Analysis of Piezoelectric Transducer as an Energy Generator Over Speed Breakers

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Abstract- *This paper is a study of piezoelectricity and its application and also the possibility of producing electricity and storing energy generated using piezoelectric materials. The purpose is to highlight one of the non conventional method and technology, which can be easily established for producing energy through natural movements and pressures inhibited on earth and by their people. Piezoelectric crystalline transducers have the ability to convert kinetic energies of vehicles on roadways into electrical energies abound with a proper mechanism. Moving vehicles emit a large amount of energy which is kinetically generated and is put into use for initiation of strain for the transducers; this gives a unique solution for accessing clean energy. This solution does not need huge expenses for execution so is commercially viable, feasible, scalable and safe. The law of conservation of energy is met and a renewable form of electricity is produced on-site. Going with this trend and making an effort for electricity generation in today's world will prove to be helpful in the coming future.*

Keywords- Piezoelectricity; Kinetic energy; Pressure Transducers; Speed breakers; Roadway traffic; On-grid electricity

I. INTRODUCTION

The gross electrical consumption has been increased to 1,208 KWh every year and so the need for pressure to produce this energy is also high. A sustainable and feasible way of generating energy, is using a piezoelectric energy harvesting technology established over the speed breakers on roadways, using piezoelectric materials based on pressure differences. With the increase in traffic and road ways in India, the best way to extract energy is from the number of speed bumps by using a cantilever operation based on the piezoelectric principle. This system uses the energy that is derived as kinetic energy from the vehicles due to strain produced while over the asphalt road surface. This idea is as efficient as other existing modes of producing renewable energy and less harmful than the hazardous methods which makes it environment friendly. This approach can be executed on plains too. So, it can be established widely over the country and worldwide too, without any high investments.

II. THEORETICAL SURVEY

A. Piezoelectricity

Piezo-crystal is one of the small-scale energy sources. When these crystals automatically warp, producing a voltage, this is known as piezoelectricity. This is a form of polarized electrical energy and may not be suitable for use in industrial applications, but is well suited for low commercial and primary purposes.

When a force is applied to a piezoelectric material, there is an electrical charge on the glass walls. This can be calculated as a voltage proportional to the stress applied. A static force will result in the same load on the sensor. See image below which shows various layers of the transducer. See image below which shows various layers of the transducer:

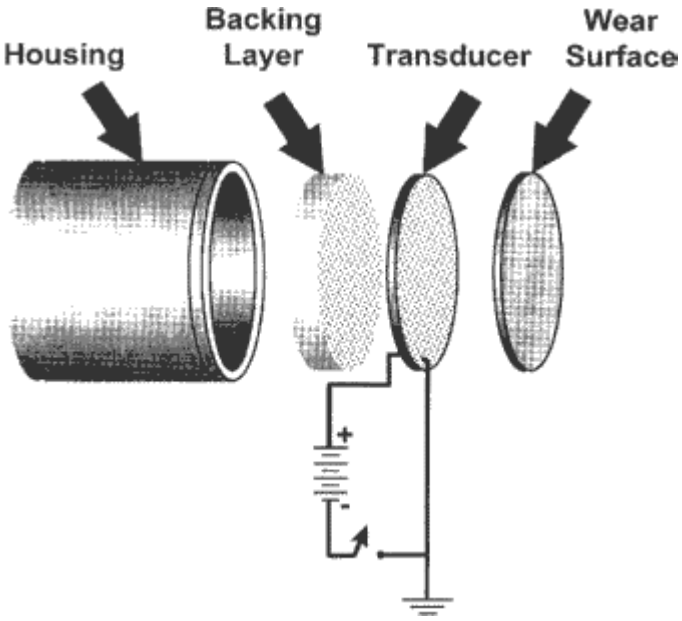

Figure.1. Internal Image of Piezo Crystal

The piezocrystal undergoes polarization and results in transfer of ions and atoms when a pressure is exerted.

