International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 14, No. 3, September 2023, pp. 1633~1638
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i3.pp1633-1638

An investigation of piezoelectric tile with drop test technique for energy harvesting application

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Article Info

Article history:

Received Sep 13, 2022
Revised Jan 19, 2023
Accepted Feb 6, 2023

Keywords:

Bending mechanism
Drop test
Fall concept
Piezoelectric tile
Transducer

ABSTRACT

This paper present test and analyses of piezoelectric transducers tile with drop test technique. This piezoelectric tile was tested together with bending mechanism. The bending mechanism was designed using SolidWork software and manufactured by employing 3D printer technology to conduct the evaluation. The piezoelectric transducers connected in a parallel configuration and inserted in piezoelectric tile together with bending mechanism. The drop test employed to test this piezoelectric tile with various loads and speeds. This test conducted based on free fall concept. A wooden box used as a guide to drop an object onto the piezoelectric tile. The various weight load released at a fixed height with different speeds. The output power generated based on the weight and speed of the object were recorded with average force applied on piezoelectric transducer. The highest output power generated was 634.54 µW when 6 kg load released at 2 drop/s with 1.89 N average force applied on each piezoelectric transducer. The lowest output power generated was 6.28 µW when 1 kg load released at 0.5 drop/s with 0.22 N average force applied. The results showed good output power of the piezoelectric transducer was generated for energy harvesting application.

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1. INTRODUCTION

A person can go without food for a couple of weeks, water for a few days, and air for mere minutes. But without electricity, it's hard to say as this electrical energy become the most basic needed in this era for all our daily activities. It will collapse our economy, production, infrastructure and even worst our humanity. Fossil fuel, natural gas and coal are usually the main sources of electricity generation in Malaysia [1], [2]. These existing non-renewable reservoir sources are the main factor leading to air pollution, polluted soil, water shortages, widespread human illness, and ecosystem degradation [3], [4]. It also continuously declines, and it cannot fulfil the demand as the human population increases. This has prompted researchers to seek an alternate approach to harness energy from a different source such as renewable energy [5]. Renewable energy resources are more socially, environmentally friendly and they will not diminish run out as they can be rapidly replenished. However, renewable energy resources are irregular and intermittent as it is also vulnerable to weather and climate change.

In line with the growth of the human population, humans can be a replacement for the source of electrical energy. The human body contains massive amounts of energy produced by metabolism, thus offering an alternative source of energy. This energy steams from typical body movements and essential body functions such as arm and leg swings, bending joints and elbows, finger movements while typing, blood movements, air movement while breathing and energy while walking. Generally, this energy is wasted as heat and other types of energy, however, this energy can be harvested and converted into electrical energy [6]. Walking is the main activity throughout our daily life and the average step for an individual in a day is around 3000 to 5000 steps [7]. Moreover, based on [8] the highest average daily power is generated from foot strikes making walking activities the most suitable for energy harvesting and will become enormous resources for electrical energy. In addition, harvesting this kind of energy from human walking is more reliable as it did not rely on or depend on climate change or location [9]. Harvesting energy from the human body has become an attraction to many researchers as in this technology, the individual becomes the producer as well as a consumer for the self-produced energy and they are no longer an end user as they would be for other renewable energy. These are known as the feedback loops as all the energy harvested is reused by the producer [10]. The mechanical energy produced by the footsteps can be used to generate electrical energy. There are three types of mechanical energy that can be converted to. electrical energy, namely electromagnetic, piezoelectric, and electrostatic but piezoelectric is the most prominent [11]. To harvest this energy, the most suitable transducer that can be used is piezoelectric transducer. This transducer detects the vibration or pressure that is applied to it and then converts it to electrical energy [12].

There are several methods used in generating power energy by using human footsteps. Usually, walking energy is harvested by placing the piezoelectric transducer in shoes or attached to the legs. Basani *et al.* [13] harvest the energy from human motion through macro fiber composite (MFC) piezoelectric patch. In this research, the piezoelectric patch was placed at the knee or elbow joint and collected the kinetic energy from the movement of the bending joint and collected about 10.4 µW output power. Fan *et al.* [14] is one of the researchers that mounted piezoelectric transducers in the shoe to generate energy from walking. This shoe was tested on the treadmill by a male subject of 1.7 m height, 65 kg weight and walking speed ranging between 2 km/h to 8 km/h and generated power output from 0.03 mW to 0.35 mW. In addition, Joo and Zuraini [15] also harvest the energy through walking by inserting piezoelectric transducer into shoes and tested with four different walking speeds and generated about 96.25 µW. On another note, Izadgoshasb *et al.* [16] conducted slightly different from other research by holding the piezoelectric element with a cantilever beam and the accelerometer. This prototype is attached to the shin of the leg and tested with the leg swung during walking. The highest power produced was about 2779 µW. Besides that, piezoelectric transducer also can embed into the floor to harvest the energy as a macro power source that implanted in a wide area. A study done by Kim *et al.* [17] harvest energy from the floor tile with a size of 20×20 cm^2 consisting of piezoelectric PZN0.5C thick films, resulting in peak voltage and current of about 42 V and 11 µA, respectively when it stepped on by a subject with 80 kg weight.

