Electrical Energy Harvester from Piezoelectric Tiles on Asphalt Roads and Pavements

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Abstract: **The paper aims to design a piezoelectric harvester which is capable of harvesting electrical energy in response to the applied mechanical stress. In this contemporary world, the piezoelectric energy is one of the primary form of energy source and it is also one of the renewable energy source which can be harvested easily by means of converting mechanical stress into electrical energy. In this paper, a model of piezoelectric tile which consists of piezoelectric transducers and this can be implanted under the pavements and underneath the asphalt roads to convert those mechanical stresses created by footsteps and moving of vehicle tyres into electrical energy is proposed. By embedding those piezoelectric tiles on the asphalts and pavements, it changes over those mechanical vibrations made by the moving vehicle into the valuable type of the energy and furthermore the point of manageable advancement is accomplished.**

Keywords: **Energy Harvester, Mechanical Stress, Piezoelectric Tile, Battery Storage.**

I. INTRODUCTION

There has been a critical expansion in interest in the reception of Renewable energy collecting strategy for underlying energy reaping frameworks all together to limit the expense of customary frameworks. [1, 2, 3]There are three basic, methods that can convert the wasted mechanical energy into electrical energy: piezoelectric, electromagnetic, and electrostatic transductions. Because of the ease of application and high power densities of piezoelectric materials, piezoelectric transduction has received the most attention. [4, 5] Piezoelectric transducer (PZT) will generate electric field under the application of stress, it is called piezoelectric effects; in the reverse, PZT will generate strain under the application of an electric field. This effect also exist in reverse such that Converse effect. It is a phenomenon in which mechanical stress is produced to piezoelectric materials by an applied electric field. [6] Piezoelectric materials have been widely used for harvesting energy from various ambient energy sources, such as vibrations of structures or motion of biological organs, elastic energy dissipated by absorbers. Quartz, Berlinite, and tourmaline are natural piezoelectric crystals that convert mechanical force into electrical energy. Gallium orthophospate, potassium nibium trioxide, and sodium tantalum oxide are the other manufactured crystals.. The most commonly used piezoelectric crystals are Quartz (SiO2) and the Zincoxide. [7]The piezoelectric ceramics were Pb (lead), Zr (zirconium), and Ti (titanium), which together form Piezoelectric tile, which has efficiency than Quartz.

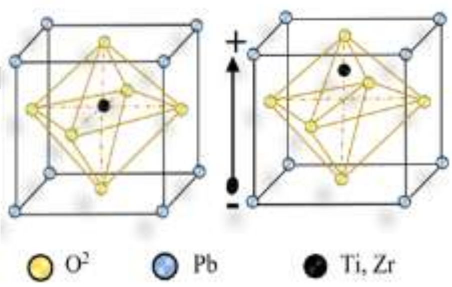


Figure 1 Crystal's Structure above and below curie point

As a result of their great piezoelectric capacities, minimal expense, and simplicity of assembling as energy collecting gadgets, piezoelectric fired materials are widely used as piezoelectric components in energy gathering frameworks. PZT is perhaps the main piezoelectric artistic due to its striking piezoelectric attributes and high curie temperature. Moreover, contingent upon the mechanical energy source's qualities, piezoelectric pottery can be changed in different mixes. [8] Multilayered stacks of piezoelectric ceramic materials can be utilised for energy conversion to harvest energy from mechanical vibrations. [9] Energy harvesting refers to the collection of various energy sources from the environment and transforming it into electric energy directly for use so as to reach the target of energy recycling and reuse. [10] Energy harvesting is one of the most supportive technologies in response to the global energy problems without depleted natural resources. Energy harvesting is a technical tipping point when the power requirements for electronic devices are decreasing while the efficiency of energy harvesting devices is increasing. Piezoelectric vibration energy harvesting has emerged as the method of choice for powering meso-to-micro scale devices, out of a variety of viable energy harvesting technologies. Energy harvesting can be accomplished using piezoelectric materials and transducers that can take a wide variety of input frequencies and forces.

