

Conceptualizing Implementation of Piezoelectric Materials in Transportation to Harvest Energy

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Abstract - In order to tackle the increasing global energy consumption and consumers, we need to develop and implement efficient, clean and renewable power sources. This paper's objective is to introduce an alternative source of energy by using piezoelectric materials. It proposes mainly three ways in which it intends to fulfill its objective:

(1) A road designed with embedded piezoelectric materials underneath which will generate electricity from the stress applied on the road by the movement of automobiles over it.

(2) A railway track designed with the addition of piezoelectric material under the tracks which will generate electricity from the stress applied on the tracks due to an above running locomotive.

(3) Floors at Public places where the number of people walking is appreciably high; the floors can be replaced with piezoelectric tiles from which we can harness energy as people step on them and exert pressure on the tiles while they walk. This can be applied to airports, malls and supermarkets, sidewalks, public squares, and public parks.

Key Words: piezoelectric effect, transportation, energy harvesting, crystal, piezo generator,

1. INTRODUCTION

1.1 The need for alternate sources of energy

The importance of finding alternate sources of energy will be comparable to better use of existing energy sources for the coming years. Development of new technologies becomes essential as the world's demand for energy keeps growing with an ever-growing population. Conventional technologies of harvesting energy may have high efficiencies in meeting the demand, but have a significant impact on the environment and resources.[9]

- I. Fossil fuels like coal, oil, petroleum, natural gas and liquefied petroleum gas (LPG) are not sustainable. In fact, they are depleting in nature.
- II. Carbon dioxide (green house gas) emission is involved in the use of carbon-rich fossil fuels. High levels of this carbon dioxide lead to global warming, which cause adverse effects to the environment of

our planet, like the rise in atmospheric temperature, melting of glacial and polar ice, change in ocean currents, acidification of rain and ocean water and so on - all of which are harmful to the overall ecosystem.

Thus, the need of the present age in the field of energy harvesting is to develop alternative sources of energy that are renewable and do not involve environmentally damaging techniques in the process of their retrieval. One such method that we can consider in this field is by scavenging low-grade ambient energy sources, such as environmental vibrations and human power into usable electrical energy. Such devices are thus much more likely to replace power sources in equipments that function on electronic energy. In order to achieve that, the use of piezoelectric materials as a medium for harvesting consumable energy is proposed.

1.2 A brief history of the initial discovery and uses of piezoelectricity

The word Piezoelectricity comes from Greek and means "electricity by pressure" (Piezo means pressure in Greek). Hankel in 1881 named the phenomenon that the Curie brothers- Pierre Curie and Jacques Curie discovered a year before. These crystals when acted upon by mechanical stress resulted in generation of electrical voltages which were in turn proportional to the stress of the applied force. The converse effect, however, was deduced later in the same year Hankel coined the term 'Piezoelectricity'. In World War I these crystals were used to manufacture ultrasonic transducers to be used in SONAR in submarines and later also found application in ceramic phonographs. Nowadays, piezoelectricity is used in everyday life. For example in gas lighters and so on.

2. THE PIEZOELECTRIC EFFECT

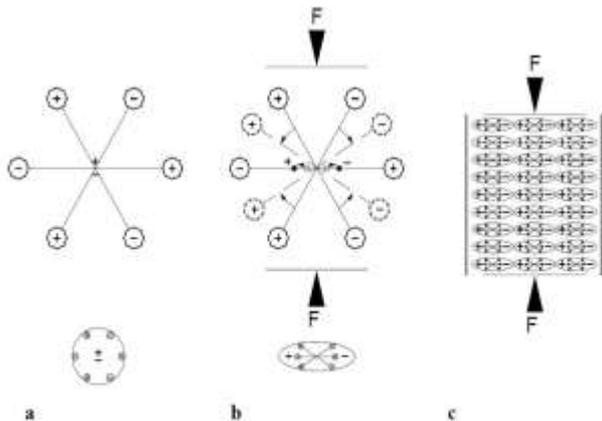
2.1 Description of the Piezoelectric Effect.

