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Energy Harvesting Using Piezoelectric Floor Tiles

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ABSTRACT: The unique piezoelectric energy harvesting from materials is a sustainable and innovative way to generate electricity from human motion and ambient vibration. This paper showcases the recent progress in piezoelectric floor materials and device breakthrough with the potential to enhance energy conversion and challenge proven practical applications. The effect of the last decade's increasing demand for clean, safer, and renewable energy has reflected onto the continuous development of piezoelectric materials intended for harvesting from the floor. The paper begins with the fundamental principle of piezoelectricity and its application in the context of energy conversion. The established key material characters such as those associated with specific lead-free compound and organic plastic forms developed for flooring have your detailed. Breakthroughs in material synthesis methods, processability, and characterization techniques are addressed to showcase the advances in improving piezoelectric conversion coefficients heterogeneity and mechanical stability. This study additionally explores the contribution of energy storage materials and cells, supercapacitors, batteries, or the like, to combine them with piezoelectric floor devices, providing the potential for energy continuity and reliability. Along with the material and device design breakthroughs, the project covers equally critical case studies concerning the practical aspects of applying piezoelectric flooring operations. Additionally, it addresses the ecological impact and society's cost-benefit analysis of piezoelectrically produced floors compared to traditional energy sources. To conclude, the present paper encompasses a wide array of studies on materials developments, device designs, and practical applications, evidencing the substantial potential of piezoelectric floor systems as an efficient and clean energy generation approach. In order to reduce the global carbon footprint and meet the needs of the future, researchers, engineers, and policymakers need to focus on optimal piezoelectricity applications.

KEYWORDS: Piezoelectric materials, Energy harvesting, Flooring technology, Device designs, Sustainability.

I. INTRODUCTION

Piezoelectricity is a quality of certain materials that is rooted in their crystal structure and symmetry. Crystals from non-central symmetric crystal classes, which include the 32 crystal classes without a centre of symmetry, have piezoelectric capabilities. Some of the most common piezoelectric materials are quartz, Rochelle salt, and various ceramic materials. The principle of a direct piezoelectric effect states that when a piezoelectric material is mechanically deformed or compressed, it will immediately produce an electric charge on its surfaces. This effect is both direct and reversible. In contrast, the inverse piezoelectric effect describes the deformation of a piezoelectric material when an electronic field is applied. It is used in actuators and sensors when tight control over mechanical displacement is required. Because piezoelectric materials have a non-uniform distribution of charge, electric dipoles will form. These dipoles will contribute to the material's overall polarization. The direction of this polarization is determined by the type and orientation of the crystal lattice. In ferroelectric piezoelectric materials, such as PZT, domains of different polarization can emerge^[14]. When an external electric field is applied, they further align, increasing the material's piezoelectric effect.

Piezoelectric effect is characterized by piezoelectric coefficients that correlate the induced charge or voltage to the applied mechanical stress or electric field^[10]. Various coefficients are used to describe different kinds of deformation or polarization. For instance, d_{33} describes the charge induced in the direction perpendicular to the applied stress. One of the most common applications of piezoelectricity is energy harvesting, which involves transforming mechanical vibrations or motion into electrical energy. As a result, the piezoelectric material may be incorporated in devices like energy harvesting flooring to generate electrical power from human footfalls or mechanical vibrations. This has been integrated into investments in sustainable energy in smart buildings and urban development. Consequently, sensors powered by piezoelectricity include pressure sensors, accelerometers, and ultrasound transducers, among others, while actuators are used for precise motion in a variety of applications.

II. LITERATURE REVIEW

In the following tables the current state-of-art developments in piezoelectric floor tiles is presented focusing on materials, device designs, and potential application.

TABLE 1- MATERIALS

Type of material	Researcher	Results
Piezoelectric Ceramics	Zhang et al. (2016) ^[1]	Lead-based ceramics like PZT (Lead Zirconate Titanate) offer high efficiency but raise environmental concerns. Explored lead-free alternatives like Barium Titanate-based ceramics (BTFPs) with promising results.
Piezoelectric Polymers	Chang et al. (2017) ^[3]	Polyvinylidene Fluoride (PVDF) is a popular choice due to its flexibility and lightweight nature. Investigates PVDF nanofiber composites for enhanced performance.
Piezoelectric Composites	Islam et al. (2020) ^[4]	Explored 3D printing of lead-free ceramic/polymer composites for PEF EH devices.

