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Design and Implementation of Piezoelectric Tiles on Pavements and Asphalt Roads

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A B S T R A C T

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 foot steps and moving of vehicle tyres into electrical energy is proposed. By implanting those piezoelectric tiles on the pavements and asphalt roads , It converts those mechanical vibrations created by the moving vehicle into the useful form of the energy and also the aim of sustainable development is achieved.

Keywords: Piezoelectric energy harvester, piezo bender, underneath the asphalt roads , battery storage , piezoelectric tile, vibration energy harvester.

Introduction

There has been a significant increase in interest in the adoption of Renewable energy harvesting methodology for structural energy harvesting systems in order to minimize the cost of traditional systems. [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 (SiO_2) and the Zincoxide.

Because of their good piezoelectric capabilities, low cost, and ease of manufacture as energy harvesting devices, piezoelectric ceramic materials are extensively utilised as piezoelectric elements in energy harvesting systems. PZT is one of the most important piezoelectric ceramics because of its remarkable piezoelectric characteristics and high curie temperature. Furthermore, depending on the mechanical energy source's characteristics, piezoelectric ceramics can be adjusted in various combinations. [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

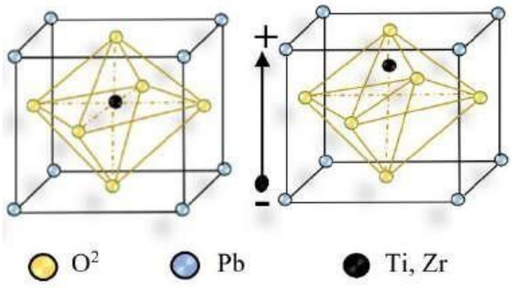

Figure 1. Crystal's Structure above and below curie point

Materials and Methodology

Piezoelectric transducers generates electricity through mechanical vibrations. [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(v_{oc}), 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.

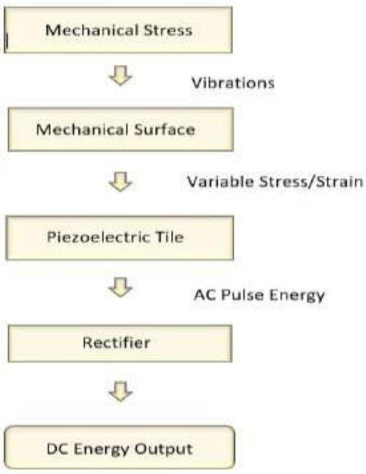

Figure 2. Piezoelectric Tiles Energy Reaper Flow Diagram

Piezoelectric Tiles on Pavements and Asphalt Roads

Throughout the day and night, a large number of people visit and depart from train stations in practically every country. As a result, all of the roadways around the stations are constantly congested with various heavy and light-weight transport vehicles. We can generate green electricity and supply it to the station by putting piezoelectric materials in these roads. A study was conducted in the United Arab Emirates with the goal of producing electricity from Piezoelectric Roads. [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. [14] The energy source in pavement is driven by stress more than vibration. The frequency of the moving vehicle load is only 0.110 Hz.[15, 16]

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 tight 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.

Design of piezoelectric tile :

The piezoelectric tile can be designed by connecting the piezoelectric transducers as the array in any supporting medium.This piezoelectric transducer has the ability to transform the mechanical form of energy into the electrical form of energy. High tension spring can also be provided below the array to create extra tension.

This setup can be designed as the piezoelectric tile which has the dimension of length 75 cm and breadth of 75 cm.

Area of the piezoelectric tile(as rectangular structure) = 75cm * 75 cm

= 5625 cm^2

Figure.3.Piezo transducers as an array.

This area of 5625cm^2 is equivalent to 6 square feet area This kind of tile can implanted in a railway stations and pavement, the study shows that the continuous stepping by people can produce about 30W of power during the peak hours.

The continuous stepping on tile surface produces 1 W to 10 W per module with an average of 7 W.