Electric polarization occurring across certain materials when a mechanical stress acts upon it is called Piezoelectric effect. The measurable potential difference occurring across the material is proportional to the stress of the acting force. Many naturally occurring crystals like quartz, Rochelle salt, even human bone exhibit direct piezoelectric effect. There are materials available that have specifically been made showing

pronounced piezoelectric effects, for ex: Lithium niobate and Lead zirconate titanate(PZT).

2.2 Cause of the piezoelectric effect

The piezoelectric effect is caused by the application of force on a piezoelectric material which results in the accumulation of opposite charges on its surfaces. Let us consider a piezoelectric crystal having a molecular model as shown in the following figures.



Simple molecular model for explaining the piezoelectric effect: a unperturbed molecule; b molecule subjected to an external force, and c polarizing effect on the material surfaces

Fig-2.2.1: Molecular model at different stages of pressure exertion. [1]

- **Figure a** shows the initial condition of the Piezoelectric crystal when the gravity centers of the positive and negative charges are at the same point within the crystal thus the effects of the positive and negative charges being reciprocal to each other are cancelled.
- **Figure b** shows that small dipoles are formed due to the separation of the positive and negative charge gravity centers getting separated when the structure of the crystal is deformed by an external pressure.
- **Figure c** shows when the crystal is considered as a whole, charges appear at the surface of the crystal and the linear dipoles inwards within the crystal mutually cancel out each other.

An electric field is generated as a result of the polarisation. This electric field is the means of obtaining the electrical energy from the mechanical energy. In a monocrystal the dipoles are aligned in a particular direction. In case of a polycrystal the crystal is divided into several regions and each region have a particular direction in which the dipoles formed in that region due to mechanical stresses, are aligned. A monocrystal is symmetrical, and a polycrystal is asymmetrical. Fractured pieces of a same polycrystal will not have the same resultant polar axis. In order to harvest the

piezoelectric effect, the polycrystal is heated up using a strong electric field. Molecules get heated up due to the electric field which then forces the dipole to align almost in the same direction.

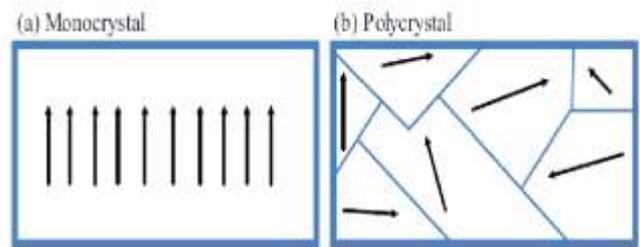


Fig-2.2.2: Structure of Piezo crystals.

To explore this further, when force is applied to the piezoelectric material or it is compressed or stretched, this produces a voltage. The voltages developed by compression and elongation have opposite polarity. Conversely, if we apply a voltage across the piezoelectric material, with the same polarity, we will see deformation in the material. However, if we reverse the polarity of voltage, the material will compress.[3]

2.3. Working and Circuit Diagram

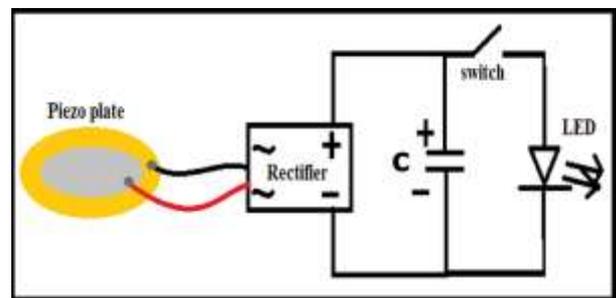


Fig-2.3.1: Circuit Diagram.

