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The Effect of Piezoelectric Shape on Energy Harvesting Shoes

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Abstract: Piezoelectric elements are commonly installed in shoe sole to make use of the piezoelectric effect due to the vibration generated by the human motion. Piezoelectric shoe is a great device that can be used to harvest energy and can be improved by adding more piezoelectric elements and providing storage to store the harvested energy. However, not many researchers focus on the analyzation of piezoelectric elements' shape that may affect the efficiency of energy harvesting. In this paper, piezoelectric energy harvesting shoes are designed with piezoelectric elements installed inside the soles of the shoes, thereby gaining mechanical energy from user while walking and running. The mechanical energy was applied to the piezoelectric elements and converted into electrical energy. Bridge rectifier was used to convert the AC voltage output into DC voltage. The project focused on analyzation of the efficiency between round and square shaped piezoelectric elements. Different shape of the piezoelectric element produced different amount of output voltage. Square shaped piezoelectric tended to produce lesser output voltage than the round piezoelectric element. A round piezoelectric with diameter of 4.5cm produced mean output voltage up to 11.56V and square piezoelectric with size of 4.5cm x 4.5cm produced 6.12V. However, this all depended on how much pressure that was applied onto the piezoelectric elements.

Keywords: Piezoelectric elements, Portable power supplies, Power harvesting shoes.

I. INTRODUCTION

Nowadays, energy shortage is becoming a serious issue with the increasing of energy consumption from the constantly growing population. With the usage of fossil fuels as energy sources throughout the years, mankind will be facing an energy crisis due to the exhaustion of the fossil fuels [1], not to mention the environmental problems they are leading to.

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As a result, there has been an increase of demands in developing energy harvesters. Wearable devices are getting a great attention with the current lifestyle of the human beings that demand some portable power supplies especially those who depend largely on their mobile devices. Many different type of energy harvester that using several of mechanisms namely thermoelectric [2], triboelectric Nano generator [3]-[4] and piezoelectric. Among these mechanisms, triboelectric Nano generator and piezoelectric energy harvesters are the simplest as they can directly convert mechanical energy into electrical energy. However, the triboelectric Nano generators use materials that are not available in the market [5], thus this project centered on the piezoelectric energy harvester. There are two types of piezoelectric effect such as the forward piezoelectric effect which converts mechanical energy into electrical energy and the inverse piezoelectric effect which in contrast, converts electrical energy into mechanical energy [1]. Piezoelectric energy harvesting uses the forward piezoelectric effect which triggers whenever pressure is exerted on the piezoelectric elements. Lead zirconated titanate (PZT) and polyvinylidene difluoride (PVDF) are piezoelectric materials that have high piezoelectric performance. PZT is inflexible, fragile, and weighty on the other hand, PVDF is fairly flexible, stable, and can be shape easily [5]-[7]. During walking and running, human produces vibration onto the shoes sole. This phenomenon is what make piezoelectric materials are suitable to be used in shoes for energy harvesting as forward piezoelectric effect will convert the mechanical energy produced by the vibration into electrical energy [8]. Besides that, a shoe has multiple spots in which high pressure is exerted, which are the heel and toe spots [3]. These are the most appropriate spots to place piezoelectric elements to acquire mechanical energy. There are only a few researches on piezoelectric elements for energy harvesting that focused on the comparison between two common shapes of piezoelectric elements, round and square. From the previous researches done, there were hardly any of them that focuses on the performance analysis of the shape in terms of their efficiency and suitability. The efficiency of the piezoelectric elements differed by their output voltage produced and besides that, these shapes have different properties in terms of their flexibility and durability. From these dissimilarity, a deeper analysis must be conducted to determine which shape piezoelectric element is more efficient on energy harvesting. This paper presents the analysist of the piezoelectric elements shapes effect on energy harvesting shoes.

The objectives are to create piezoelectric based shoes using round and square shaped piezoelectric elements, and to analyze the efficiency and suitability of the piezoelectric elements on the output voltages produced, to be used for energy harvesting through walking and running. This manuscript briefs the work of this study, which include the background of the piezoelectric, problem statements, objectives, scope of work and limitations. Then follows with the discussion on the piezoelectric effect, piezoelectric materials, and a review on past researches. The analyzation and comparison of output voltage produced by round and square shaped piezoelectric are discussed prior to the conclusion of this studies.

II. LITERATURE REVIEW

The mechanism of piezoelectric which are vibration and pressure, leads to several of projects with different type of applications. One of them is using wind, which developed as wind energy harvester. The generation of energy came from the vibration of piezoelectric elements that triggered by wind energy source [7]. Besides that, energy harvesters that used clicking mechanism were developed as well [1]. Electricity is generated by hitting and vibrating piezoelectric cantilever beams which can be applied from human footstep according to them. The clicking mechanism can be applied at sidewalk and roadway so it can be efficient especially in busy areas. Piezoelectric elements are widely involved in devices triggered by human motion. They are also installed in shoes to make use of the human motion. The shoe will convert mechanical vibration energy into electrical energy when pressure is applied to the shoe when it is used during walking or running [8].