1 module can give upto 7W average power

10 module = 10* 6 square feet

=60 square feet

The 10 module can cover a area of 60 square foot .

ecifications :

Piezoelectric transducers –

Impedance :≤500Ω; Voltage:≤30Vp-p; Operating temperature:-20°C~+60°C

Full wave rectifier- Maximum Input Voltage (VRMS): 560V,Maximum Peak Reverse Voltage (VRRM): 800V,Output DC Current: 1.5A (max),Voltage Drop Per Bridge: 1V @ 1A

DC-DC Converter - Output dc voltage-12v , current- 10 A

Rechargeable batteries - 12V, 1.3AH Battery. It varies according to needs

The irregular structure of the molecules in the crystal is primarily responsible for the piezoelectric action. Whenever an electric potential is applied, the irregular structure of molecular rises, bringing about piezoelectric age. [17] 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 crystal's charge sensitivity and *F* is the force in Newton.

$$Charge\ Q = d * F\ Coulomb \qquad .... (1)$$

alters the crystals' thickness. Where *A i*s the area of crystal's $meter^2$, [18] 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.

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

The constant Young's modulus just applies to straight flexible 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.

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

$$A = w\ l$$

$$E = \frac{Ft}{A\ \Delta\ t}\ N/m^2 \qquad ....(3)$$

By subsituting the values of Eq. (2) in Eq. (1)

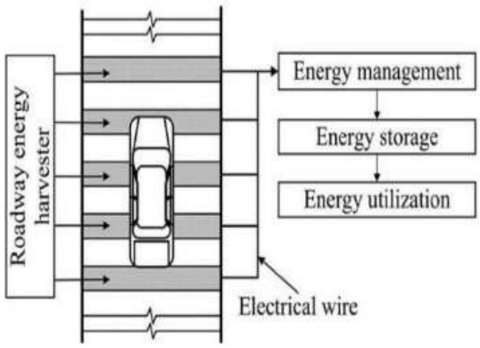

Figure 4. Generation of Piezo electricity from Pavements and Asphalt Roads

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

The Output voltage is obtained by electrodes charges.

$$E_o = \frac{Q}{C_p} = \frac{d\ F}{\varepsilon r\ \varepsilon o\ A / t} \qquad ....(5)$$

$$E_o = \frac{d}{\varepsilon r\ \varepsilon o} \cdot t\ P \qquad .....(6)$$

$$g = \frac{d}{\varepsilon r\ \varepsilon o}$$

$$E_o = g\ t\ p ....(7)$$

The voltage sensitivity of the crystals is denoted by the letter g. [19] 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.

$$g = \frac{E_o}{t\ P} = \frac{E_o / t}{P} \qquad ...(8)$$

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.

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. [20] The number of the piezoelectric layer and electrode connection type influence the performance of an energy harvester. [21] The energy derived, usually small in rating, is then stored and used to power low-rated (current or voltage) devices, systems, or sensors. [22] Using batteries as a source of power for dense sensor networks in the road may not be feasible due to the continuous replacement requirement. [23] This electrical energy can be used to feed power to the road side electric appliances, such as traffic signal lights, advertising boards etc.

Results and Discussion

Simulation

Matlab (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 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.

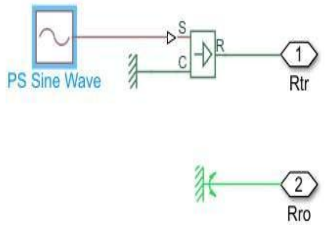

Figure 5. Vibration source subsystem

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 comprises diodes as displayed in below figure

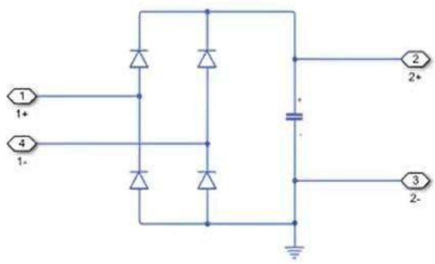

Figure 6. Full wave rectifier

Buck converter operation

The dc voltage from full wave rectifier is fed to DC-DC buck converter . main purpose is to step down the dc voltage according to the suitable rated voltage of battery .This process is mainly because for storing the voltage in the battery for the future usage. Diode across the ensure the unidirectional flow of current to the battery. In our Simulink model load is also included in addition to the battery . If there is any need of power to load it can be connected to circuit by closing the single pole single through switch. The Single pole single through switch

