Footstep Power Generation Using Piezoelectric Sensor

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ABSTRACT

Human beings have increasingly relied on energy for sustenance and well-being since time immemorial. This growing demand has led to the depletion and wastage of many energy resources. In this context, the proposal to harness waste energy from human footfall is particularly relevant for densely populated countries like India, where public spaces such as railway stations and temples remain crowded throughout the day.

By integrating piezoelectric technology into flooring systems, the mechanical pressure exerted by footsteps can be captured using floor sensors and converted into electrical energy via piezoelectric transducers. This energy can then be stored and used to power various applications, including street lighting, home appliances, agricultural systems, and remote sensors.

This research focuses on generating electricity through the everyday act of walking. The aim is to harness the otherwise wasted kinetic energy from human movement and convert it into usable electrical power. Addressing the global energy crisis, this innovative approach may not fulfill the entire energy demand, but it presents a significant step forward. For instance, if a system can generate 100W of power from just 12 steps, it could produce 1000W from 120 steps. Installing such systems on 100 floors could potentially yield 1 megawatt of electricity—an achievement that underscores the viability and importance of this technology.

Keywords: Piezoelectric sensor, Footstep, remote location, force and pressure, power generation

I. INTRODUCTION

With the continuous rise in population, the demand for electrical power is also increasing. Simultaneously, significant amounts of energy are being wasted in various forms. One promising solution lies in converting this wasted energy back into a usable form. As technology advances and the use of electronic gadgets and appliances grows, conventional methods of power generation are becoming insufficient to meet the rising demands.

There is an urgent need to explore alternative methods of power generation. One often overlooked source of energy loss is human locomotion—every step we take exerts force that is typically wasted. By utilizing this force effectively, it is possible to generate power in a sustainable manner. This can be achieved using piezoelectric sensors, which convert mechanical pressure into electrical voltage.

The proposed system harnesses the force of footsteps to generate electricity. When integrated into flooring, the piezoelectric sensors generate voltage with every step, which can then be stored or directly used to power small loads. This concept of footstep power generation is particularly useful in high-footfall public places such as bus stands, theaters, railway stations, shopping malls, and temples. When these systems are strategically installed at entrances or exits, they can continuously generate power from human movement. The system comprises piezoelectric sensors, a voltmeter to measure output, LED lights for visual indication, a weight measurement setup, and a battery to store the generated energy. Additionally, this method contributes to the conservation of natural energy resources by reducing reliance on conventional sources. In essence, footstep power generation offers a practical and eco-friendly approach to energy recovery in everyday environments.

II. LITERATURE SURVEY

Earlier developments in piezoelectric circuitry primarily focused on capturing small vibrations and strain, often resulting in low voltage outputs. Additionally, many early systems required external voltage supplies and experienced significant energy losses, reducing overall efficiency.

In December 1929, scientists from the U.S. Navy conducted extensive research on piezoelectric crystals. Their primary focus was on the dimensions and orientation of the crystals. The study revealed that altering these parameters significantly affected the output voltage. This led to the design of specialized crystals such as the "Curie Cut" or "Zero Cut," which were based on specific angular configurations. These modified crystals demonstrated effectiveness in controlling the oscillations of a 50-watt vacuum tube, thereby functioning as voltage control devices.

In 1985, Sandia Laboratories explored the use of piezoelectric materials for electronic identification through handwriting dynamics. A piezoelectric sensor-equipped pen was developed to capture pen-point dynamics during writing. Design equations and operational details were established, and typical output waveforms were analyzed. The study demonstrated the sensor's ability to detect subtle pressure variations, successfully distinguishing between genuine signatures and forgeries. This highlighted the high sensitivity of piezoelectric materials to marginal pressure changes.

By 2000, research expanded into the use of piezoelectric technology for wireless sensing applications. In many industrial and military environments, there was a need to monitor machinery in remote or inaccessible locations where conventional power sources were unavailable. However, these environments often exhibited vibrational energy, which could be harnessed by piezoelectric generators. These generators were used to power microcontrollers and radio transmitters, enabling data acquisition and transmission. Techniques for efficient energy conversion, usage, and storage were developed and applied in energy-harvesting transmitter designs.

In 2005, the U.S. Defense Advanced Research Projects Agency (DARPA) launched an innovative energy harvesting project aimed at powering battlefield equipment using piezoelectric generators embedded in soldiers' boots. The goal was to capture 1–2 watts of power from the continuous impact of walking. However, the project was ultimately discontinued due to the additional physical strain placed on soldiers, which led to discomfort and increased energy expenditure.

