

Analysis of a piezoelectric energy harvester system from footsteps of passersby

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ABSTRACT

Piezoelectric materials can be used in applications designed to handle a wide range of input frequencies and forces to enable energy harvesting. Although several studies have been carried out on piezoelectric energy harvesting systems, this application is still under development. The purpose of this work is to analyze the behavior and the ability to generate electrical energy through the elements in piezoelectric tiles or platforms, specifically, piezoelectric disc elements with a diameter of 27 mm.

To do this, a platform of about 130 x 75 cm was designed to capture the footsteps of people and transmit the impact force to sensors to determine the power generation capacity of the piezoelectric elements. Tests were carried out with people weighing between 75 kg and 85 kg and the measurements obtained made possible to identify the behavior of the system and to develop a mathematical model to estimate the energy generated through the platform.

The piezoelectric elements used here proved to be fragile despite the different types of shock absorbers used to avoid their rupture. Therefore, it is recommended to delve into the design of protection mechanisms to extend the life of piezoelectric elements in energy collection systems.

Keywords: Energy generation, Energy harvesting, Piezoelectricity, Vibration

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1. Introduction

Faced with the need to produce the electrical energy required for the operation of the devices that are used daily, the human being has resorted to different types of energy sources such as energy from fossil fuels, atomic energy, among others [1], [2]. In order to generate energy without creating negative impacts on the environment, a wide range of energy sources has been considered, among which, the exploration of energy harvesting sources in indoor spaces has generated growing interest [3], [4], [5], [6]. Indoor energy sources are believed to be an important component in energy diversity and reliability when climate-related energy resources are minimal [7]. This is remarkable in places where there are few available energy sources, there is no access to resources such as the sun or large amounts of water [8].

There are a variety of usable energy sources within a building, for example waste heating, running water, electromagnetic waves, and vibrations [9]. Vibration-based energy harvesting, also called piezoelectric power generation, has received attention due to its ability to capture surrounding ambient energy and convert it into usable electrical energy, and the ease with which piezoelectric elements can be integrated into a system [10], [11], [12].

The piezoelectric effect is based on the polarization of the molecules of certain crystals such as quartz. Mechanical stresses applied to the crystal cause polarization of its molecules, resulting in a potential difference that can be used to produce an electrical current [13], [14]. The key aspects of using piezoelectric plates on a large scale are cost reduction and the quality of the collection systems. These aspects depend on the efficient use of the system, the integration of various piezoelectric technologies and the design of adequate energy transfer facilities [15]. Piezoelectric tiles present a very attractive research and development potential for implementations within buildings that have a recurrent number of passersby, which represent an energy potential that would help in saving daily electricity consumption [16],[17]. For the development of this technology, it is important to carry out studies aimed at its manufacture and fine-tuning [18] because these platforms are not easy to find commercially, in fact, in Colombia their commercialization to generate electricity is little known [19].

2. Piezoelectric energy harvesting system

2.1. Components of a piezoelectric tile

Prior to the construction of the piezoelectric platform, bibliographical research was carried out to identify the elements that can be used to make the tiles. These elements have important functions that need to be explored. Within the different studies consulted, it is identified that the piezoelectric tiles implemented for the generation of energy in areas with transit of people have the following elements (see **Error! Reference source not found.**) [15], [20], [21]:

- **Contact zone/Floor:** People place their feet on this zone to exert the force that deforms the piezoelectric elements. Among the materials that have been used for this part are wood, acrylics, plastics, ceramics, among others. Of these materials, wood is the most used since its weight and hardness make it possible to mitigate the impact on the piezoelectric and protect them from breakage.
- **Vibrating plate:** help reduce the impact force caused by a person's footstep. Its function is of great importance because piezoelectric are made of very brittle ceramics and constantly fracture. Among the most used materials are cardboard and foam, among others.
- **Piezoelectric sensors:** They are responsible for generating electrical energy by deforming due to the pressure exerted on them.
- **Base:** It is responsible for supporting the elements and anchoring to the area in which the power generation system will be installed (see figure 1).