This is the general working circuit of a single piezo plate generator. We pass the alternating current through a full wave bridge rectifier to convert it into a Direct current. Then we store this energy by means of a capacitor, which can be later discharged by a load, thus providing electricity to the load applied.

We can also combine the piezo plate generators in series or parallel in accordance with our requirements.[7]

3. IMPLEMENTATION IN TRASPORATION.

3.1. Roadways

The energy consumed by the vehicle is utilized for a variety of applications; one of them is to overcome rolling resistance. When a vehicle run over an asphalt surface, vertical deflection at the surface of the road occurs and as a result thermal energy is released. We can convert a part of

the energy that goes into deforming the road surface by placing piezoelectric generators beneath the asphalt surface, thus reducing the magnitude of energy wasted in the form of thermal energy.

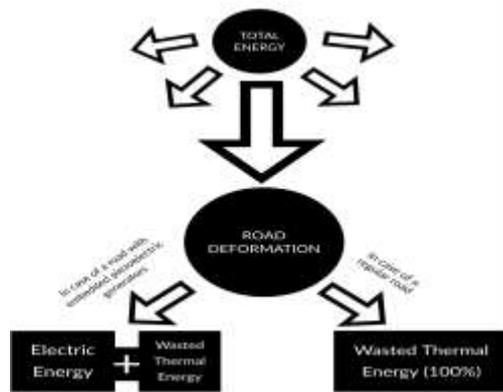


Fig-3.1.1: Flowchart depicting the energy traversal.

A large part of the energy from the combustion of fuel in the car's engine is lost and dissipated into unusable forms of energy, apart from the energy required in moving the car or running its accessories like an air conditioner. The energy spent on moving the vehicle along the road is mainly used to overcome the rolling resistance encountered by its wheels on the road while moving forward (in the horizontal direction). Other than that, a part of it is used in creating a deformation in the asphalt which happens basically due to the force imparted by the wheel on the surface. A typical asphalt road being a visco-elastoplastic material relates to the fact that its elasticity dominates over other material properties. Vertical deflection on the asphalt surface occurs and its magnitude is proportional to the weight of the vehicle and the stiffness constant of the asphalt that suffers the deflection. It is the energy associated with this mechanical deformation of the asphalt that can be intended to be harvested into electrical energy.[10][2]

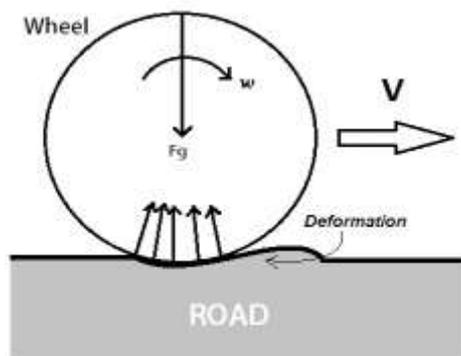


Fig-3.1.2: Figure depicting the deformation on the road asphalt due to the wheel's impact.

The external load deforms both the asphalt layer and the generators lying underneath the asphalt surface which

similar to the deformation suffered by a piezoelectric column under the application of an axial load. This arrangement works as a source of electrical energy.

This is the key concept of the piezoelectric roads. Generally, all the energy used up in the deformation of the piezoelectric crystal is transferred into electricity via the piezoelectric generator. This harvested energy can be used in powering street lights, stop lights, road sensors or even stored in batteries for later use.[5]

Estimations can be made and we can use the estimated value of output power to determine the type of device which can operate at that power level, and what can be modifications in the modeling of the transducer that can increase the total output power of the system.[8]

It has been found that when a vehicle moves for every second, in a road span of 1Km embedded with these piezoelectric crystals, then a power of 240.12KW could be produced. A typical mercury vapor lamp requires around 500W. Hence the energy derived from the piezoelectric crystals will be adequate enough for lighting these lamps on the roadside.[4]

