All the displacement analysis obtained for the materials based on the constraints having fixed support at the top side and force of 50N applied towards the Y-axis of the material. The displacement values are obtained from the simulation results of different materials shown in the below listed figures and are listed in the table I.

Table 1. Physical Properties Of Different Material Types

Material Type	Density kg/m3	Young's modulus(GPa)	poisson's ratio	Δh (at 50 N)
BaTiO3	5800	67	0.35	3.8935 e-9
PZT-5H	7500	64	0.33	4.1477 e-9
PZT-5A	7750	66	0.33	4.022 e-9
PZT-4	7600	78	0.33	3.4033 e-9
PZT-8	7500	99	0.33	2.6814 e-9
Rochelle Salt	1767	19.1	0.196	1.4972 e-8
ZnO	5600	112	0.336	2.3583 e-9
PMN-PT	8069	25	0.32	1.0703 e-8

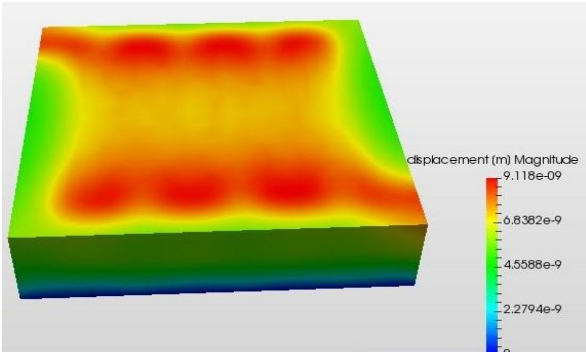

Figure 3. Simulation result of BaTiO3

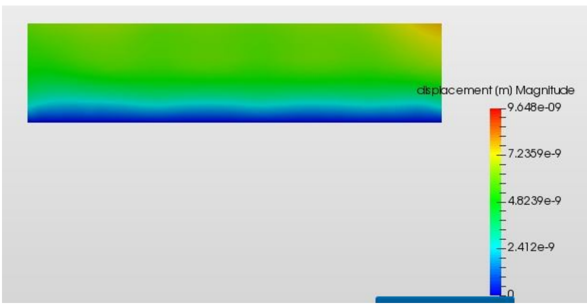

Figure 4. Simulation result of PZT-5H

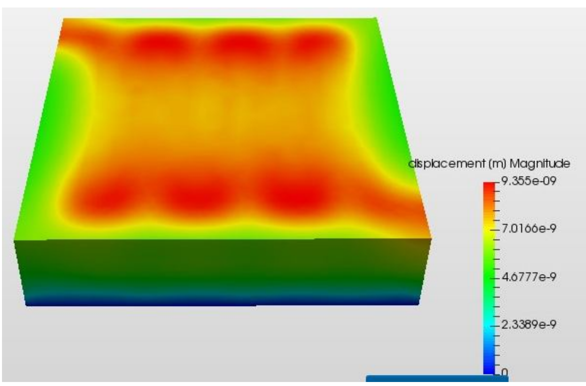

Figure 5. Simulation result of PZT-5A

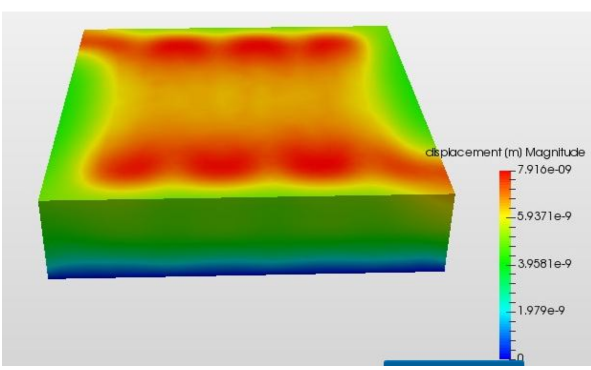

Figure 6. Simulation result of PZT-4

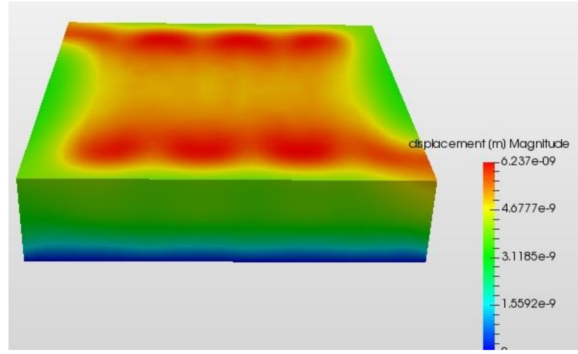

Figure 7. Simulation result of PZT-8

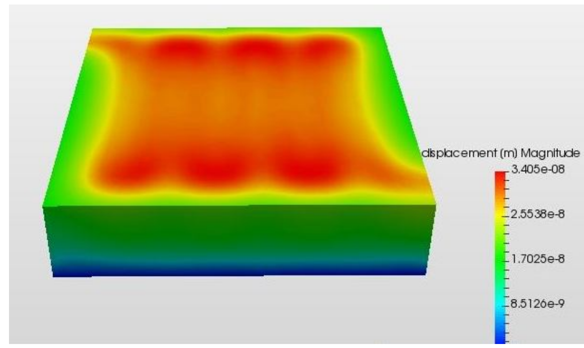

Figure 8. Simulation result of Rochelle Salt

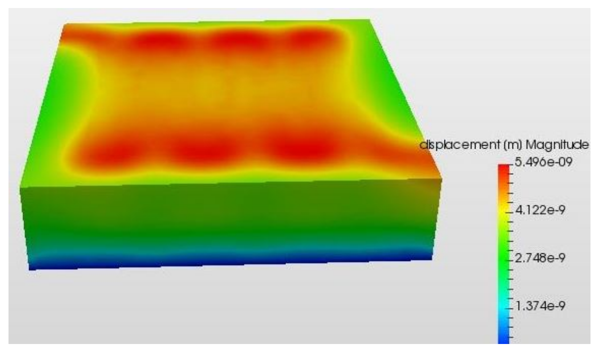

Figure 9. Simulation result of ZnO

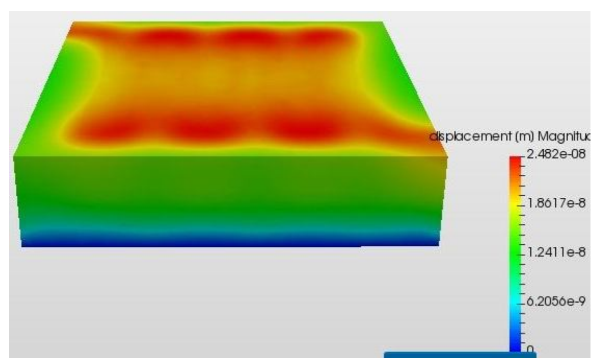

Figure 10. Simulation result of PMN-PT

V. MATHEMATICAL CALCULATION

By using the formula we can find the output voltage of a material by knowing the value of piezoelectric coefficient (d33) and displacement produced for the applied force. The output Voltage for the different material types of the piezoelectric crystal is listed in the table II.