They can be found in a wide variety of applications, electronic, and gas sensors for outlook. As piezo-electrics were first discovered in the late 1800s, scientists, and engineers had been constantly in the process of developing a new application in order to help promote the technology. Piezo technology is being used in the market of modern technology, such as medical devices, mechanical engineering, and automotive industries, or the state of technology, but it is also a feature of everyday life.

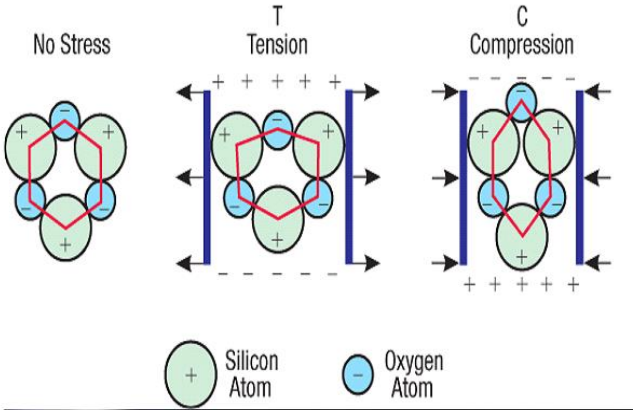

Figure.2. Piezoelectric Effect on Quartz

Sample specifications of a piezoelectric transducer can be as follows:

Resonance Frequency: 4.6 Khz +/- 0.5 Khz
Resonance Impedance: 200 Ohms
Capacitance: 20nF +/- 30% at 1 Khz
Operating Temperature -20 C +70 C
Storage Temperature -30 C+80 C
Metal Material Brass

B. Energy Demand in India

In a global pandemic, it is predicted that India's energy demand will increase by nearly 50% between 2019 and 2030, but now, with the growth rate during this period was the use in steps of 35% and 25% in the case of a Delayed Recovery.

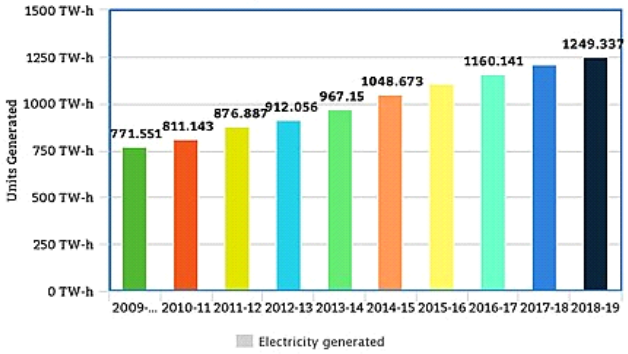

Figure.3. Electricity Generation Year wise

During the fiscal year (FY) 2019-20, the gross cost of electricity generated by utilities in India was 1,383. The gross energy consumption in 2012, is a 1,208 kilowatt-hours per capita In the Energy Forecast for India for the 2021, in MAY, saw the consumption of primary energy will nearly double, to 1,123 million tons of oil equivalent, such as a country's Gross domestic product (GDP) has increased to 8.6 trillion by the year 2040.

This approximation shows the extent of consumption of energy and need for it in upcoming years. If a method of piezoelectricity, which when standardized widely, can support in energy production and expansion.

C. Traffic Count Example

India's increasing population has resulted in an increase in traffic congestion. Most of the days the roadways are filled with vehicles and the frequency of moving heavy and light motor vehicles is maximum. The Average Annual Daily Traffic(AADT) lets us estimate an approximate traffic count every year or per day.

Most of the states in the country have a comprehensive network of roads ranging from 19,000 kilometers to 32,000 kilometers. For example, the average traffic density of Chennai is 2089 vehicles per kilometer and that of a higher populated area like Mumbai or Pune is about 1121 vehicles per kilometer. So, it is evident that all such long stretches of roads are equipped with a number of speed breakers and the busy roads require a 24 hour electrical lighting system too. About 84,652 series of lights on streets use 70-watt Sodium vapor lamps, 48,340 use 40-watt tube light, 42,250 use 250-watt Sodium vapor lamps. Therefore, the total energy consumption in a city like Chennai, would account about 20MW.

