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Eco-friendly Energy Harvesting Using Piezoelectric Material for Smart Applications

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Abstract—This research is endeavored to study the generation of electric power using Piezoelectric effect to harness the electrical energy through material sources following the “law of the conservation of energy”. In this regard efforts have been made to discover the eco-friendly sources of electrical energy. Some of the methods have already been successfully implemented owing to advancement in the state of the art technology. In parallel it is aimed to convert the mechanical energy into electrical energy by using the suitable apparatus with the concept of piezoelectricity and the produced eco-friendly electrical energy is rectified and filtered to get a stable output.

Index Terms— Berium Titanate, Light Emitting Diode (LED), Macroscopic Piezo-electric Coefficients (MPEC), Piezoelectric effect, Polyvinylidene fluoride (PVDF) and Piezo ceramic wafer.

1 Introduction

Self-sufficiency in the generation of electrical energy is the guarantee to improve the economy of the country. Similarly, as per the international analysis, the reserves for oil and gas are diminishing day by day & as per estimation those can be finished in the second half of this century and the Pakistan is mostly depending on the oil and gas reserves especially and utilizing them. Also the energy crisis is gradually increasing and destroying the country’s economy and causing a cumulative loss of Rs. 1000 billion per annum on this account and fueling instability is an additional drawback. The worldwide electricity is generated through natural gas up to 19% where as in Pakistan it is 45%, the world is generating electricity by oil is only 7% but in Pakistan it is generated 16% and similarly the world is getting electricity from nuclear resources up to 16% but on the contrary Pakistan is generating 2% and as per the total world’s electrical energy production though Hydel Power plants is 16% but our country limits up to 3.3% which transpires that we are solely dependent on non-renewable energy sources, thus way to overcome on this hectic situation is to move towards renewable energy sources.

Now in this research it is being introduced a method of renewable energy source of production of electrical energy through piezo electric effect. The Piezoelectric material has the ability to convert the mechanical stress applied on it into electrical energy though suitable mechanism. This project can be implemented on the area where it gets a huge amount of stress i.e. on heavy traffic roads, railway tracks, busy airports, walking paths, dancing clubs, entrances of public places like parks, restaurants, shopping malls etc. Its implementation to any surface is easy because the piezoelectric material can be drawn in any form according to the requirement and it’s another important characteristic is that it can be attached to any surface i.e. it can be glued with cement, stones, wood etc.

A piezoelectric material, PZT, senses the stress applied on it and converts the stress into electrical signals which flows into the outer circuit which is further rectified, filtered, stored and supplied to the connected load.

2 Basic concept of Piezoelectric Effect

The Piezoelectric Effect is termed as the ability of the materials to generate the electrical energy when the mechanical stress exerted upon them. The letter “Piezoelectric” is taken from Greek the “Piezein” which narrates to press and piezo is Greek latter which meant “subjected to pressure”.

Whenever force is applied to the piezoelectric material its structure deforms and as a result a potential difference is produced across its two faces.

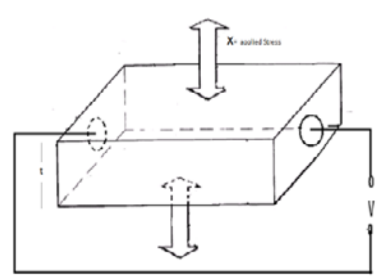

Figure 1 Piezo Electric Material producing potential difference under

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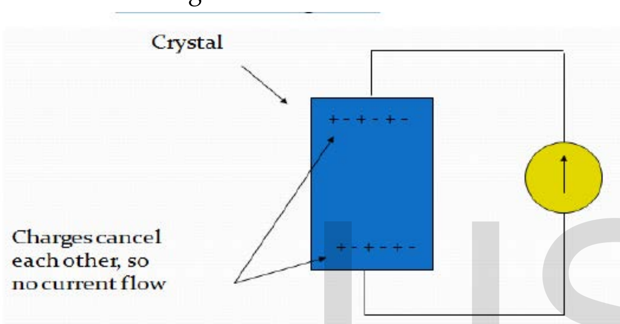
stress.

Normally, the piezoelectric crystal contains the balance no of charges in it & hence cancel out their internal effect resulting no any net charge of the crystal on surface even if they're not symmetrically arranged but when we squeeze the crystal or apply pressure on it, the charges go on unbalanced.