II. MATERIALS AND METHODOLOGY

Piezoelectric ceramics generates electricity through mechanical stress. [11] This technique produces electricity with the assistance of electricity components that create use of the energy of human footsteps. The imposed stress is turned into electrical energy by piezoelectric transducers when a person walking in shoes walks on the floor. The output of the piezoelectric disc in the tile is directly proportional to the mechanical vibration, which means that the greater pressure (weight) or force applied to the disc at one moment, the higher the output. When a person walks, the front and rear parts of the tile on the floor may be seen. Mechanical energy is generated when pressure is exerted from within the foot to the piezoelectric discs. The piezoelectric transducers take this mechanical energy and transform it to electrical impulses. Because the electric voltage generated by a potential difference between the charges is an AC voltage (due to differences in vibrations caused by varying amounts of pressure applied), a bridge rectifier circuit is employed to convert the AC voltage to DC voltage for use in electronic devices. A battery connected directly to a rectifier produces a constant Voltage, making it an ineffective energy harvester. As a result, a DC-DC power converter can be added to the circuit to change the rectified voltage with regard to the piezoelectric open-circuit voltage(voc), increasing the circuit's harvesting power.To transform mechanical stresses into energy, this piezo electric tile can be implanted on pavement and under the asphalt layer of roads. The final direct current is fed to a dc-dc converter, which steps down or up a dc voltage. Batteries can be used to store this electricity.

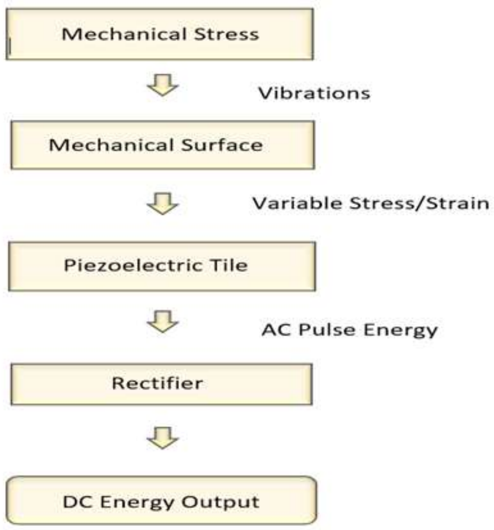


Figure 2 Piezoelectric Tiles Energy Reaper Flow Diagram

III. PIEZOELECTRIC TILES ON ASPHALT AND PAVEMENTS

Over the course of the constantly, countless individuals visit and withdraw from train stations in essentially every country. Therefore, each of the streets around the stations are continually clogged with different weighty and light-weight transport vehicles. We can create green power and supply it to the station by placing piezoelectric materials in these streets. A review was directed in the United Arab Emirates fully intent on delivering power from Piezoelectric Streets. [12] Asphalt and Portland cement concrete (PCC) are the most commonly used pavement materials the investigation was successfully directed, and now the commonsense streets are being developed. The roadway vitality reaper is a pressure-based system that generates vitality under pressure drive, with a heartbeat control linked with each pressure cycle. [13] Vibrations and deformations of roads under heavy traffic loads have led to a considerable loss of mechanical energy. The energy source in pavement is driven by stress more than vibration. The frequency of the moving vehicle load is only 0.110 Hz. Pavement will bear millions of times of the axle loadings from traveling vehicles in its service life, resulting in deformation and vibration, incredible mechanical energy is squandered during this interaction. The adequacy of piezoelectric streets is impacted by various things. For instance, the vehicle's speed and weight, as well as traffic stream limit. With sped up, more energy is created. Essentially, the more tightly the requirement, the more important stones are misshaped, thus more life is given. A similar standard applies to vehicles: a truck creates more imperativeness or energy than light-obligation vehicles and bikes. This boundary would be viewed as first subsequent to carrying out such an advancement. Control asphalts worked in ranges where less nonstop vehicles travel would unquestionably supply less imperativeness to the general development execution. Control asphalts are expected for use on blocked streets with a sensible number of vehicles. Energy dark top arranging is a basic decision for tending to energy challenges.