Hence, establishing a mechanism by which energy can be extracted from the busy city roadways is one possibility and matter of importance that can be looked into.

D. Average weight of vehicles necessary for stress

Stress can be considered as a physical quantity that expresses the internal forces that neighboring particles of the same material exert on each other, and the distortion is a measure of the deformation of the material. It is a strain that a vehicle is capable of exerting on the road or speed breaker because of its kinetic energy.

Vehicle Class	Curb Weight in Kilograms
Compact car	1,324 kilograms
Midsize car	1,524 kilograms
Large car	1,760 kilograms
Compact truck or SUV	1,628 kilograms

III. MATERIALS AND PRINCIPLES

Basically we know that, piezoelectric means electricity caused due to pressure. Considering a car moving at the speed of 60kmph over a highway, when it's wheels strike a speed bump on the road, the reducing velocity along with the extreme weight of about 1,600 kilograms of the vehicle, exerts a great stress/strain on the bump causing a vibration.

This vibration if imparted on piezoelectric plates that are bound beneath, in the form of a truss or spring or a cantilever like structure, creates a bounce mechanism. At the same time transferring the vibrations or the push wielded on the transducer plates making the ions of the piezocrystal material to boost up electricity to charge up batteries.

A. Working methodology

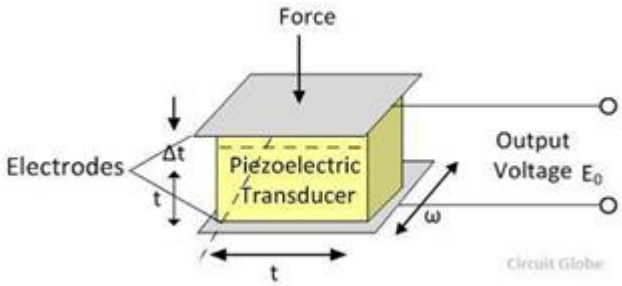

Figure.4. Schematic of a Piezoelectric Plate

where,
t = thickness of the plate
Δt = Change in thickness of plate between the two parallel electrodes
ώ = Width difference
Eo = Output voltage EMF

So every time a vehicle crosses a speed bump, it makes two great strained pressures, in simple words a double strike of power generation.

B. Technological Principle

As we know the law of conservation of energy which states that energy is neither created nor destroyed but transferred from one form to another, similarly as above stated the kinetic energy of the moving vehicles on the streets due to vibration and strain, is converted to electrical energy.

With the use of piezoelectric transducers the applied mechanical stress into an alternating electrical force which can be rectified to induce power.

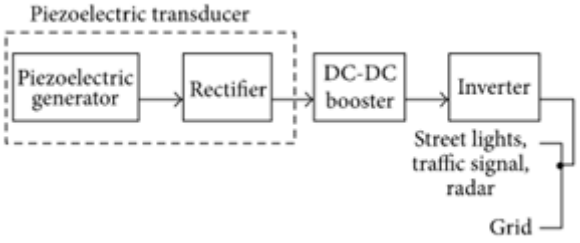

Figure.5. Block Diagram of Transducer

In addition to the piezoelectric crystal generator, the construction requires a set of rectifiers and boosters which is used to amplify the power produced.

1) Rectifier

A rectifier is a device that converts alternating bi-directional alternating current (AC) in form of direct current (DC). Rectifiers may be a variety of physical forms of a vacuum diode and crystal radios, as well as modern silicon-based designs.

Figure.6. Bridge Rectifier Module

2) Amplifier

It is an electronic system that uses electric power from a power source to an increase in the amplitude of a signal applied to its input terminals, producing a proportionally greater amplitude signal at its output.