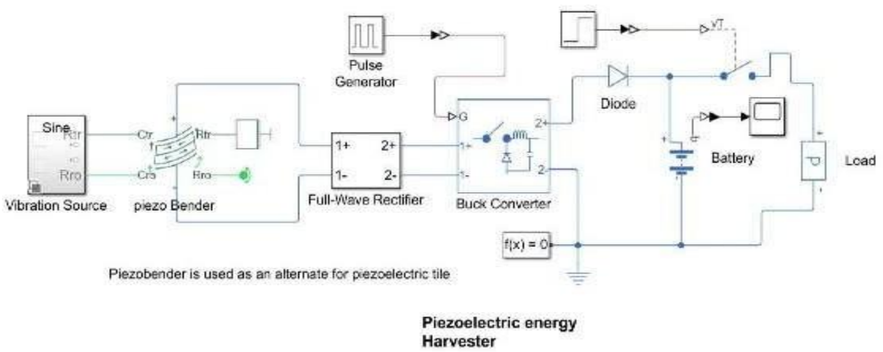

Figure.7.simulink model of piezoelectric harvester

The figure.8 represents output of the battery which we are obtaining from scope block. This result wave is drawn between the battery capacity in milli ampere hour and time period in seconds. Our battery output exactly shows the charging time of around 800mAh to the respective vibrations we are generating. It is showing some discharge of 0.003mAh due to the irregularities from vibration source.

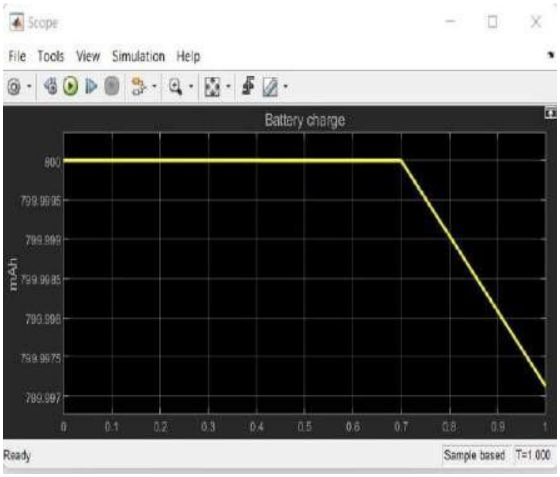

Figure 8. Ampere hour capacity during charging process

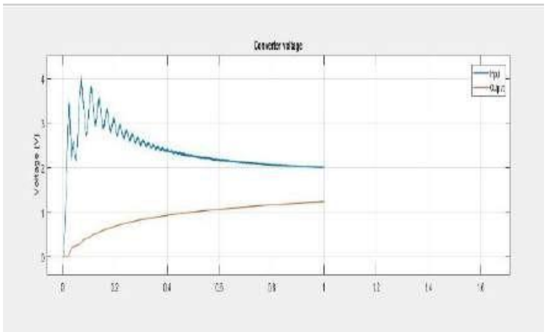

Figure 9. DC-DC converter Input and Output voltages

for the given vibration to the piezo bender, input voltage to the buck converter has the peak value of 4V, this voltage is step down with the help of buck converter and reached to the value of 1.25V for the purpose of storing it in a battery. According to the need of the load it can also be stepped up with the help of the boost converter

In this simulation, output power reaches a maximum value of 31 W. This power in real time application can be increased by implementing more efficient modules and implanting it in a dense traffic areas.

In the real time applications,the street lights which consumes about 30-40 W can be powered by implanting the piezoelectric tile modules according to the energy needs.

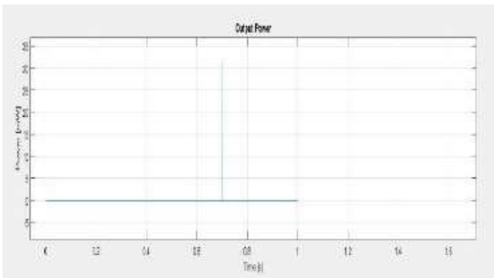

Figure.10 Converter output power

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.