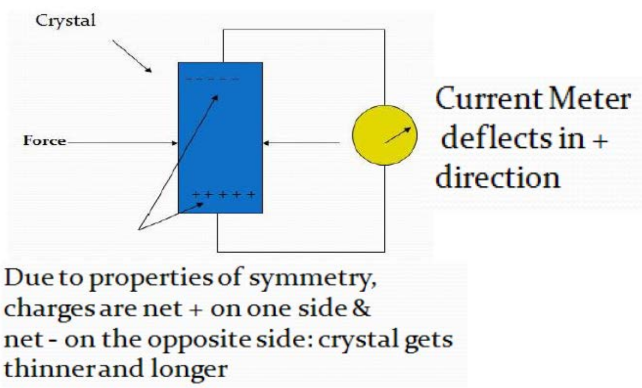
Hence, the charge's effect do not be cancelled i.e neutralized & resultantly +ve and –ve charges appeared on alternate sides of crystal and by pressing the crystal material a voltage across its opposite faces is generated which is termed as piezoelectricity or piezoelectric effect.

This piezoelectric effect is further demonstrated as below:

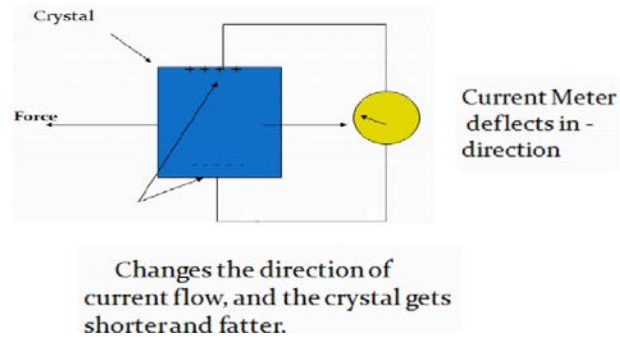
i. Crystal material is at rest, no force is applied and hence net current flowing is 0.



ii. Crystal material with forces applied in direction of arrows.



iii. Changing the direction of the applied force



3 LITERATURE REVIEW

The phenomenon of Piezoelectricity was discovered in 19th century and in the 1880, Pierre and Jacques Curie performed the initial experiment and demonstrated the link amid the macroscopic piezoelectric phenomena and crystallographic structure. Their experiment consisting the certain measurements of charges appeared on the surface of crystals made up of quartz, tourmaline and Rochelle salt specially when the mechanical force was applied on them [1].

Also, during the following years ending to 1910, an extensive research had carried out to obtain a complete & detailed framework defining 20 classes of natural crystal and amongst them the occurrence of piezo-electric effect observed and explained the complete 18 suitable macroscopic piezo-electric coefficients accompanied by an energetic thermodynamic treatment for the solid crystals using suitable tonsorial analysis [2].

The "Sonar" was the first piezo-electric application developed in the era of World War-I. Paul Langevin and his colleagues invented the ultrasonic submarine detector in France during 1917. A transducer was contained in the detector manufactured with a slim quartz material stuck between the two steel plates with very high attention and reflected echo was detached with a hydrophone [3].

On contrary with the secrecy-policy in practice at United States, the piezo-ceramic producers in the beginning of the industry, many Japan based companies and Universities launched a Competitively Cooperation Association as a research company for Berium Titanate Application during 1951 [4].The motive of the established organization was to face the challenges regarding manufacturing and technical along with the introducing the various market areas. At the beginning of 1965, the Japan-based commercial enterprises initiated harvesting the beneficiaries of the development work for the material and applications duly started by the successful experiment in 1951.As per the international business point of view, the owners were bound for promotion of new technology, encouragement of latest applications and processes and also an area for fresh commercial market in a transparent and profitable way [5].

During 1996, Umeda et al examined the generation of power in such a way that a plate equipped with a Piezo ceramic wafer was effected when a steel ball freely falling on it [6].

During 1996, Starner explained the possible location for power generation from piezoelectric devises around the human body and declared the human blood pressure, upper limb movement and walking of the human. Also the claim of the author is that a power of 8.4 watts can be generated by a PZT if inserted in the shoes [7].