Hamid *et al.* [18] also used the floor concept to harvest the walking energy as they designed piezoelectric tiles with four piezoelectric in parallel connections. This piezoelectric tile was tested using the standard interface technique, and power of 1.61 mW was generated, but when attached to the flyback converter, the optimum power obtained was about 1.3468 mW. The circuit was completed when the buck converter was attached, and the maximum power output measured was 1.03 mW. In addition, Putri *et al.* [19] and Hwang *et al.* [20] also designed a floor tile and generated about 6.04mW for average power and 0.12mW for root mean power respectively. Panthongsy *et al.* [21] also harvest the energy by using floor tile but the concept of harvesting was a little bit different as it operated based on the concept that the lead zirconate titanate (PZT) unimorph cantilever deflects when there was an interaction between the permanent magnet and an iron bar. The tile was tested and 1.24 mW average power was generated. As the output of the piezoelectric transducer is low, a bending machine is designed to assist the piezoelectric transducer in its deflection process. Plinio *et al.* [22], Abdal and Leong [23] and Asry *et al.* [24] decided to design a bending mechanism to assist their piezoelectric transducers to generate more energy. The results of their research showed that the output energy with a bending mechanism was higher compared to without a bending mechanism. The performance of the piezoelectric output must test by applying pressure or force to it. Usually, the piezoelectric tile is tested with a human footstep, but the force applied by the human cannot be controlled. The free-fall concept is used to solve the problem and imitates human footsteps. Abdal and Leong [25] used a free-fall concept to study the effect of impact force on the piezoelectric transducer. The experiment was conducted with different objects and different masses from 5 gm to 40 gm. The object freely falls from different heights giving the impact force to the piezoelectric transducer that is mounted with the 3D printed prototype. This paper presents the piezoelectric tile tested with the drop test technique. The nine-round piezoelectric transducer was connected in parallel connection and inserted into the piezoelectric tile with bending mechanism then it was tested with a drop test using the free-fall concept to generate electrical energy. The amount of the electrical energy generated is based on the weight load and speed that release to press on the piezoelectric tile. The force applied to the piezoelectric tile is also being measured by a force sensor that is placed on each of the piezoelectric transducers.

2. RESEARCH METHOD

In this research, lead zirconate titanate (PZT) is used as a transducer to harvest the mechanical energy from human footsteps and convert it into electrical energy. The nine-round shape piezoelectric transducers crystalline structure with a diameter of 50 mm are used to form a piezoelectric tile. Piezoelectric tiles consist of piezoelectric transducers in parallel configuration together with a bending mechanism and the force sensors that are placed on the piezoelectric transducers. A drop test was conducted on the piezoelectric tile to generate electrical power based on different weight loads and speeds. This test was conducted based on the free-fall concept. In this research, a wooden box was used as a guide to drop objects onto the piezoelectric tile. The object used in this research was water containers of various weights. The drop test was conducted with different weight loads and speeds to analyze their effects on the average power generated by the piezoelectric transducer. This drop test technique was used to test the output power from the piezoelectric tile. It resembled a human walking on the piezoelectric tile with different body weights and walking speeds. Instead of using humans, this drop test enables the force applied to the piezoelectric tile to be controlled. Figure 1 shows the wooden box for the drop test set up with a water container as weight.

Different load weights were selected to carry out the test. The loads were divided into six different weights, namely 1, 2, 3, 4, 5 and 6 kg. Each weight was released at four different speeds, such as 0.5 drop/s (10 drops in 20 s), 1 drop/s (20 drops in 20 s), 1.5 drop/s (30 drops in 20 s) and 2 drop/s (40 drops in 20 s). The weight load was released at a fixed height of 50 mm. Table 1 shows the factors included in this test.

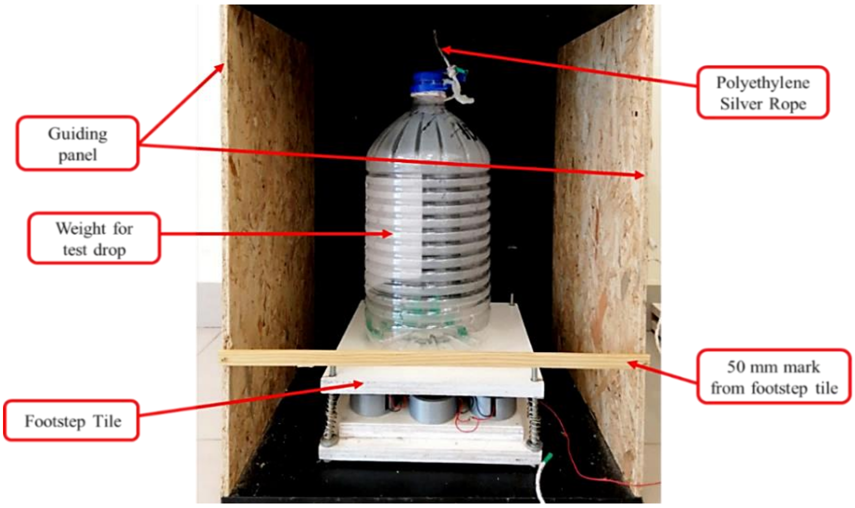

Figure 1. Drop test setup

Table 1. Parameters included in the test

Factors	Details
Weight load range	1 kg
	2 kg
	3 kg
	4 kg
	5 kg
	6 kg
Height	50 mm
Speed	0.5 drop /sec (10 drops in 20 s)
	1 drop/sec (20 drops in 20 s)
	1.5 drop/sec (30 drops in 20 s)
	2 drop/sec (40 drops in 20 s)

