Performance Analysis of Piezoelectric Materials in Energy Harvesting

Divya Giridiyal[1], Pratibha Singh[2]
[1]*Department of Physics, JSS Academy of Technical Education, NOIDA, U.P, India*
[2]*Department of Chemistry, JSS Academy of Technical Education, NOIDA, U.P, India*

***Abstract*-The present article analysis the current applications in almost every field like production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, to drive an ultrasonic nozzle, and ultrafine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, the scanning probe microscopies, such as STM, AFM, etc., and everyday uses, such as acting as the ignition source for cigarette lighters, and push-start propane barbecues, as well as the time reference source in quartz watches. This article also assesses the functionality of piezoelectricity in roads to utilise energy executed from the moving vehicles. The energy is converted into electrical energy using piezoelectric technology to replace fossil fuel in streetlight applications. The vitality of this technology arises as fossil fuels is being over consumed which makes it challenging to provide sufficient power in the next era as an effect of growing population. Being dependent on renewable energy to account for a greater global consumption level is essential to overcome the risks associated with fossil fuels. Piezoelectric road is a new energy evolution to provide a sustainable solution in terms of environment, economy, and social needs**

***Index Terms*- stress, polarization, ultrasonic, frequency**

INTRODUCTION

As the demand of fossil fuel is enormously increasing over time, the future of generating power using non-renewable energy will come to a halt. This overconsumption and risks associated is pressuring the environment and economy as well. In 2004, the global energy consumption level of non-renewable energy has risen to 80%, and will remain increasing in the next 20-30 years due to population growth as a main factor.

This level results in a drastic amount of CO emissions and greenhouse gasses being pumped into the air raising concerns on rising sea levels, increasing average temperature, and extreme weathering conditions. The increase of energy demand will cause a price increase on fossil fuel contributing to tax policies and thus higher electricity bills to end users. The major issue is that fossil fuels used to supply energy to feed recent generation are by one word, exhaustible [1]. On the other hand, if energy consumption continues growing, then meeting future energy demand is challenging. Phillips and Mighal [2]claims that energy extracted from fossil fuels are being consumed 100,000 times faster than they are being formed. He also discuss fossil fuel resources, targeting oil and gas, are expected to get depleted in the end of 21 century [2].

As stated in IISD Report the G7 countries, a group of finance ministers and central bank governors, agreed to phase out the usage of oil, gas and coal at the end of 2100 [3]. This form of agreement seeking for sustainable solutions made by leading countries offers a green light to great investments opportunities around the globe. Sustainability is simply a shortcut to a long term profit earnings and an incentive towards harnessing the “greenies” to expand and produce clean-energy products [4]. Piezoelecric Technology is new concept for sustainable energy production.

Piezoelectricity

Piezoelectricity is the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. [1]. Piezoelectricity was discovered in 1880 by French physicists Jacques and Pierre Curie.The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry.[5] The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied

mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field. The inverse piezoelectric effect is used in the production of ultrasonic sound waves. (Figure 1)

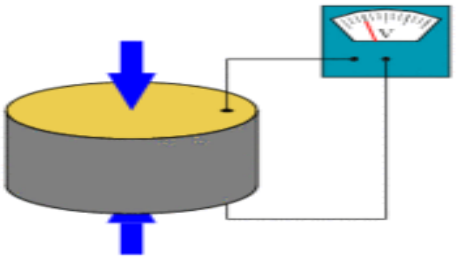

Figure 1: Piezoelectric disc

Of decisive importance for the piezoelectric effect is the change of polarization ***P*** when applying a mechanical stress. This might either be caused by a reconfiguration of the dipole-inducing surrounding or by re-orientation of molecular dipole moments under the influence of the external stress. Piezoelectricity may then manifest in a variation of the polarization strength, its direction or both, with the details depending on: the orientation of within the crystal; crystal symmetry; and the applied mechanical stress. The change in appears as a variation of surface charge density upon the crystal faces, i.e. as a variation of the electric field extending between the faces caused by a change in dipole density in the bulk. Piezoelectric materials also show the opposite effect, called the converse piezoelectric effect, where the application of an electrical field creates mechanical deformation in the crystal

Piezoelectric Materials:

In general piezoelectric materials can be broadly divided into following categories:

NATURALLY OCCURING CRYSTALS: Examples include Tendon Silk Wood due to piezoelectric texture. Enamel Dentin DNA Viral proteins, including those from bacteriophage. One study has found that thin films of M13 bacteriophage can be used to construct a piezoelectric generator sufficient to operate a liquid crystal display.