TABLE 2- DEVICE DESIGNS

Type of material	Researcher	Results
Single-layer devices	Dallago et al. (2018) ^[2]	A review of the state-of-the-art in PEF EH designs.
Multi-layer devices	Yang et al. (2019) ^[7]	Reviewed multi-layer PEF EH devices, with some achieving record-high power densities.
Multi-modal devices	Paradiso et al. (2005) ^[6]	Discussed multimodal energy harvesting for wireless sensor networks, applicable to PEF EH.
Hybrid devices	Priya et al. (2018) ^[8]	Explored hybrid energy harvesting for increased efficiency.

TABLE 3- APPLICATIONS

Type of material	Researcher	Results
Smart buildings	Priya et al. (2015) ^[9]	PEF EH as a potential power source for the Internet of Things (IoT) in buildings.
Smart cities	Z.L. Wang, et al. (2015) ^[17]	Powering sensors for environmental monitoring, traffic management, and waste collection.
Wearable devices	Z.L. Wang, et al. (2015) ^[17]	Low-power wearable electronics can potentially be powered by PEF EH integrated into shoes or insoles.

III. DESIGN OF PIEZOELECTRIC TILES

The piezoelectric tile can be designed by connecting the piezoelectric transducers as the array in any supporting medium. The piezoelectric transducer examines the formation of electricity from mechanical energy. The piezoelectric transducers are then connected as the array and finally a high-tension spring may also be given below the array to generate the additional tension. Then this set up can be designed as the piezoelectric tile which has the dimensions as:

Length = 60cm

Breadth = 60cm

Area of Piezoelectric tile = 60cm * 60cm = 3600cm²

This area of 3600cm² is equivalent to 3.875 ft² area and with this much area it can easily be implanted in pavements, staircases in commercial buildings, railway stations etc.

According to the case study conducted in November 2021 at a metro station in Cairo, Egypt, “Energy generation in public buildings using piezoelectric flooring tiles; A case study of a metro station, Rania Rushdy Moussa and Walaa S.E. Ismaeel, Sustainable Cities and Society Volume 77, February 2022, 103555”, 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.

Area covered by 10 modules = 10*3.875 = 38.75 ft²

Technical specifications:

Piezoelectric transducers –

Impedance : ≤500Ω

Voltage: ≤30Vp-p

Operating temperature: -20°C to +60°C

Full wave rectifier-

Maximum Input Voltage (V_{RMS}): 560V

Maximum Peak Reverse Voltage (V_{RRM}): 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 varying 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. Most of the work in large-displacement piezoelectric behaviour 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.

$$\text{Charge } Q = d * F \text{ Coulomb (1)}$$

$$\text{Force} = (A E/t) * \Delta t \text{ Newton (2)}$$

Where A is the area of crystal in m², 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 in Newton per meter square.

The constant Young’s modulus just applies to straight flexible materials. The proportion of stress, 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 is length of crystal in meter.

$$E = \text{Stress/ Strain} = (F/A) * (t/ \Delta t)$$

$$A = w l$$

$$E = (F t) / (A \Delta t) \text{ N/m}^2 \quad (3)$$

Substituting equation 2 in equation 1

$$Q = d A E (\Delta t/t)$$

The Output voltage is obtained by electrodes charges.

$$E_o = Q / Cp = (d F) / (\epsilon_r \epsilon_o A t) \quad (5)$$

$$E_o = [d / (\epsilon_r \epsilon_o)]. t P \quad (6)$$

$$g = d / \epsilon_r \epsilon_o$$

$$E_o = g t P \quad (7)$$

The letter g stands for the crystals' voltage sensitivity. The sum of the piezoelectric strain coefficient (t) and the piezoelectric voltage (g) energy densities of the material parameters. The proportion of the electric field power and strain is utilized to ascertain the precious stones' voltage responsiveness. Charges are produced when mechanical distortion happens in precious stones.

$$g = E_o / (t . P) = (E_o/t) / P \quad (8)$$

The voltage sensitivity of the crystals is determined by comparing the intensity of the electric field to the pressure. Charges are produced when mechanical mishappening happens in gems. The voltages across the terminals are created because of this charge^[13]. The bearing of the Piezoelectric precious stone is significant. The extremity of the still up in the air by the heading of the ductile or compressive power. The size and course of the applied power decide the greatness and extremity of the charges. This piezoelectric ceramic can be used for piezoelectricity harvesting in a variety of settings, but its primary application is in locations with high mechanical stress, such as airport pavements, sports arenas, shopping malls, and railway stations. An energy harvester's performance is influenced by the type of electrode connection and the number of piezoelectric layers. The energy determined, typically little in rating, is then put away and used to control low-appraised (current or voltage) gadgets, frameworks, or sensors. Involving batteries as a wellspring of force for thick sensor networks in the street may not be possible because of the constant substitution prerequisite. This electrical energy can be utilized to take care of capacity to the street side electric apparatuses, for example, traffic light lights, promoting sheets and so on.