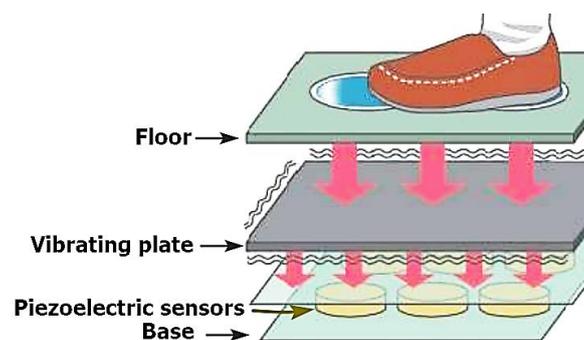


Figure 1. Flooring Tiles with Piezoelectric Crystals [22]

Three main criteria were considered for the selection of piezoelectric sensors: the accessibility in the market (which refers to the cost and if it must be imported or is available in the local market), the energy harvested (which is related to the voltage generated), and the durability of the element (which refers to its fragility or its ability to withstand blows and deform).

Most of the piezoelectric discs available in the local market can produce the same voltage despite the difference in the impedance values. Table 1 shown some characteristics of the available piezoelectric devices. The factor that makes the difference between the sensors analyzed is the cost. Hence, the selected device was the 27 mm piezoelectric disc (Figure 2).

Table 1. Piezoelectric discs characteristics.

| Plate size | Impedance | Max. input voltage | Cost |
|------------|--------------|--------------------|------------|
| 35 mm | 350 Ω | 30 Vpp | US \$ 2.35 |
| 27 mm | 300 Ω | 30 Vpp | US \$ 0.92 |
| 18 mm | 350 Ω | 20 Vpp | US \$ 1.65 |
| 12 mm | 300 Ω | 30 Vpp | US \$ 1.53 |

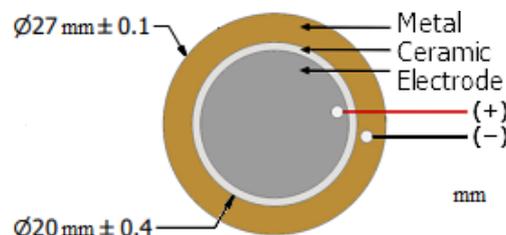


Figure 2. 27 mm piezoelectric disc

2.2. Materials selection

The lifespan of piezoelectric discs depends directly on the selection of the materials with which the tile is built. The use of wood stands out to form the contact area and the base for having a flexibility that cushions the steps and protects the piezoelectric discs from strong blows.

In order to select the materials for the shock absorber plate, several tests were carried out. From the tests with cardboard, it was shown that after a couple of steps on the wooden boards that make up the contact zone, it deforms and begins to behave like a rigid element and the piezoelectric discs begin to fail, this being totally unproductive for applications. of daily use. Subsequently, tests are made with a sheet of foamy and a better behavior is observed since the operation of the generating discs lasts a greater number of steps maintaining the voltage ranges.

For the construction of our tile, a film of hot-melt glue (silicone) was used as a base to avoid accelerated deterioration of the piezoelectric element and protect it from the abrasion generated by footsteps, a sheet of foam (Produeva #5) was used as a vibrating plate on which the piezoelectric discs were glued with a silicone cover to protect and cushion the ceramic, and wooden boards were used as contact zone on which the feet are placed.

2.3. Tile construction

In the design process, a series of tests are required to analyze the ability of piezoelectric to generate energy and determine the type of connection and assembly of the elements. In the first tests carried out, the types of connections that can be made with piezoelectric sensor and their behavior were analyzed. Figure 3 and Figure 4 show the tiles constructed with the piezoelectric sensors connected in series and parallel respectively.