$V = \Delta h / d_{33}$

V -output Voltage produced for the applied force(volts)

Δh-change in displacement (m)

d_{33}- piezoelectric co-efficient (10^{-12} m/V)

Table 2. Output Voltage Of Different Material Types

Material Type	Δh (at 50 N)	d_{33}(10^{-12} m/V)	V
BaTiO3	3.8935 e-9	190	20.49
PZT-5H	4.14773 e-9	585	7.09
PZT-5A	4.022 e-9	374	10.75
PZT-4	3.4033 e-9	295	11.53
PZT-8	2.6814 e-9	225	11.91
Rochelle Salt	1.4972 e-8	165	90.73
ZnO	2.3583 e-9	124	19.01
PMN-PT	1.0703 e-8	1589	6.73

VI. CONCLUSION

From the simulation we have found that the Rochelle Salt piezoelectric material have the high efficiency for the applied force of 50N with output voltage of 90.73 V where as PMN-PT piezoelectric material have low efficiency with output voltage 6.73 V . By fabricating and using the Rochelle Salt piezoelectric material for the energy harvesting we can increase the efficiency of the energy produced and use in a effective manner. We can store the energy produced and use to drive street lights, light, signals etc and also we can use the energy produced directly.

VII. FUTURE SCOPE

We have taken different type of material to find the efficient material. We can further improve the efficiency by increasing or decreasing the dimension of the material. We can also modify the shape of the material to change the efficiency of the material. Therefore the more efficient material can be further obtained by modifying the shape and size of the material.

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