MAN MADE CRYSTALS: It include Galliluim Orthophosphate (GaPO4), Langasite (La3Ga5SiO14), Barium Titanate (BaTiO3), Lead Titanate(PbTiO3) . Although it occurs in nature as mineral macedonite, it is synthesized for research and applications.

Piezoelectric technology

Redirecting routes to integrate the principle of piezoelectric devices to urban roads is significant, at this stage. Focusing on the transition of energy to piezoelectric integrated roads, a renewable energy harvesting method, will lead the next power generation into a feasible and more reliable source of energy.

The term Energy Harvesting or Renewable Energy, such as solar panels or wind turbine, is a method of producing electrical energy by utilizing the energy surrounding the environment from the sun and wind, for example [5]. However, energy formed from various vibration machines, objects in motion, or any other source of mechanical energy is not being captured. Therefore, this source of energy is dispersed and thus wasted. As an effective method to utilize this loss, piezoelectric material is used to absorb the wasted mechanical energy and convert it to electrical energy [6].

Piezoelectric working principle

The principle of piezoelectricity lies behind the crystals. As shown in Figure 2, electrical voltage is induced when crystalline materials are subjected to external force, pressure, or strain. There are several types of natural crystals, found at the surface or deep within the earth, which can be used today to apply piezoelectricity effect such as clear quartz and amazonite. A variety of artificial crystals are formed by chemical compounds, as well. These include Barium Titanate, Lead Titanate, and Lead Zirconate Titanate, etc. [7].

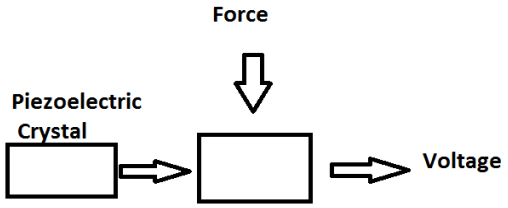

Figure 2: Principle of piezoelectric effect [7].

The efficiency of piezoelectric devices is influenced by the type of crystals due to the variety of their properties. However, Lead Zirconate Titanate (PZT) crystals are being used widely to achieve a high piezoelectric effect. The ease of fabrication to any complex shape, high material strength and long-life service, resistant to humidity and heat temperature

over 100°C, are all distinctive factors of PZT [8]. In addition to crystalline material suggested, Table 1 shows other parameters that play a major role to determine the best outcomes of piezoelectricity [6].

Geometry	The most efficient form to produce more energy is tapered shape
Thickness	More energy is produced with thinner material
Loading Mode	More energy is produced with increase in mass or force
Fixation	Fixation at one end will result in more deflection, thus more energy when subjected to external force, than when fixed at two ends
Structure	Bimorph structures produce double the energy output than unimorph structure

Table 1: Piezoelectricity parameters.

The basic diagram shown in **Figure 3**, illustrates piezoelectricity undergo certain process prior to energy output. AC voltage is generated as pressure or force is exerted on piezoelectric device. The generated voltage is then adjusted and converted into DC voltage and stored in batterieML or capacitors for electric application purposes [9].

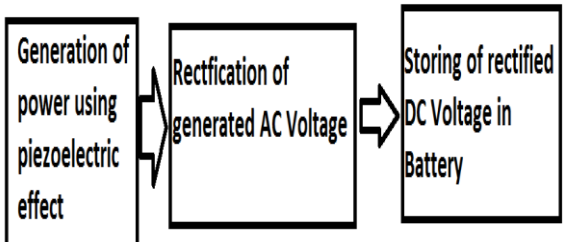

Figure 2: Block diagram.