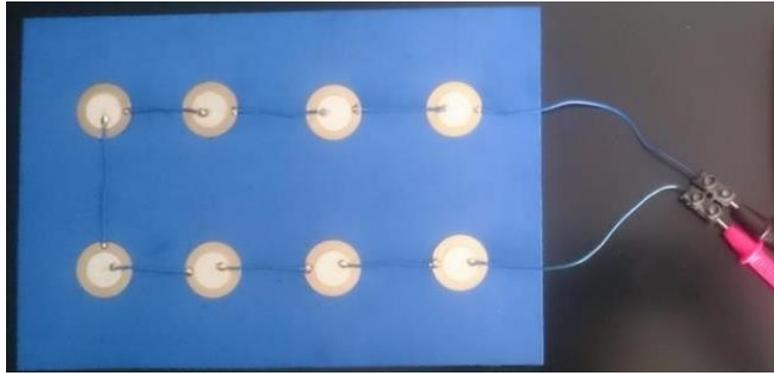


Figure 3. Tile with piezoelectric discs connected in series

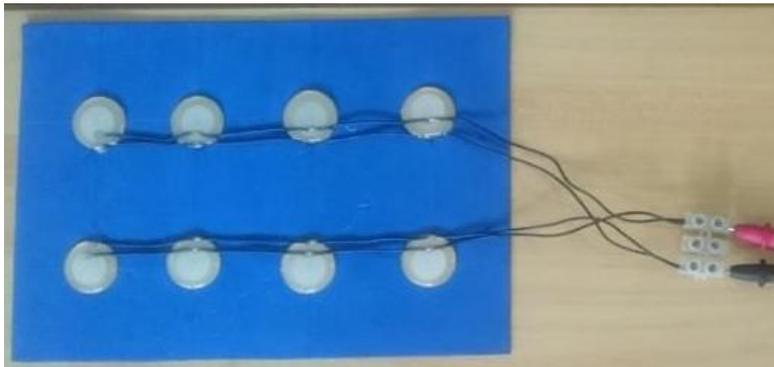


Figure 4. Tile with piezoelectric discs connected in parallel

It was observed that the voltages obtained in both tests are similar to those observed in different previous studies [14], [21], [23]. It was noticed that the voltages generated by the piezoelectric tiles are momentary and manifest in spikes. Therefore, in a series circuit it is not possible to add the voltage instantly and the probability of coincidence of the trigger times is low, but when this happens it is possible to reach voltages of up to 120 V.

An important aspect that was observed in these tests is the fact of the fragility of the piezoelectric elements, which are easily damaged when a lot of pressure is applied to them, this is a product of the coefficient of deformation of ceramic materials, which is low and makes it difficult the functionality of the series circuit. When the ceramic material of a piezoelectric element fractures, it behaves like a short circuit. Due to this, when the piezoelectric elements are connected in series and one of them breaks, a decrease in the generated voltage occurs.

Unlike the series circuit, with the parallel circuit it was observed that when one of the piezoelectric fails, it behaves in a similar way to that of a resistance, since the voltage generated by the other piezoelectric that are connected in parallel is absorbed by the damaged piezoelectric.

Tests show that the best connection for power generation is parallel. This agrees with other authors who, during their research, also conclude that the parallel connection of the piezoelectric sensor allows greater stability in voltage generation [24],[20].

The construction of a platform with dimensions of 130 cm × 75 cm is proposed, including a frame of steel angles to prevent the movements of its components. The constructed platform is shown in the Figure 5. The 27 mm piezoelectric disc were evenly distributed across the foam sheet in an 8 × 14 array. Once the discs were installed and connected, they were covered with silicone. These elements were then assembled with the steel frame, the contact area, and the base.



Figure 5. Top and bottom view of the piezoelectric tile constructed

3. Results

To analyze the behavior of the piezoelectric with respect to the weight of the people crossing the platform, three people of different weight were used: one weighing 75 Kg, another 80 Kg, and another 85 Kg. The voltages obtained when each of these people passed was recorded using a voltage meter connected directly to the terminals of the piezoelectric sensors on the platform. It was identified that the useful life of piezoelectric elements oscillates between 80 and 100 footsteps, for which ways must be sought to better protect the element or use ceramics with greater resistance.