IV. RESULTS AND DISCUSSION

Simulation

The piezoelectric energy harvester, which serves as a primary unit in an array of transducers integrated into a floor tile for increased efficiency, was simulated using MATLAB (R2024a).

Vibration source

A vibration source was utilized to make a mechanical pressure to energy collector. The vibration source comprised of two parts a sine wave generator and an ideal interpretation speed source. The physical signal is transformed by the velocity source into the corresponding velocity that was to be sent to the end of the piezo-bender to initiate motion.

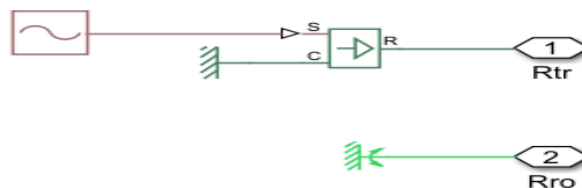


Fig.1 Vibration source sub-components

Piezo-bender

It converts mechanical form of energy to electrical energy. One of the ends of this bender is connected to a mass and other connected to a pulley. When the movement between mass and vibration source is not synchronised, it creates a mechanical stress to the piezo-bender and it generates AC voltage.

Rectifier operation

After the generation of AC voltage from the piezo-bender, that AC voltage is fed into the full wave rectifier which converts AC voltage into DC voltage.

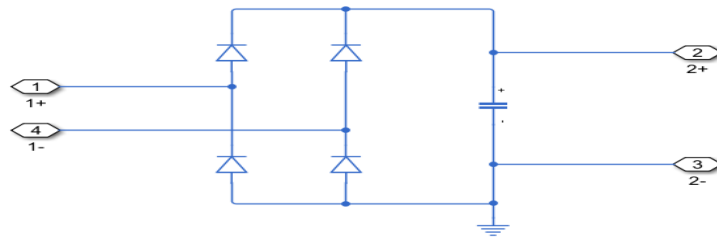


Fig.2 Full-wave rectifier

Buck converter

A DC-DC buck converter receives the DC voltage from the full wave rectifier. Principal reason for this is to step down the DC voltage as per the appropriate voltage rating of battery. The primary purpose of this procedure is to store the battery's voltage for future use. Diode across the guarantee the unidirectional progression of current to the battery. The battery and load are both included in the Simulink model that has been presented. Assuming that there is any need of ability to stack it very well may be associated with circuit by shutting the single shaft single through switch.