3.2. Railways

When a train and its carriages run over a railway track, it exerts pressure on the track vertically downwards. This stress created on the railway tracks deforms the tracks and also the beams underneath the track at the point of contact. The elastic potential energy stored in the railway tracks due to the deformation is released as thermal energy and is dissipated into the atmosphere. A part of the energy lost as thermal energy is converted to electrical energy and utilized using piezo generators (by piezoelectric effect). This energy generated can be used to operate and automate the railway crossing gates and the signals. When a train approaches the railway crossing, running over the tracks which exert pressure on the piezo generators connected to the crossing gates, the gates are activated. The Piezoelectric Generator can be placed between the railway tracks and the beams at the point of contact.[11]

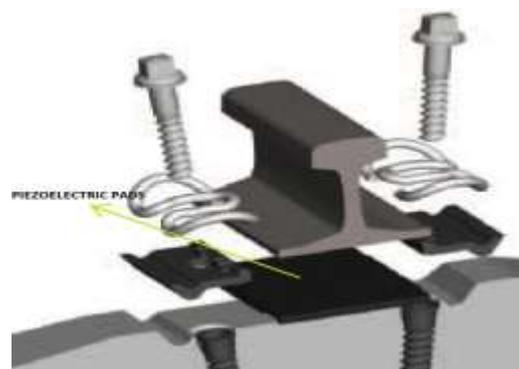


Fig-3.2.1 Implementation of Piezoelectric pads in Railway Tracks.

3.3. Implementation in floor tiles of public places

3.3.1. Supermarkets, shopping complexes and parks

Piezoelectric generators can be simply placed underneath floor tiles, which can help in harvesting energy when anyone steps on it. A fraction of the energy wasted in every footfall can be converted to electrical energy and then utilized to reduce the cost of energy consumption. This can be very much effective in public places like supermarkets, shopping complexes, and parks. The money saved on energy consumption can then be invested in maintenance thus elevating the standard and appeal of the place concerned.

3.3.2. Sidewalks, pavements, and subways

Piezoelectric generators placed under the floor tiles can be used to light up sidewalks, pavements, and subways. Moreover, it makes the lighting much more efficient. The sidewalks, pavements, subways will be lit immediately when someone walks onto or into the sidewalks and subways respectively and will conserve energy by being off when not in use. The excess energy produced during the rush hour period can be stored in a battery and can be later used to supplement the energy requirements when the sidewalks, pavements, and subways are sparsely occupied in comparison to other times of the day.[6][12]

3.4. Advantages and disadvantages of this approach

3.4.1. Advantages

1. Due to the constant movement of traffic on roadways, railways, pavements, and sidewalks, a constant source of power is generated.
2. The power generated is completely environment-friendly and green in nature and doesn't harm the ecology in its retrieval.
3. This power can be very well utilized for street lighting and other small-scale purposes.
4. This source of electrical energy will be unaffected by climate changes and has the capability to be a long-term consistent independent source.

3.4.2. Disadvantages

1. Implementing this concept is a little bit tedious in the real world.
2. Efficient planning and procedure for implementation have to be taken or it might lead to traffic congestions all over the city.
3. The present-day roads need to be constructed all over again in order to implement this concept.

4. CONCLUSIONS

At an age when the current condition of the existing environment demands eco-friendly methods of harvesting energy that do not involve environmentally damaging techniques of retrieval and consumption, harvesting the mechanical energy that is otherwise wasted and dissipated into heat during transportation on roads, highways, railways and even pavements, sidewalks and subways, into usable electrical energy by the said concept, can prove to be an effective mode of retrieving energy.

This method doesn't involve any exclusive input requirements, as it is just harvested by the consumers themselves without any participation. Even though this concept has got some limiting issues when it comes to practically implementing them in structures in the real world, with further study and research over the years they could be overcome and the long-term benefits surely are worth enough for enduring the shortcomings temporarily. Thus, this concept of the overall method manifests a promising solution to the existing energy crisis.

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