The results of the test with the 75 kg person are shown in Figure 6. There it is observed that there is a decreasing behavior in the measured voltages until they stabilize when reaching values below 5V. At the end of the test, an evaluation of the piezoelectric disc was carried out and it was identified that most of these were damaged, so it was necessary to replace them before testing the system with a different weight.

The tests with people weighing 80 kg and 85 kg yielded results that also show decreasing behavior as the number of steps increases, as shown in the Figure 7 and Figure 8 respectively.

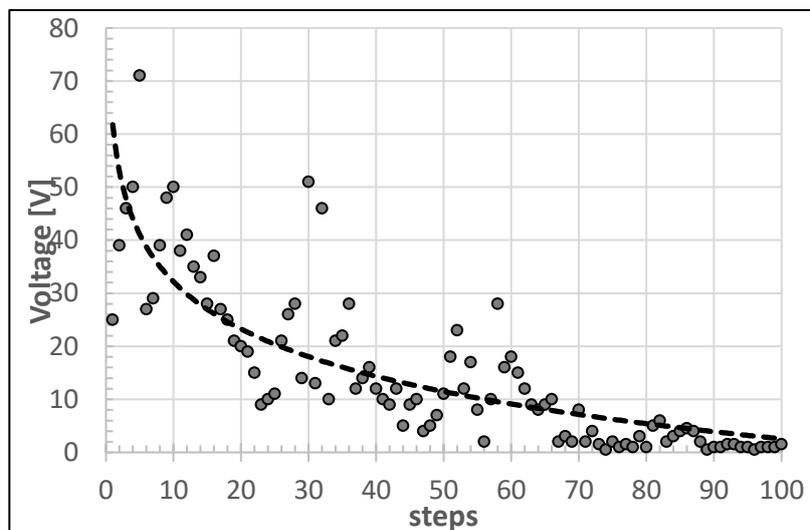


Figure 6. Voltage generated by the steps of a 75 Kg person

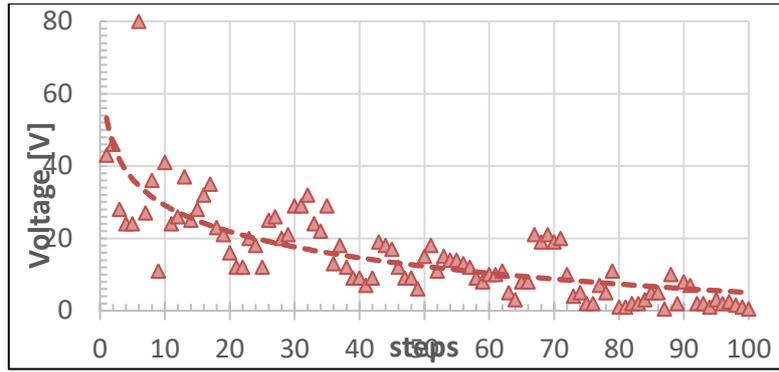


Figure 7. Voltage generated by the steps of an 80 Kg person

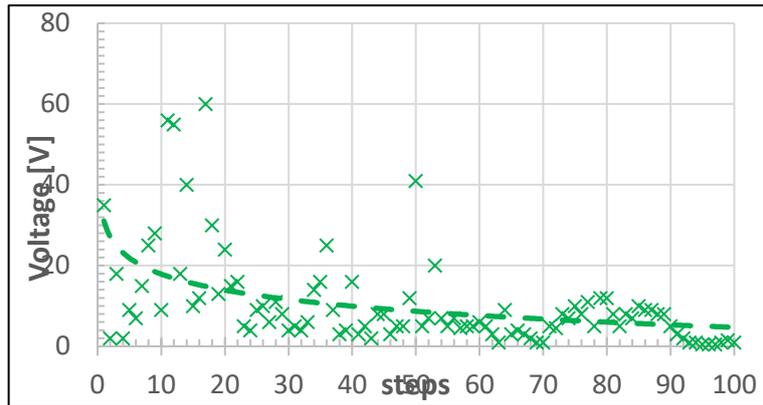


Figure 8. Voltage generated by the steps of an 85 Kg person

Likewise, it was possible to identify that the discs are subjected to deformations or loads that exceed their working limits, obtaining values above those specified by the manufacturer. However, the extra effort causes damage to the piezoelectric elements, so the energy generated decreases progressively with the use of the system. Additionally, as force is repeatedly applied to the piezoelectric disk, it tends to deform a lot and takes longer to return to its resting position.