In 1997, Umeda examined the characteristics of storing the power of piezoelectric system having PZT, full-wave bridge rectifier and a capacitor. Pursuing the investigation, a prototype was designed and claimed for the efficiency more than 35% which is three times greater than that of the solar cell's efficiency [8].

In 1998, Kymissis et al examined piezofilm for charging a capacitor and energizing a RFID transmitter by harvesting the energy from the shoes of a walking man. He used polyvinylidene fluoride (PVDF) material in shoe's sole to absorb the energy during walking of human and a piezo-ceramic thunder actuator had used in the heel of shoe to convert energy into electricity [9]. This work transpired that the generated power by piezoelectric materials was enough to power the wireless functioning devices and also capable to transmit the 12-bit signal with the frequency of five to six times for every few seconds.

In 2000, besides the applied force in the direction of poles i.e d33 mode, Ramsay & Clark had examined & compared with the transvers force (d31mode) for a PZT generator and declared as a 1 cm3 piezo-ceramic wafer is capable to supply the power to a MEMS device in microwatt range [10].

In 2001, Elvin et al, experimentally & theoretically examined a self-powered, wireless sensor employing PVDF (PolyvinylideneDifluoride) [11].

An Innowattech, the Israel based company claims the patents for technologies which can harvest the mechanical energy through vehicles moving on Roadways, Railways, and airports runway which collect the mechanical energy to convert into

Electricity & same way the company has created the different types of Innowattech Piezo Elect: Generator sets (IPEG) which are as follows:

- Roadway Generator sets
- Railways track based Generator sets
- Airport Runways Generator sets

The Innowattech company claims that the IPEGs can harvest the form of energy from weight, motion, vibrations and temperature changes and also as per the assurance by the company that 1 kilometer travel by railroad can generate the power of 150 KW per hour and similarly 1 KM of roadway journey or airport runways can generate 0.5 MW of power per hour and the harvested electricity by IPEGs can be added to the national grids.

Also the Australian scientists has made a research on the Laptops powered by keyboard typing at the Royal Melbourne Institute of Technology & have succeeded by inserting a thin capacity of piezoelectric film into the key board of laptop for collecting the mechanical pressure exerted on it to convert to electricity and by this research the Laptops can be powered through typing.

4 The mechanism of Piezoelectric effect

Nature wise the piezoelectric material isdeeply resembling to electric dipoles containing in it in major quantity. The dipoles are induced in the shape of ions in crystal lattice sites with asymmetric charges surroundings or with the cause of molecular groups having the electric properties. Commonly, the dipole is termed as P and is a vector quantity having the value according the electric charges at its around and a definite direction. Each dipole has the similar direction when arranged one after the other and also they jointly built regions known as "Weiss domain" & these randomly oriented Weiss domains may be properly aligned with the poling process, a process with the strong electrical field applied on the subjected material but all the piezo-electric materials can't be poled. The cause for the voltage generation by the piezo-electric materials is defined as "when the mechanical force is applied on the material, the shape of the crystal disturbs & similarly the direction of Polarization P of electrical dipole is changed". On depending the dipole nature, this type of changing of polarization may be due to the ions reconfiguration in the structure of crystal or due to the molecular groups' reorientation. Resultantly, higher the mechanical force exerted the greater change in the polarization occurs and greater electric energy can be generated.

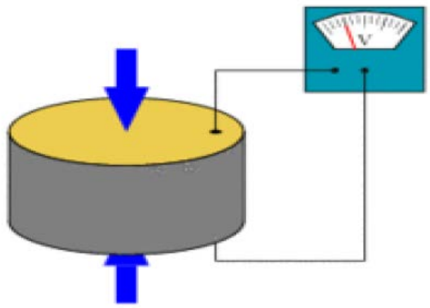
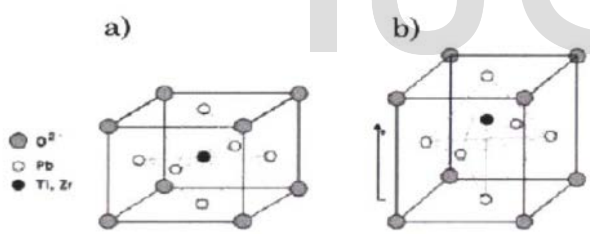