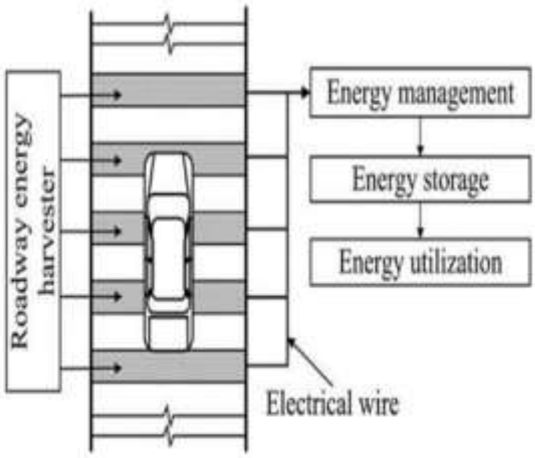


Figure 3 Generation of Piezoelectricity from Pavements and Asphalt Roads

Piezoelectric materials have been laid on a street asphalt, the street surface vibration energy is utilized for piezoelectric power age, and the assistance climate of piezoelectric materials is used to endure the tension of traffic and walkers out and about, with the goal that the street conditions decide the limit of the piezoelectric gadgets, it tends to be investigated through influence factors, for example, the speed, the recurrence and the vehicle traffic on piezoelectric gadgets.

IV DESIGN OF PIEZOELECTRIC TILE

The sporadic construction of the atoms in the precious stone is fundamentally liable for the piezoelectric activity. Whenever an electric potential is applied, the sporadic design of atomic ascents, achieving piezoelectric age. Most of the work in large-displacement piezoelectric behavior has been focused on the theoretical formulation of the governing differential equations. The direction of the applied forces determines the polarity of the charges. Where d is the crystal's charge sensitivity and F is the applied forces in Newton.

Charge $Q = d * F$ Coulomb ….(1)

The force alters the crystals' thickness. Where A is the area of crystal's meter^2, as the area of the applied force decreases, the more the pressure becomes, causing more stress to the piezo disc. t is the crystal's thickness in meter, E is Young's Modulus Newton per meter square.

$Force = \frac{A\,E}{t}\ .\ \Delta t\ \ Newton$ ….(2)

The unchanging Young's modulus only applies to linear elastic materials. The proportion of stess, which relates to the material's pressure, determines the Young's Modulus of such a material. w is crystal's width in meter and l crystal's in meter.

$E = \frac{Stress}{Strain} = \left(\frac{F}{A}\right) \cdot \frac{1}{\Delta t/t}$

A = w l

$E = \frac{F\,t}{A\,\Delta\,t}\ N/m^2$ ….(3)

By subsituting the values of Force in the equation Charge Q, Eq. (2) in Eq. (1) we obtain

$Q = d\ \ A\,E\ \left(\frac{\Delta\,t}{t}\right)$ ….(4)

The O/P voltage is obtained by electrodes charges.

$E_o = \frac{Q}{C_p} = \frac{d\,F}{\varepsilon_r\,\varepsilon_o\,{}^{A}/_{t}}$ ….(5)

$E_o = \frac{d}{\varepsilon_r\,\varepsilon_o}\ .\ t\,P$ ….(6)

$g = \frac{d}{\varepsilon_r\,\varepsilon_o}$

$E_o = g\,t\,p$ ….(7)

The voltage sensitivity of the crystals is denoted by the letter g. The energy density of the material parameters of piezoelectric voltage (g) and the piezoelectric strain coefficient (t) multiplied by (t*g). The ratio of the electric field intensity and pressure is used to calculate the crystals' voltage sensitivity. Charges are generated when mechanical deformation occurs in crystals.

$g = \frac{E_o}{t\,P} = \frac{{}^{E_o}/_{t}}{P}$ ….(9)

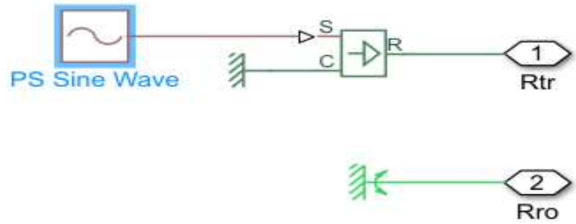
The ratio of the electric field intensity and pressure is used to calculate the crystals' voltage sensitivity. Charges are generated when mechanical deformation occurs in crystals. The voltages across the electrodes are developed as a result of this charge. The direction of the Piezoelectric crystal is important.

The polarity of the voltage is determined by the direction of the tensile or compressive force. The size and direction of the applied force determine the magnitude and polarity of the charges.