As shown in Figure 9, the behavior of the piezoelectric tile in all cases shows high voltages in the first steps, but later, the generated voltage decreases considerably as the use of the tile increases. This trend continues until reaching the point where power generation is minimal, which does not represent an advantage for power generation considering the costs of the installation.

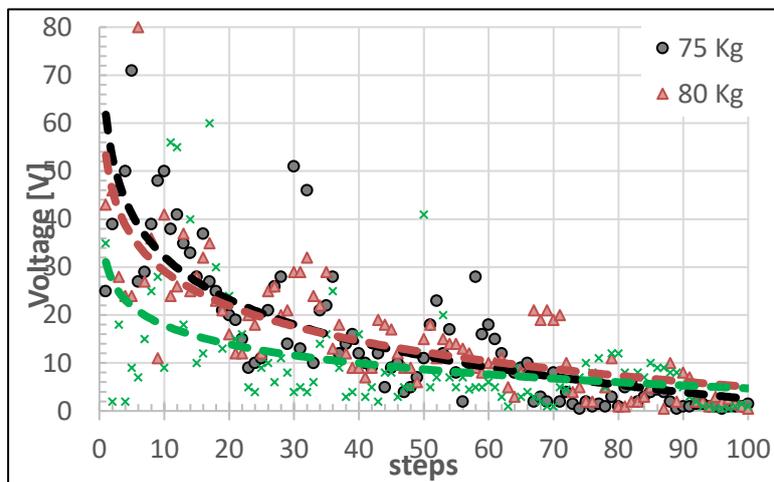


Figure 9. Voltage generated by footsteps of passersby

4. Conclusions

The development of this work made it possible to identify the behavior of piezoelectric elements as energy generators when used in a platform that captures the steps of people and transmits the impact force to the sensors. The fragility of these was observed, which fracture when receiving loads above their tolerance, turning them into a load for the generating system. Thus, the use of piezoelectric materials without adequate protection or impact control generates damage to the integrity and functionality of the sensors.

Circular cardboard sheets of the same diameter as the piezoelectric were implemented and adhered to the bottom of the piezoelectric. Tests conducted in this way showed that the piezoelectric generate the expected theoretical average voltage, but the cardboard quickly lost its damping capacity after a few steps and behaves in the same way as a rigid surface. Despite the different coatings used in the construction of the implemented platform, they do not completely cushion the impacts of footsteps. Therefore, the piezoelectric sensors fractured after a few steps, resulting in a low lifetime for their application as energy harvesters in spaces such as institutions with high flow of people. The different materials used in the implementation of a platform can be analyzed and considered by other researchers to increase the lifespan of energy harvesting systems with piezoelectric elements.

The objective of this work was to identify the electric power generation capacity when implemented in educational facilities, but the short working times and the decreasing trend in voltages only show that under the exposed conditions its lifetime is low. The short period of work presented by piezoelectric sensors generates a predictive mathematical model with a decreasing behavior. The behavior of the voltage generated by the piezoelectric sensors is logarithmic, which is evidenced by the rapid drop in the generated voltage. The largest voltage spikes are generated at the beginning, going from around 70V to 30V after the first few steps. This is related to the effort that the sensors must make to return to their resting state after being deformed and to the damage that is generated with use.

It is possible to prolong the lifetimes of piezoelectric sensors through improvements in the damping system, it is recommended to analyze the investment costs of the sensors with respect to the capacity to generate energy. As an example of a damping system, it is recommended to explore the incorporation of energy storage mechanisms such as springs that can be deformed by accumulating mechanical energy and then delivering it in a controlled way to piezoelectric.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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