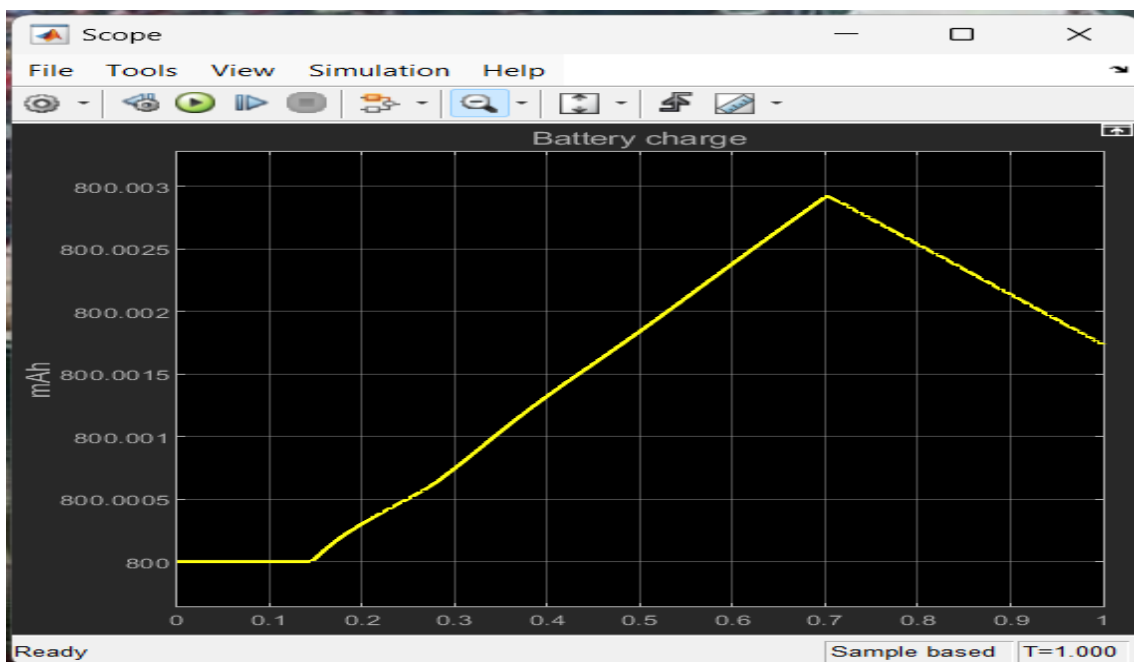


Fig.4 Charging of battery by energy generated by piezo-bender

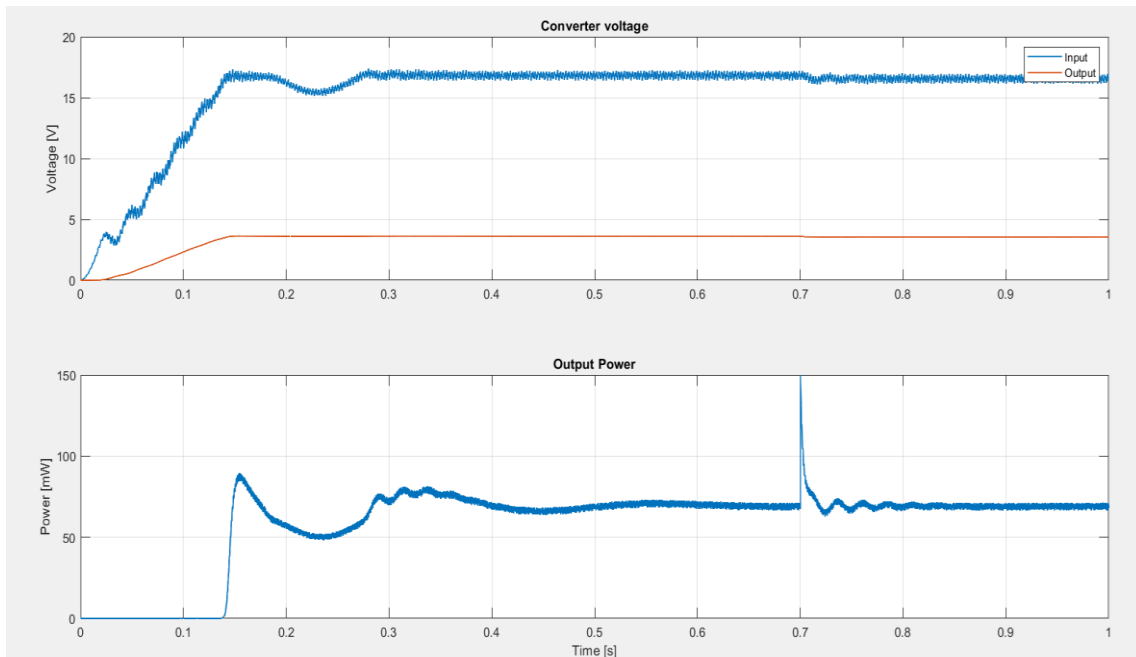


Fig.5 Converter voltage and output power plot

When a mass of 1 kg was used at the vibration source to produce mechanical stress, the designed piezo-bender model was able to charge a battery from 800mAh to 800.003mAh in one second, as shown above.

For this given vibration source, buck converter had a pinnacle input voltage of roughly 4V which was ventured down to around 1.25V for stockpiling in battery.

In this simulation, output power reaches a maximum value of 67.7889 mW.

Number of modules in one tile in one layer	Peak power that can be generates in Watt(approx.) using one tile
10	0.677
20	1.355
30	2.033

Table 4: Calculation of power from results of simulation

This power application can be expanded by executing more effective modules and embedding it in a thick rush hour gridlock region. For ongoing applications, the streetlamps which consumes around 30-40 W can be controlled by embedding the piezoelectric tile modules as indicated by the energy needs.