Simulation using the piezo bender is done in order to realize the piezoelectric tile and the battery capacity reaches a value of 800 mAh. The buck converter reaches a peak voltage of 4 V and power reaches a maximum value of 31 mWh per module. This power can be increased by increasing the no of modules. In order to increase the efficiency and the life time of piezoelectric tile, the piezoelectric material must be placed in a environment like dense traffic road in order harvest maximum amount of energy. It can also be implanted under the speed breakers and the dance floors in order to obtain concentrated mechanical stress from a confined area.

References

[1] Y. Song, C. H. Yang, S. K. Hong, S. J. Hwang, J. H. Kim, J. Y. Choi, S. K. Ryu, and T. H. Sung, "Road energy harvester designed as a macro-power source using the piezoelectric effect", International journal of Hydrogen Energy, Vol. 41, no. 29, pp 12563–12568 (2016), DOI:10.1016/j.ijhydene.2016.04.149.

[2] Zhang, Z.W., Xiang , H.J., and Shi, Z.H, "Modeling on piezoelectric energy harvesting from pavements under traffic loads", Journal of Intelligent Material Systems and Structures, Vol . 27 , no. 4, PP. 567–578, (2015), DOI:10.1177/1045389X15575081.

[3] Erturk, A, " Piezoelectric energy harvesting for civil infrastructure system applications: Moving loads and surface strain fluctuations", Journal of Intelligent Material Systems and Structures, Vol. 22, no. 17, PP-1959–1973, (2011). DOI:10.1177/1045389x1142059.

[4] Varadha E and Rajakumar S," Performance improvement of piezoelectric materials in energy harvesting in recent days – a review ", Journal ofvibro engineering, Vol. 20, no. 7, pp. 2632-2650, (2018).DOI:10.21595/jve.2018.19434.

[5] Zhao, H.D., Yu, J., and Ling, J.M," Finite element analysis of cymbal piezoelectric transducers for harvesting energy from asphalt pavement", Journal of the Ceramic Society of Japan, Vol. 118 no. 1382, PP- 909–915, (2010), DOI:10.2109/jcersj2.118.909.

[6] Chen, Y. S., Zhang, H., Zhang, Y. Y., Li, C. H., Yang, Q., Zheng, H. Y., and LU, C. F, "Mechanical energy harvesting from road pavements under vehicular load using embedded piezoelectric elements", Journal of Applied Mechanics, Vol. 83, no. 8, PP. 1-7, (2016), DOI:10.1115/1.4033433.

[7] H. Roshani, P. Jagtap, S. Dessouky, A. Montoya and A. T. Papagiannakis, "Theoretical and experimental evaluation of two roadway piezoelectric-based energy harvesting prototypes", Journal of materials in civil engineering, Vol. 30, no. 2, pp 1-10, (2018). DOI: 10.1061/(asce)mt.1943-5533.0002112.

[8] F. U. Khan, "Review of non-resonant vibration based energy harvesters for wireless sensor nodes", Journal of Renewable Sustainable Energy, Vol. 8, no. 4, PP. 044702 -044738 , (2016), DOI: 10.1063/1.4961370.

[9] R. Li, Y. Yu, B. Zhou, Q. Guo, M. Li, and J. Pei, "Harvesting energy from pavement based on piezoelectric effects: Fabrication and electric properties of piezoelectric vibrator", Journal of Renewable and Sustainable Energy, Vol. 10, no. 5, pp. 701-711 (2018), DOI:10.1063/1.5002731 .

[10] Ehsan Maani Miandoab, Amir Hossein Jafari and Aref Valipour, " Design of Piezoelectric Tile for Energy Harvesting: Experimental Approach", Journal of Materials and Applications, Vol . 10, no. 2, pp . 83-89, (2021), DOI:10.32732/jma.2021.10.2.83.