Building upon these past developments, the current project focuses on the use of piezoelectric crystals and films in high-vibration environments with optimized arrangements for enhanced efficiency. Special attention is given to the design of amplification circuits to ensure that the output power is significantly higher than that of previous systems.

III. NEED FOR THE SYSTEM

The utilization of waste energy generated from human foot power during locomotion is both necessary and highly relevant, especially in densely populated countries such as India and China. In these nations, public spaces like roads, railway stations, temples, shopping malls, and other crowded areas witness constant foot traffic from millions of people around the clock.

A significant amount of mechanical energy is dissipated during walking, which typically goes unused. Capturing this otherwise wasted energy presents an opportunity to supplement power generation in a sustainable and environmentally friendly manner. By harnessing the kinetic energy from footsteps and converting it into electrical energy using piezoelectric technology, this system provides an innovative solution to partially address the energy crisis.

This approach not only helps in utilizing renewable forms of energy but also contributes to reducing dependency on conventional power sources, conserving natural resources, and promoting energy awareness in public infrastructure. Given the high footfall in urban environments, implementing such systems could lead to substantial energy recovery on a daily basis, making it a practical and impactful solution.

IV. PIEZOELECTRIC SENSOR

A piezoelectric sensor is a device that utilizes the **piezoelectric effect** to measure changes in physical parameters such as pressure, acceleration, strain, force, or temperature by converting them into an electrical charge. This conversion occurs when a mechanical force is applied to a piezoelectric material, generating a voltage across its surfaces. The magnitude of the voltage is directly proportional to the applied pressure.

When a static or dynamic force is exerted on the sensor, it causes deformation in the piezoelectric material, leading to the accumulation of electric charge. This charge can be detected and quantified as a voltage output. The sensitivity of piezoelectric sensors allows them to detect even minute forces or pressure changes with high accuracy.

Piezoelectric sensors are widely used in a variety of applications and industries, including:

- **Healthcare:** Ultrasound imaging, diagnostics, and monitoring.
- **Aerospace:** Vibration analysis and structural health monitoring.
- **Consumer Electronics:** Touch-sensitive devices and motion detection.
- **Nuclear Instrumentation:** Radiation detection and reactor monitoring.
- **Industrial Systems:** Vibration and impact monitoring in machinery.

Due to their compact size, high sensitivity, and ability to function without external power sources, piezoelectric sensors are ideal for integration into everyday objects and smart infrastructure systems. In the context of footstep power generation, they play a crucial role in converting mechanical foot pressure into usable electrical energy.

Fig 1. Piezoelectric Sensor

V DESIGN

The design phase of the "Foot Step Power Generation using Piezoelectric Sensor" project is where the conceptual ideas and requirements from the analysis phase are transformed into a detailed plan for implementation. It's the blueprint that guides the development process, ensuring that the final product meets the project's objectives and specifications. This phase involves making critical decisions about the system's architecture, components, and functionalities. The design phase translates the user and system requirements from the analysis phase into detailed specifications for the hardware and software components of the system. This phase involves defining the overall structure of the system, including its components, their interactions, and the flow of data and control.

The design phase involves selecting the appropriate components and technologies for the system, considering factors such as performance, cost, availability, and compatibility. This phase involves creating detailed designs for the hardware and software components, including circuit diagrams, flowcharts, and user interface layouts. The design phase involves evaluating different design alternatives to identify the most suitable solution for the project

5.1 Energy Harvester Circuit

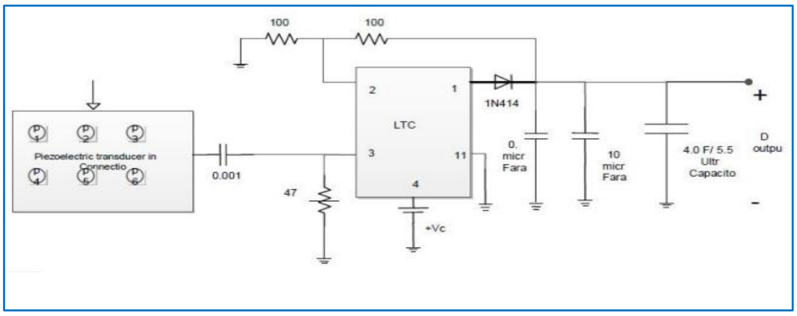

Fig:2 Energy harvest circuit

The ac output voltage when a variable strain is applied on the tile is shown in above figure. The voltage obtained without bridge rectifier is of alternating nature of frequency below 10Hz. The magnitude of ac output obtained depends on the various factors such as packing density of piezoelectric transducer, frequency of excitation, and type of strain applied on the surface. The AC voltage obtained is further processed via energy harvester circuit that consists of the rectifier IC LTC3588. Earlier the bridge rectifier has been used with electrolyte capacitor as the storage but it caused the drop of generated power across the diode and electrolyte capacitor. The electrolyte capacitor has been replaced by the ultra-capacitor but it was not charging since the frequency of the harvested power was very low. Then we have used an IC which not only rectifies with low drop but also multiplies the frequency. LTC3588 is the energy harvesting IC programmed for low power generation that integrates the bridge rectifier and the efficient energy storage hardware algorithm. The output of IC is low ripple containing DC with 51.33 % ripple factor.