V. CONCLUSION

The project hereby concludes that, implantation of piezoelectric floor tiles in pavements of commercial spaces and even asphalt roads may provide opportunity for harvesting non-conventional and renewable form of energy from mechanical stress generated by footsteps and vehicles in these areas. It also provides a chance to attain sustainable development. These tiles can also function as self-fueled sensors to provide data for accurate crowd control and management and to further enhance the capabilities of these floor tiles.

The simulation done here, is a proof that piezoelectric floor tiles are capable of real world application. In order to increase efficiency and product life of these floor tiles, this needs to be placed in areas of dense traffic activity or pedestrian activity and using new environment friendly materials in their construction. These tiles can also be used in confined areas like dance floors, concert venues, speed breakers etc. to harvest energy.

Overall, piezoelectric floor tiles provide another method of harnessing energy from non-conventional sources.

REFERENCES

- [1] "Recent Advances in Lead-Free Piezoelectric Ceramics for Energy Harvesting" by Y. Zhang, et al. in Journal of Advanced Ceramics, vol. 5, no. 2, pp. 108-125, 2016.
- [2] "Piezoelectric Floor Energy Harvesting: A Review of the State-of-the-Art" by E. Dallago, et al. in Smart Materials and Structures, vol. 27, no. 10, 2018.
- [3] "Piezoelectric Polymer Nanocomposites for Energy Harvesting and Sensing Applications" by C. Chang, et al. in Nano Energy, vol. 33, pp. 305-323, 2017.
- [4] "3D Printing of Piezoelectric Energy Harvesters: A Review" by M. A. Islam, et al. in Advanced Materials Technologies, vol. 5, no. 9, 2020.
- [5] "Advances and Challenges in Piezoelectric Energy Harvesting" by S. Priya, et al. in Nature Energy, vol. 1, no. 5, p. 16008, 2016.
- [6] Paradiso, J. A., & Starner, T. (2005). Multimodal Energy Harvesting for Self-Powered Wireless Sensor Networks. Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems (pp. 491-502).
- [7] Yang, G., Gu, L., & Qin, Y. (2019). Multi-Layer Piezoelectric Energy Harvesters: A Review. Applied Energy, 236, 267-288.
- [8] "Hybrid Energy Harvesting: Opportunities and Challenges" by S. Priya, et al. in Energy Harvesting Systems, vol. 5, no. 1, pp. 1-11, 2018.
- [9] "Piezoelectric Floor Energy Harvesting: A Potential Power Source for the Internet of Things" by S. Priya, et al. in Energy Harvesting Systems, vol. 2, no. 1, pp. 1-18, 2015.
- [10] "A Comprehensive Review on the State-of-the-Art of Piezoelectric Energy Harvesting" by A.R. Ramya, et al. in Energy Science & Engineering, vol. 8, no. 12, pp. 3310-3333, 2020.
- [11] "Piezoelectric Energy Harvesting: Material, Design, and Readout Circuits" by M. Kiani, et al. in MDPI Materials, vol. 12, no. 12, p. 45, 2023.
- [12] "Special Issue: Recent Advances in Piezoelectric Energy Harvesters and Their Applications" in MDPI Energies, vol. 15, no. 12, 2022.
- [13] "A Review of Piezoelectric Energy Harvesting: Materials, Design, and Readout Circuits" by A.R. Ramya, et al., MDPI Materials, vol. 12, no. 12, p. 45, 2023.
- [14] "Lead-Free Piezoelectric Materials for Energy Harvesting" by T. Karaki, et al. in Materials Science and Engineering: B, vol. 249, pp. 109-124, 2019.
- [15] "Laser-Based Micromachining of Piezoelectric Materials for Energy Harvesting and Sensor Applications" by H. Zhu, et al. in Journal of Materials Processing Technology, vol. 277, pp. 116483, 2020.
- [16] "Roll-to-Roll Manufacturing of Piezoelectric Energy Harvesters for Large-Scale Applications" by S. Xu, et al. in Nano Energy, vol. 37, pp. 135-150, 2017.
- [17] "Piezoelectric Nanogenerators: From Fundamentals to Applications" by Z.L. Wang, et al. in Nano Energy, vol. 14, pp. 535-557, 2015.



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