[11] Hari anand and binod kumar singh, "Piezoelectric energy generation in India: an empirical investigation", Journal of Energy Harvesting and Systems, Vol . 6, no. 3-4, pp. 69-76, (2019), DOI:10.1515/ehs-2020-0002.

[12] S. Ahmad, M. A. Mujeebu, and M. A. Farooqi, "Energy harvesting from pavements and roadways: A comprehensive review of technologies, materials, and challenges", International Journal of renewable Energy, Vol. 43, no. 6, pp. 1974–2015, (2019), DOI:10.1002/er.4350.

[13] G. Ding, X. Zhao, F. Sun, and J. Wang, "Effect of subgrade on piezoelectric energy harvesting under traffic loads", International Journal of Pavement Engineering, Vol. 19, no. 8, pp. 661–674 ,(2018). DOI:10.1080/10298436.2017.1413241.

[14] H. Zhao, J. Ling, and J. Yu, "A comparative analysis of piezoelectric transducers for harvesting energy from asphalt pavement", Journal of Ceramic Society of Japan, Vol. 120, no. 1404**,** PP. 317–323, (2012) .DOI:10.2109/jcersj2.120.317.

[15] H. Yang, L. Wang, B. Zhou, Y. Wei, and Q. Zhao, "A preliminary study on the highway piezoelectric power supply system", International Journal of Pavement research and technology, Vol. 11, no. 2, pp. 168–175 (2018), DOI:10.1016/j.ijprt.2017.08.006.

[16] H. Yang, L. Wang, Y. Hou, M. Guo, Z. Ye, X. Tong, and D. Wang, "Development in stacked-array-type piezoelectric energy harvester in asphalt pavement", Journal of materials in civil engineering , Vol. 29, no. 11, PP . 1-9, (2017). DOI:10.1061/(asce)mt.1943-5533.0002079.

[17] Elvin NG and Elvin AA , " Large deflection effects in flexible energy harvesters", Journal of Intelligent Material Systems and Structures, Vol. 23, no. 13 , PP- 1475–1484 , (2012), DOI: 10.1177/1045389X11435434.

[18] Dzamaklu Bless Yaw Eli, Kankam Nathaniel, Kojo Boakye, Lord Anertei Tetteh, Abigail Mba and Alfred Konglo Elolo, " Using Piezoelectricity for Power Generation to support high utilization of power at University Campuses", Research Journal of Engineering and Technology, Vol . 11, no. 4, pp. 197-204, (2020), DOI: 10.5958/2321-581X.2020.00030.6.

[19] Xu Xiaochen, Cao Dongwei, Yang Hailu and He Ming , "Application of piezoelectric transducer in energy harvesting in pavement", International Journal of Pavement Research and Technology, Vol. 11, no. 4, pp-388-395, (2018), DOI:10.1016/j.ijprt.2017.09.011.

[20] Talib, N. H. H. A., Salleh, H., Youn, B. D. and Resali, M. S. M, "Comprehensive Review on Effective Strategies and Key Factors for High Performance Piezoelectric Energy Harvester at Low Frequency", International Journal of Automotive and Mechanical Engineering, Vol. 16, no. 4, PP. 7181- 7210 , (2019),DOI:10.15282/ijame.16.4.2019.03.0537.

[21] Wong Voon-Kean , Ho Jee-Hou, Yap Eng Hwa and Chai, Ai Bao , " Dynamics of a piezoelectric energy harvester in a simulated rain environment", Journal of Mechanical Engineering Science, Vol. 232, No. 15, PP-2642-2654, (2017), DOI:10.1177/0954406217722804.

[22] Jiang, Xuezheng; Li, Yancheng; Li, Jianchun; Wang, Jiong; Yao, and Jin , "Piezoelectric energy harvesting from traffic-induced pavement vibrations", Journal of Renewable and Sustainable Energy, Vol. 6, no. 4, PP. 1-15, (2014) ,DOI:10.1063/1.4891169 .

[23] Nilimamayee Samal and O. Jeba Shiney, " Energy Harvesting using Piezoelectric Transducers: A Review", Journal of Scientific Research, Vol. 65, no.3, pp. 163-176, (2021), DOI:10.37398/JSR.2021.650320.