PZT VOLTAGE GENERATION

This piezoelectric ceramic is used in wide range for harvesting the piezoelectricity it is majorly implanted in high mechanical stress producing areas like airports pavements sport arenas, shopping malls, railways stations. The tile having a dimension of 75*75 cm

produces typically 30 w of continuous output. The average value of continuous stepping by a person produces 1 W to 10 W per module. The number of the piezoelectric layer and electrode connection type influence the performance of an energy harvester. The energy derived, usually small in rating, is then stored and used to power low-rated (current or voltage) devices, systems, or sensors. Using batteries as a source of power for dense sensor networks in the road may not be feasible due to the continuous replacement requirement. This electrical energy can be used to feed power to the road side electric appliances, such as traffic signal lights, advertising boards etc.
Power generated varies with different steps in piezoelectric array that is used. Based on practical results voltages obtained are:



- Minimum voltage = 1V per step
- Maximum voltage = 4V per step

Considering average weight as of the person stepping on the system to be 53 Kg the average calculation is:
Steps are required to increase 1 V charge in battery = 700 To increase 12 V in battery:
Total steps needed = (12 × 700) =8400 steps

- Considering the implementation of this system in places like college biometrics where footsteps as source is easily available, if:
- Time required for 2 steps is 1 second
- Time required for 8400 steps = 8400/(60 × 2) = 70 minutes

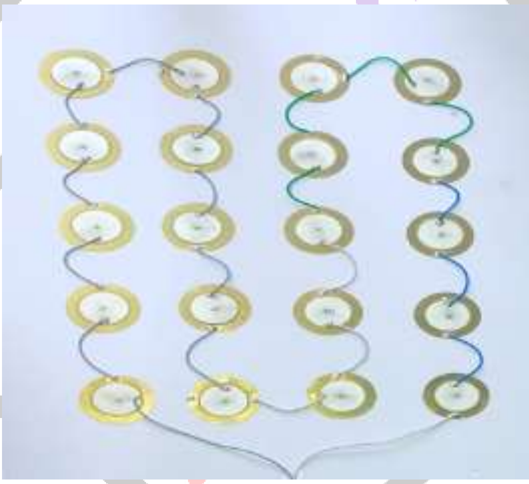


Figure 4 Piezoelectric Tile

V.SIMULATION AND DISCUSSION

Simulation Methodology
In this project, Matlab Simulink (R2021a) is used for simulating the piezoelectric harvester which has the ability to convert mechanical stress into the electrical energy using the piezoelectric effect.

Creating a subsystem to vibration source
In this Simulink model we are using vibration source to create a mechanical stress to the piezo bender, in response to the vibration created, the piezo bender generates the ac voltage, this Short version of the title (Running head): Less than 60 letters. 5 vibration source consist of two components one is sine wave generator and another one is ideal translational velocity source. This ideal translational velocity source actually convert the physical sine signal into the corresponding velocity. To start the motion, this velocity is sent to the piezo bender end.

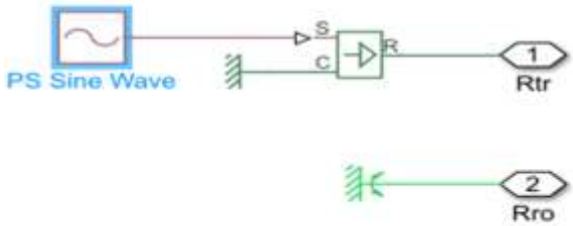


Figure 5 Vibration Source System

Piezo bender operation

Piezo bender is similar to piezoelectric transducer which changes mechanical form of energy into electrical energy. one end of the piezo bender is connected to the mass and another end is connected to the rotational pulley which is used initiate the motion. when the movement of velocity source and the mass is not in a synchronised manner it creates a mechanical stress to the piezo bender and it generates the ac voltage.

Rectification process

After the generation of ac voltage from the piezobender, that ac voltage is fed into the full wave Rectifier which converts ac voltage into dc voltage. This full wave rectifier system consists the subsystem. This subsystem comprises of diodes as displayed below figure.