Figure 2. Piezo Electric Material producing potential difference under stress

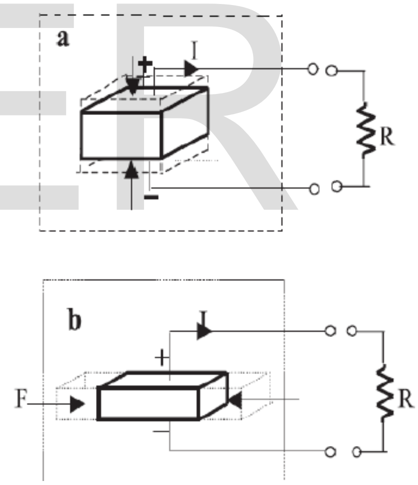
A traditional material of piezo-electric ceramic is the mass of the crystal of perovskite ceramic containing a tetravalent metal ion mostly zirconium / titanium in shape of lattice of greater metal ions of divalent nature. Mostly, the lead or barium metal & ions of 02. The condition conferring the rhombohedral / tetragonal symmetry of crystals, a dipole movement in each crystal contained. Although, changing in P is the consequence of variation in density of charges at the surface of the crystal i.e electric field variation extended among the faces. As 1 cm^3 of quartz material bearing a force of 2 Kilo Newton (500 lb.) applied is capable to generate 12.5 KV.



Commonly there are two coupling modes to be used for piezoelectric generators which can be identified with the application of the mechanical force applied & the direction of the electrical charges. Conventionally, the polarization's direction is represented in '3' direction, hence both type of modes are:

1. '33' mode (k33)
2. '31' mode (k31)

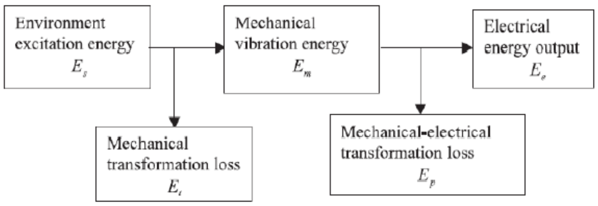
The fig: (a) showing the mode '33' suggests the collection of charges at electrode surfaces acting as perpendicular to the direction of polarization whenever the mechanical compressive force is exerted on the polarization axis.
Similarly, figure (b) shows the '31'mode transpiring that charges are being gathered at surfaces of electrode acting as perpendicular with the polarization's direction whenever a mechanical force is exerted in the direction duly perpendicular with the polarization's axis.
Comparatively, there is larger the coupling factor for mode-33, k33 than mode-31, k31 in most of the piezo-electric materials.
The coupling factor for 33-mode, k33 is larger than that of the coupling factor of 31-mode, k31 in the most piezoelectric materials. In 31-mode, the mechanical stresses are exerted along with the1-axis. Hence, the stress can be obtained fluently through piezo-electric material's bonding with a sub-structure which tend to bend easily. In mode-33, a higher output of power can be achieved through the conversion of the energy with the increase of the ceramic layer for a source of v.low pressure & limited size. Similarly, mode-31 has an advantage for energy conversion. The application for the MEMS structures comprises the smaller generator size and also the mechanical energy producing sources by the environment are also limited. Hence, the energy conversion by mode-31 is an appropriate for the piezo-electric micro-Generators to be used in MEMS structures.



The energy flow chart is defined as initially the transformation of environmental energy into mechanically vibration form of energy of seismic mass and later on this energy is converted into Electrical Energy by the application of piezo-electric effect of the piezo-electric material. The mechanical system stores this mechanical vibration energy (E_m) and further the E_m can be divided into two parts:

$E_e = E_m - E_p = E_m \eta_{me}$

Where, the Ee is the production of electrical energy by the piezo-electric element's action & Ep is the energy loss during the conversion from Mechanical energy to Electrical energy.