5.2 Module design and organization

The piezoelectric transducer remains in direct contact with the source of vibration. When the vibration occurs, the piezoelectric transducer induces the electric charge. The rate of change of these induced charges with respect to time gives the alternating current pulses. A static converter is used before feeding the storage unit or the electrical load.

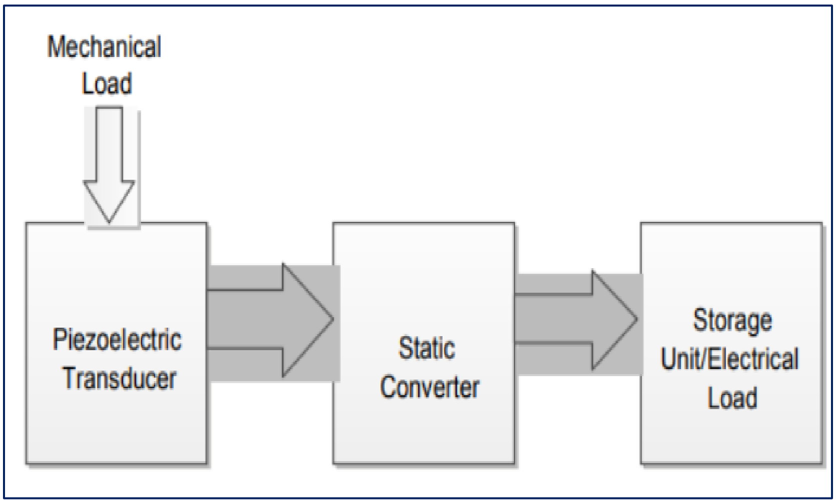

Fig :3 Schematic diagram of a vibrating piezoelectric Harvester model

One disadvantage of piezoelectric sensors is that they cannot be used for truly static measurements. A static force results in a fixed amount of charge on the piezoelectric material. In conventional readout electronics, imperfect insulating materials and reduction in internal sensor resistance causes a constant loss of electrons and yields a decreasing signal. Elevated temperatures cause an additional drop in internal resistance internal resistance and sensitivity. The main effect on the piezoelectric effect is that with increasing pressure loads and temperature, the sensitivity reduces due to twin formation. While quartz sensors must be cooled during measurements at temperatures above 300 °C, special types of crystals like GaPO4 gallium phosphate show no twin formation up to the melting point of the material itself.

However, it is not true that piezoelectric sensors can only be used for very fast processes or at ambient conditions. In fact, numerous piezoelectric applications produce quasi-static measurements, and other applications work in temperatures higher than 500 °C.

Piezoelectric sensors can also be used to determine aromas in the air by simultaneously measuring resonance and capacitance. Computer controlled electronics vastly increase the range of potential applications for piezoelectric sensors.