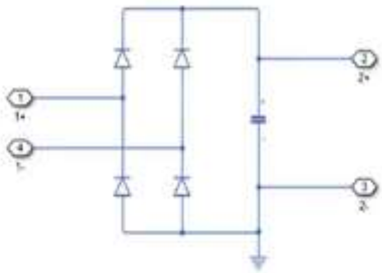


Figure 6 Full Wave Rectifier

The above figure 8 clearly represents output voltage of the buck converter. We are using the buck converter for the purpose of stepping down the voltage as per the requirement to the input voltage of the battery. With the help of the SSC Explorer block, we able to visualize the output of buck converter. It clearly step down the voltage amplitude according to the rated input voltage of the battery. The power in the buck converter reaching linear peak at 0.7 second and it decreases after that due to the irregularities in the vibration. This can be rectified in the hardware implementation by implanting those piezoelectric tiles in concentrated position which receives high mechanical vibrations.

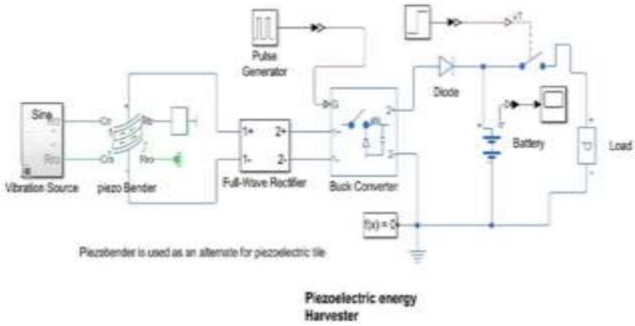


Figure 7 Simulink model of the piezoelectric harvester

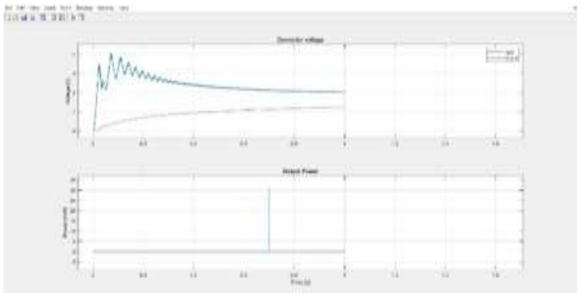


Figure 8 Output voltage curve of buck converter.

VI. RESULT AND DISCUSSIONS

Piezoelectric transducers are implanted into disc structure. These plates are associated serially to give ceaseless high voltage and current. The piezoelectric materials manages the result of various piezoelectric materials and picking of the right material in view of proficient result. The generated AC signal is applied across the bridge rectifier, during the positive half cycle, terminal A becomes positive while terminal B becomes negative. This results in diodes D_1 and D_3 to become forward biased while D_2 and D_4 become reverse biased. The three main components of the charging circuit is to have constant current, constant voltage and AC cut-off voltage through the process. The charging circuit prevents the intermittent current discharge in the battery.

Depending on the dielectric, the capacitance of the capacitor various. Super capacitor which has the highest storage capacity (1000µF, 2.7V) is used in the circuit. The indicator as a led light is connected across the super capacitor and battery to indicate the flow of current.

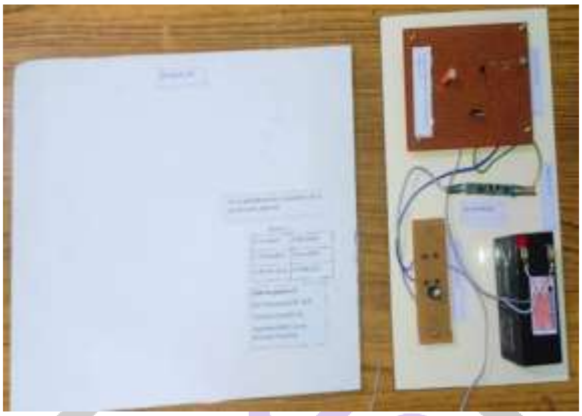


Figure 9 Prototype of the Hardware

VII. CONCLUSION

This implantation of piezoelectric tiles in pavements and asphalt roads which provides an opportunity for harvesting renewable form of energy source from the stress created by footsteps and vehicles on pavements and asphalt roads.It also gives a chance to attain the state of sustainable development. This approach can be make each stride and development of vehicle usable and is profoundly ideal as it is cost effective, effectively material and easy to understand as well. The proposed energy reaping hardware can eminently build the separated power from the piezoelectric component than straight forwardly associating a battery to the piezoelectric rectifier. Piezoelectric tiles can function admirably as self-fueled sensors, following the development of individuals through these public spaces. For those keen on getting a superior image of pedestrian activity and development designs, piezoelectric tiles could be very valuable.

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