RECENT APPLICATIONS

The application list of piezoelectric materials is endless they are there in every field be it medical, mechanical, energy, motors etc. In today's world growing concern is for the health hazards caused due to lead there is growing concern regarding the toxicity in lead-containing devices driven by the result of restriction of hazardous substances directive regulations. In order to solve this concern, there has been resurgence in the compositional development of lead-free piezoelectric materials. [2]

Simple home based products like the electric cigarette lighter is also an application of piezoelectricity. In a lighter on pressing the button causes a spring-loaded hammer to hit a piezoelectric crystal, producing a sufficiently high-voltage electric current that flows across a small spark gap, thus heating and igniting the gas. The portable sparkers used to ignite gas stoves work the same way, and many types of gas burners now have built-in piezo-based ignition systems. A piezoelectric potential can be created in any bulk or nanostructured semiconductor crystal having non central symmetry, such as the Group III–V and II–VI materials, due to polarization of ions under applied stress and strain. This property is common to both the zinc blende and wurtzite crystal structures. [3]

A piezoelectric transformer is a type of AC voltage multiplier. Unlike a conventional transformer, which uses magnetic coupling between input and output, the piezoelectric transformer uses acoustic coupling [5]. Piezoelectric sensors especially are used with high frequency sound in ultrasonic transducers for medical imaging and also industrial nondestructive testing (NDT). Atomic force microscopes and scanning tunneling microscopes employ converse piezoelectricity to keep the sensing needle close to the specimen. On many inkjet printers, piezoelectric crystals are used to drive the ejection of ink from the inkjet print head towards the paper. The traveling-wave motor used for auto-focus in reflex cameras, Inchworm motors for linear motion.

Piezoelectric Impedance-Based Health monitoring system [6], Piezoelectric Energy Harvesting Devices: An Alternative Energy Source for Wireless Sensors Many projects are using piezoelectric films to extract electrical energy from mechanical vibration in machines to power MEMS devices [7]. This work extracted a very small amount of power ,Piezoelectric materials have also been studied to generate electricity from pressure variations in micro hydraulic systems Other work has used piezoelectric materials to convert kinetic energy into a spark to detonate an explosive projectile on impact[8] . Still other work has proposed using flexible piezoelectric polymers [9] for energy conversion in wind- mills and to convert flowing oceans and rivers into electric power .A recent medical application has pro- posed the use of piezoelectric materials to generate electricity to promote bone growth .

As the results shows that by using double actuators in parallel we can reduce the charging time of the

battery and increase the power generated by the piezoelectric device [10].

Street lightening using piezoelectric roads

Piezoelectric crystals can be embedded underneath the asphalt layer to utilize the energy generated due to the vehicle motion, as illustrated in Figures 4 and 5. As the vehicles move over the asphalt layer, the wheels exert a force or pressure into the crystals and thus deform. This deformation will absorb the force and undergo the process of power generation, as shown above, to be stored in batteries [10]. The use of storage is essential at this stage, since street lights are operated for 12 h per day. Therefore, the energy can be dispersed when required.

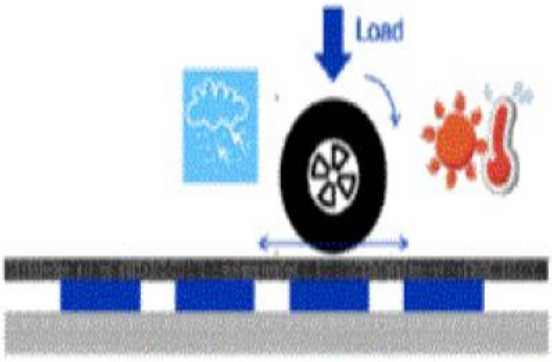

Figure 4: Piezoelectric road cross-section.

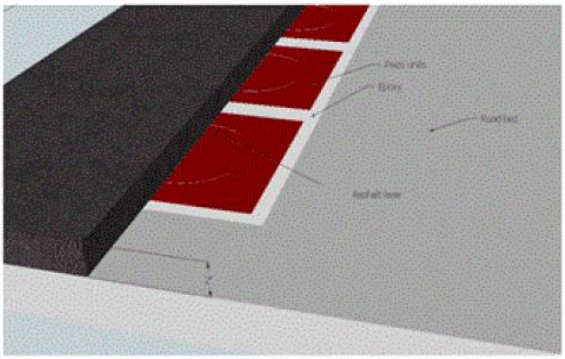

Figure 5: Cross-sectional diagram of the roadway [12].