3. RESULTS AND DISCUSSION

The test was carried out to investigate the effect of different weight loads and speeds on the amount of electrical energy generated by the piezoelectric transducers. The force sensitive resistor placed on each piezoelectric transducer was collected for each load and the total force was recorded as shown in Table 2. The total force represented the forces of all nine piezoelectric transducers, while the average force was the force estimated for each piezoelectric transducer. Table 3 shows the average power generated when the different weight loads and speeds were applied on the piezoelectric tile. Figure 2 shows the amount of electrical energy generated by different weight loads under different speeds with constant height.

Table 2. Total amount of force and average force for each load

Load	Total force (N)	Average force (N)
1	2	0.22
2	5	0.56
3	8	0.89
4	11	1.22
5	14	1.56
6	17	1.89

Table 3. Average power generated by different weight loads under different speeds

Load/time	0.5 drop/s (μW)	1 drop/s (μW)	1.5 drop/s (μW)	2 drop/s (μW)
1	6.284	23.44	31.89	47.82
2	14.87	42.39	61.34	98.73
3	39.74	94.58	136.30	167.31
4	54.78	106.40	166.04	195.72
5	98.05	159.88	264.76	316.19
6	127.21	307.30	457.78	634.52

Since the piezoelectric transducers were installed into the piezoelectric tile in this research, a water container was used as a load to provide stress to the tile. The weight load was represented by the amount of water filled in the water container. Based on theoretical, the greater the weight load released on the footstep tile, the greater the amount of stress applied onto the piezoelectric transducers. Hence, a greater amount of electrical energy was produced. Based on Figure 2, as expected, the result showed that as the weight load increased, the output power of the piezoelectric transducer also increased.

As mentioned above, the amount of the electrical energy produced increased linearly with the load applied to the piezoelectric tile. Moreover, as shown in Figure 2, the electrical energy generated also depended on the load speed. The load speed represented the number of drops released on the piezoelectric tile in 20 s. The lowest load speed of 10 drops was recorded in 20 s, while the highest load speed was 40 drops in 20 s. Faster load speed applied to the piezoelectric tile resulted in higher output electrical energy produced. The output power generated by piezoelectric transducers increased with the increasing of speed released onto the footstep tile as shown in Figure 2. This proved that the results obtained in the testing followed the theory.

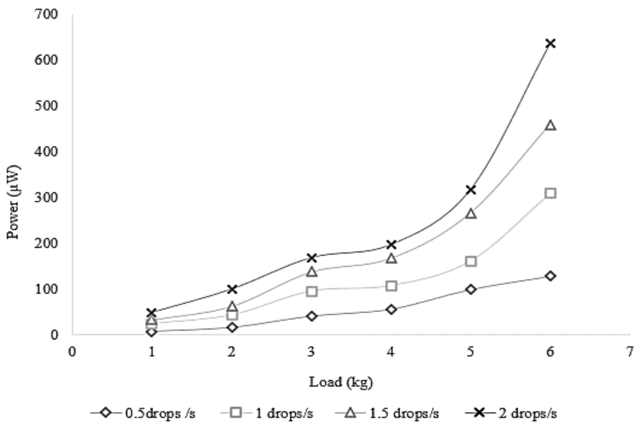

Figure 2. Amount of average power generated by different weight loads under different speeds

4. CONCLUSION

This research paper outlined a drop test on piezoelectric tile. In this test, the loads ranging from 1 kg to 6 kg were released at a constant height in four different speeds. Each force value for each load was measured with force sensitive resistor. The highest output power recorded was 634.54 μW when the load with 6 kg was released at speed of 2 drop/s with average force of 1.89 N for each piezoelectric transducer. This drop test resembles the human footsteps step on the piezoelectric tile. This test shows that the piezoelectric transducer can harvest the energy from human footstep. This test also proof that the output power also depends on the weight load and load speed as the increase of weight and speed the output power also increase. In future, the piezoelectric tile can be placed in crowded area and it is specifically suitable to be placed at pavement street, stairs, ticket counter and exercise equipment such as treadmill. The walking energy that harvests by this piezoelectric tile will become useful energy and can be used to power up the light along the stairs, garden lamp, light street and other low power appliances.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge the support of the Universiti Tun Hussein Onn Malaysia through Tier 1 Grant No. H799.

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