Figure.7. Power Amplifier

3) DC- DC Converter

A DC to DC converter is an electronic or electromechanical device that converts direct current (DC) voltage from one voltage level to another. It enables conversion for electric power. Power levels available, ranging from very low (small batteries) to very high power transmission.

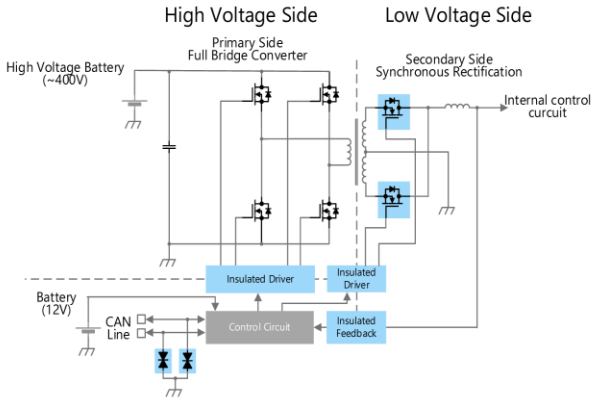

Figure.8. DC-DC Booster with Inverter Circuit

4) Grid Distribution

The power grid takes its position in the places where electricity is made. The non conventional sources of energy like solar or the mentioned piezo electric method are better options and cheaper, but just a few grid infrastructure essential for centralized distribution.

After the generation of electricity needs to be transmitted and distributed to consumers. There has to be a system for power transmission networks and distribution of resources to the power grid.

Typically, the electrical power is transmitted at very high voltages on the power lines, which dot the landscape. The higher the voltage, the less current is needed for the same amount of energy, thereby reducing energy loss. (The resistor and the current in the lines, it produces heat, which causes some to lose). When the current reaches the consumer, transformers convert the high-voltage electricity to lower the distribution of homes and businesses.

C. Vehicle Kinetics

Kinetic energy is the external energy that an object inhibits or of a molecule, due to its motion. If the energy transfer is the work done on an object by the application of force, then the object or vehicle in this case speeds up, and so it gains kinetic energy.

The friction that a vehicle exerts on the road is like an opposite reaction caused due to the weight of the vehicle and tires grip velocity. The constant friction and increased kinetic energies resulting on speed breakers along with the pressure acting on it, is what the entire action depends on.

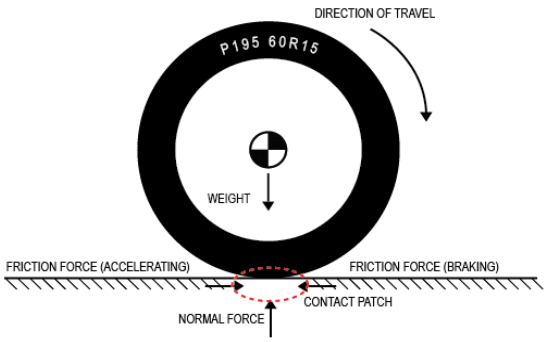

Figure.9. Frictional Force as a Fraction of Weight

IV. SCHEMATIC CONCEPT

Given below is the image description of a model speed breaker and its basic mechanism using springs and piezoelectric plates placed parallel to be hit when the wheel rolls over.

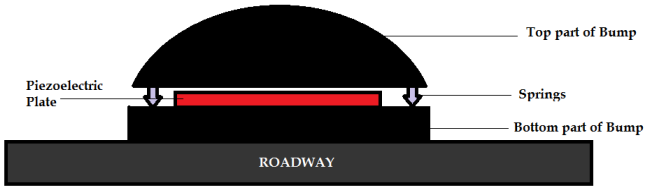

Figure.10. Side View of Speed Bump

Below side view of the speed bump with the visible assemblage of piezoelectric plates generating electricity and

amplified to be stored when stroked by the vehicles' kinetic force.