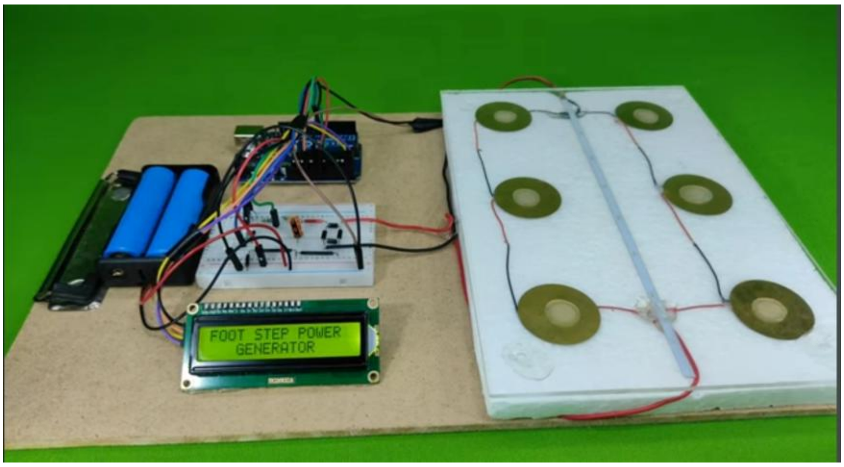

Fig :4 connection of sensor with other components

VI. WORKING

The main components of the system include piezoelectric sensors, voltage boosters, voltage regulator, PIC microcontroller, battery, LCD display, LDR and a socket for mobile charging. Here in this this system, at first, the output from an array of piezoelectric sensors is fed into voltage booster. In the system, two voltage boosters are used to boost the voltage to get the desired output. The output from piezoelectric sensor is in the range of 3 V to 4 V. It has to be boosted to a range of 9 V to 12V with the help of voltage boosters. A constant output voltage irrespective of fluctuations will be maintained by a voltage regulator. This regulated voltage is stored in the battery and is fed to the microcontroller. The LCD which is interfaced with the microcontroller in turn displays the amount of charge stored by the battery. In this system the power generated has been used for two applications such as lighting a street light and charging a mobile phone. A LDR is used to indicate the street light application. A buzzer is used to alert when the battery voltage falls below the required voltage for charging the microcontroller. For PIC microcontroller 5 V is required for its working. The mobile charging socket also requires 5 V for its operation. A pull down resistor is used in the socket to pull down the voltage to 5 V. The power is generated by simply walking over a step. The system does notneed any fuel input for its functioning this is a non-conventional system in which battery is used to store the generated power. Even though the force is used to generate power, the system is applicable to particular places. Mechanical moving parts used in the system are large there by increasing the cost. The power generation using footsteps can be implemented effectively in schools, colleges, cinema theaters, shopping complexes, temples and many other buildings.

VII FUTURE SCOPE

The application of piezoelectric crystals for energy harvesting has shown promising results and holds significant potential for future development. Countries like China and Japan, where public foot traffic is extremely high in places such as railway stations, airports, and shopping malls, present ideal environments for implementing piezoelectric systems to generate electrical power efficiently.

Beyond fixed installations in public spaces, ongoing research is exploring the integration of piezoelectric materials into wearable technologies, such as shoes. With each step, the embedded piezoelectric crystals can generate electrical energy, potentially sufficient to power or charge small electronic devices such as mobile phones, MP3 players, smartwatches, and other portable gadgets.

The future of this technology lies in enhancing its efficiency, durability, and scalability. With further advancements, piezoelectric energy harvesting could become a standard feature in urban infrastructure and personal wearables, offering a sustainable and eco-friendly solution for meeting small-scale energy demands and contributing to a greener planet.

VIIIADVANTAGES AND DISADVANTAGES

A. Advantages

1. **Power Generation by Walking:** Electricity is generated simply by walking—no additional effort is needed from the user.
2. **No Fuel Required:** The system operates without the need for any fuel input, making it eco-friendly and cost-effective in the long term.
3. **Non-Conventional Energy Source:** It utilizes a renewable and sustainable method for power generation.
4. **No Moving Parts:** Fewer mechanical components mean less wear and tear, resulting in a longer service life and reduced maintenance.
5. **Compact and Highly Sensitive:** The small size and high sensitivity of piezoelectric sensors allow for easy integration into various environments.
6. **Self-Powered Operation:** The system is self-generating and does not require any external power source for operation.

B. Disadvantages

1. **Location-Specific Application:** The system is most effective in areas with high and consistent foot traffic, limiting its general applicability.
2. **High Initial Cost:** The installation and setup costs can be relatively high, especially for large-scale implementations.
3. **Temperature Sensitivity:** The output of piezoelectric materials can be affected by temperature fluctuations, which may impact efficiency.
4. **Material Fragility:** Piezoelectric crystals are prone to cracking or damage if overstressed beyond their mechanical limits.

CONCLUSION:

The exploration of footstep power generation using piezoelectric sensors and Arduino presents a compelling case for harnessing readily available kinetic energy from human activity. This project, while seemingly simple in its fundamental concept, delves into a complex interplay of material science, electrical engineering, software development, and sustainable energy practices. Throughout the development process, we've navigated the intricacies of piezoelectricity, the versatility of Arduino, and the challenges of real-world implementation.

The core principle, the piezoelectric effect, serves as the foundation upon which this project is built. The ability of certain materials to convert mechanical stress into electrical energy offers a direct and elegant solution for capturing the kinetic energy expended during walking. However, the energy generated by individual footsteps is inherently small, necessitating careful consideration of sensor selection, placement, and signal conditioning. The choice of piezoelectric material, its sensitivity, and its durability are paramount in ensuring efficient and reliable energy harvesting.

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