Energy Generated: Power asphalts used to provide electrical power to street lights was tested in Hefer intersection, Israel. The set up involved piezoelectric devices lay beneath asphalt roads, at a total distance of 10 m only. The setup has generated electrical power of two Kilowatt-Hours (KWh) [11]. Another test has been conducted by POWER leap, a licensed technology manufacturer, has provided a data proving the reliability of power asphalts. The experiment involves 1 Km stretch power asphalt with vehicle passing rate of 200-400 in 16 h. Based on this experiment, the total electrical energy generated range between 400 KWh - 600 KWh [12]. The revealed as a main source of energy as it saves cost and reduces fossil fuel consumptions.

Other factors affecting piezoelectric road efficiency

Vehicle speed: Gupta et al. [15, 16] state that vehicles moving slowly appear to generate slightly more energy than faster-moving vehicle. In contrary to DNV Kema, energy efficiency always increases with more speed. Different types of vehicles such as bus, car, and motorcycle were tested at a speed of 45 mph and 65 mph. Power output is always greater with higher speed [12]. Higher speed has a higher impact on frequency resulting in a higher decay.

Vehicle weight: Simply put, the higher the force exerted the more deformation of crystals and thus higher energy produced. The same principle applies for vehicles; a truck will generate more energy than light duty vehicles and motorcycles [12].

Traffic flow capacity: Upon implementing such technology, this parameter would be first considered. The overall technology performance will certainly provide less energy if power asphalts are designed in areas were less frequent vehicles cross over. It is suggested to apply power asphalts on busy roads were a reasonable number of vehicle capacity flow. Planning the location of power asphalt is an essential decision to meet energy needs [10].

Application

However with the analysis observed, results are not taken for granted to comply with the original hypothesis. Respondents engaged in this study employed an error variable which might fail the hypothesis. Having 34% of the respondents unaware of piezoelectricity to support research hypothesis develop misleading information. In addition to 48% respondents which generates a higher deviation away from the proven hypothesis. The data is granted for only 3% to have power asphalts in terms of street lights application.

Chi-test Statistical Approach: To further ensure bias answers provided by the respondents, a chi-test is used to have a precise measure of the percentage error by respondents. This analysis determines the significance of respondents answered by chance based on their piezoelectric awareness and power asphalt principle variable. For a valid data, the

significance level must fall under 0.005% or 5% probability for this research. However, the chi-test table provided according to table count shows insignificant results and thus fails to support the proven hypothesis of power asphalt reliability. In other words, the likelihood to have answered the power asphalt reliability is 56% by chance, as shown in two sided Pearson chi-square. This percentage deviates critically from the significant level of 0.05 which concludes unreliable results given by respondents and thus failure to support hypothesis.

Limitations

- Piezoelectric road integrated technology is a new energy evolution and hence piezoelectric awareness and expertise in this sector are very limited. This was also observed in primary data collected using questionnaires and interview to have obtain invalid and bias information.
- The power metrics provided by vendors does not provide additional technical details. The vendors were compared using vibration-based factor only. Other technical factors were not analyzed in terms of piezoelectric geometry, structure, and thickness that are mentioned in Table 1. This is common having not to reveal a full technical report of this technology to preserve innovation, invention rights and securities effective business strategies.
- Implementing piezoelectric road technology on field requires a standard specification in the execution process which has not been established. This is important as to use appropriate management and method to prevent manipulating with road infrastructure and minimize traffic congestion.

CONCLUSION

This article can help in discovering many more crystals showing not only piezoelectric effect but also its reverse one. Special mention of this effect and its application lies largely in these which will help out in power generation which is a very important research aspect in today's world. Also the fact that when electric current is applied to these materials, they actually change shape slightly has many factors yet left to be explored which can be very useful in todays tech savvy world. The study clearly shows that piezoelectric materials are the future of not only electric field but also in basic applications and gadgets. Having met the power metrics will make such invention a starting point to self-sustaining environment by being dependent on vehicle elements to curb down input energy and cost. This will be a revolution in the production of energy by meeting innovations and technologies to shape future energy. However, further concentration is required to quantify and result in a greater power outcome to become a reliable source of electricity.

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