The rectifier extracts and cancels the noise and ripple current. The inverter part will act as a power oscillator which will oscillate the direct current to alternating current supply. This can be connected to a load like the street lights or can be stored into batteries.

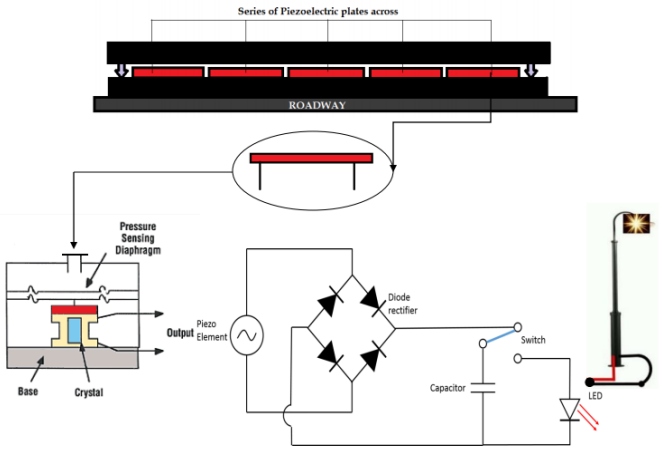

Figure.11. Working Schematic

V. POWER ANALYSIS

Based on parameters like the variation of frequency and speed of the vehicle, the following calculation is performed to analyze the amount of kinetic energy that is transformed into electrical. However, keeping in mind of losses and, as it is known that the entire kinetic of a vehicle cannot be converted to electricity but this method of using piezoelectric crystals has been able to yield maximum power comparatively, and necessary rectifiers, amplifiers, inverters are used.

A. Power Losses

The energy generated passes through a series of transformations, and it takes on many different forms as it moves. With each and every conversion it obeys, there is going to be some kind of a "loss" of energy. Even though this energy is not actually disappearing, but a certain amount of primary energy is converted into forms that we will be able to use it, or don't want to use it.

In addition, every time the power is fed by a high voltage power line, the energy of the high-voltage line is always greater than the energy that is being displayed on the other side of it. The energy loss is what processes can ever be 100% efficient. The types of energy losses that take place can be a heat loss, loss in form of light and wave motion or sound energy losses.

In case of a car, a part of its kinetic energy is lost to the sound of its engine, light from combustion, and to heat from the friction flanked by the road and the tires. For this reason, vehicles are only able to utilize around 30% of the energy content of the fuel as power, the rest is lost.

B. Power Approximation

The below calculation can be performed to calculate impact of an vehicle and considerably the amount of power produced can be predicted.

$$\frac{Mass\ of\ vehicle * Coefficient\ of\ Rolling\ Friction * Contact\ Tires}{Area\ of\ Contact * Speed\ of\ Travel}$$

By replacing with parameters, it was found that one piezoelectric plate can produce an approximate of 0.091W from a four wheeler when it is travelling at the speed of 80Kmph. So a length of speed breaker would be embedded with few numbers of plates, which can produce an approximate power of 0.89W.

So it will be evident with hundreds of vehicles travelling in roadways every hour, at different speeds and time intervals, a much higher wattage of power can be generated.

VI. CONCLUSION

Renewable energy offer reliable power supplies and fuel diversity, which enhance energy security and lower risk of fuel hazards while reducing the need for imported fuels.
The electro-generation offers of the local authorities, take the most direct access to renewable energy sources. In addition to the general benefits of on-site projects that offer some protection against financial risks, and improve the power quality and the reliability of the power supply.

Also, energy requires large area. As cost of the space and lands are growing with years, there is a huge requirement to use the available on-site areas as efficiently as possible. Here, we surveyed the potential of energy generation using the land above national road highways by constructing necessary mechanism and structure.

Using the wide advantage of an increased population and roadway transportation network, a good deed of enriching our energy sources and everyday power requirements can be achieved. It helps to conserve the world's natural resources and benefit the environment by being economical.

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