The piezo-electric element's efficiency of conversion may be shown as:

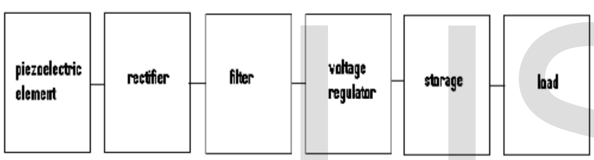
$\eta_{me} = E_e / E_m$

also, the efficiency of conversion from excitation source to the kinetic energy shown as under:

$\eta_m = E_m / E_s$

also, η_m can be improved by the mechanical transforming System's optimal design, for enhancing the efficiency of conversion at the part of the piezo-electric, a low Q factor, greater coupling factor and smaller internal damping are essential.

Block diagram



Calculations

The piezo-electric material's voltage at output is termed as;

V= Q/C

Where: C= εA/t

ε= permittivity constant

A= Area of piezoelectric material

t= thickness of piezoelectric material

Q= d33 * F

d33= Dielectric constant

F=force

Area

Radius of piezoelectric plate say = 20 mm

Area = 3.1415 * (.02)2

= 1.256 mm2

∴ C= εA/t

C= [10^-10 * 1.256 * 10^-3] / [2 * 10^-4] ∴ ε = 10^-10

= 0.628 * 10^-9

Q = d33 * F

= d33 * (mg)

Taking mass = 1 kg

Q = [6 * 10^-12] * [1 * 9.8]

∴ g = gravitational force = 9.8 m/s

= 58.8 * 10^-12

Now,

V= Q/C

Putting values of Q and C

V = [58.8 * 10^-12] / [0.628 * 10^-9]

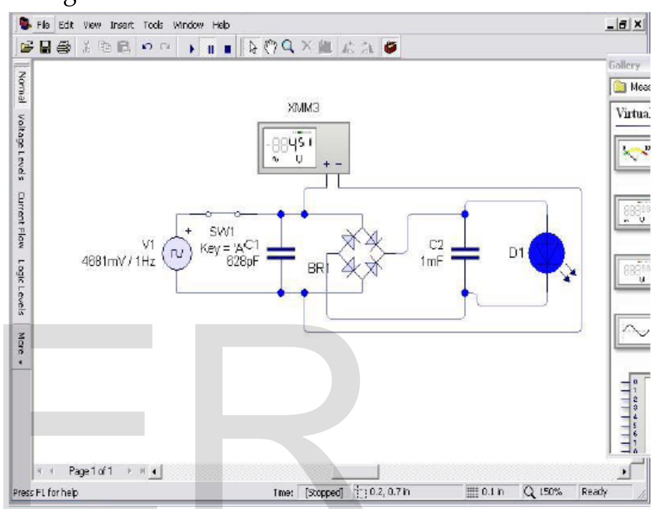
= 0.093 V

It means that when 1 kg mass (9.8N force) is applied on the piezoelectric plate used, 0.093 V is generated.

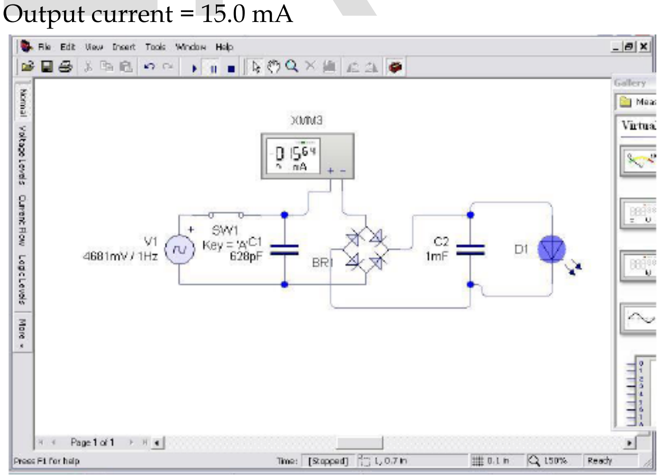
We checked the output voltage and current for different mass by using the software Livewire.

The blue LED showed in the diagram gave light when 50 kg mass was applied on the piezoelectric plate.

Voltage= 04.51



Output current = 15.0 mA



5 Conclusion

In future piezoelectricity might become a very useful source in reducing the energy crisis to a great extant. Some of the fields in which we can use the piezoelectricity are the street lights which are sourced by the pressure exerted by the moving vehicles on to the piezoelectric material installed for lighting. It can also be used to power the sign boards. The busy roads and airports can also be the specified areas for the installation for the piezoelectric material for harnessing the electrical energy for various uses.

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