A. Piezoelectric materials

Plenty of different type of piezoelectric elements are used in different harvesting energy projects. One of the material namely, Polyvininylidene difluoride (PVDF) has a flexible and stable characteristic. On the other hand, another common piezoelectric material, lead zirconated titanate (PZT) on the other hand is inelastic, fragile and heavy, thus limiting it to be used efficiently in energy harvesting [5]. From these characteristics, it is more suitable for the PVDF materials to be installed in shoes. However, PZT is also used in considerable amounts of projects due to their low cost [8]. Besides that, the same material is also suitable to be used for wind energy harvester. This due to the fact that the PZT is light weighted and much smaller in size [7].

B. The piezoelectric effect

The unique mechanism of piezoelectric came from the property of the material, known as the piezoelectric effect. There are two type piezoelectric effects namely the forward and reverse piezoelectric effect. Forward piezoelectric effect converts mechanical energy to electrical energy, while the reverse piezoelectric effect converts electrical energy into mechanical energy [1]. Using the forward piezoelectric effect, Flow of wind can be used to apply vibration force onto piezoelectric elements. This is because, the piezoelectric effect is sensitive even to a low speed wind [7].

Table I tabulates the advantages and disadvantages of using the piezoelectric effects. Piezoelectric effect uses a simple circuitry to work. While the output voltage produced are high, piezoelectric effect produced low output current which limits the usability of this characteristic of piezoelectric to generate high electricity [5]. Besides that, the piezoelectric elements are fragile and have low durability. The materials may easily break if too much pressure acted on it.

Table- I: Advantages and disadvantages of piezoelectric effect

Advantages	Disadvantages
Uncomplicated construction	Fragile material
Does not require external voltage source	High output impedance
High voltage output	Low output current

Figures 1 and 2 show the diagram for direct piezoelectric effect and inverse piezoelectric effect respectively. The direct piezoelectric effect is when mechanical stress is applied to the piezoelectric element producing electrical charge. On the other hand, the inverse piezoelectric effect happen the piezoelectric elements become strained, when electrical field is first applied to them [9].

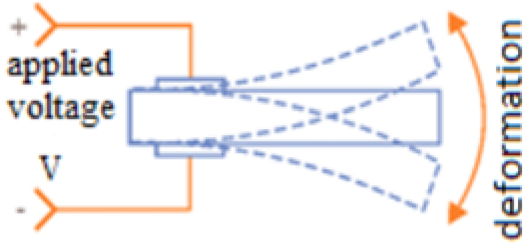

Fig. 1.Direct piezoelectric effect [9]

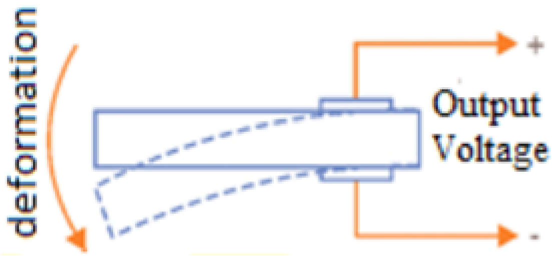

Fig. 2.Inverse piezoelectric effect [9]

C. Review of piezoelectric energy harvesting

Abundant researches have been conducted previously on piezoelectric energy harvesting using different piezoelectric materials, method used. In [8], lead zirconate titanate (PZT) was used. It was place in shoe sole to produce voltage and DC-DC step up converter used to boost up the voltage. The piezoelectric elements are placed at between toes and sole area which produced 2V and highest voltage produced when it placed at toes area which was 12V.

Meanwhile in [1], 4 polyvinylidene fluoride (PVDF) was placed below hitting pad to analyze the output generated from human footsteps.

From the study, it was shown that mean output voltage generated was 7.62V with power of 58.06mW. Maximum voltage produced was 18.44V with power if 340.04mW. In [10], multiple piezoelectric elements, PZT were stacked together. The study conducted on the effect of single, double and triple layer of piezoelectric elements on the output power produced. It was found that higher number of piezo elements produced higher output power.

In [5], PVDF was installed in sandwich structure. Multilayer PVDF were placed between two wavy plates. These plates of PVDF was placed on the ground and tested by stepping on it. Peak output voltage of 13.6V was produced from it. This method also proved that sandwich structure has high durability as the piezoelectric elements were protected by the plates. As previous study conducted in [10], when multiple layers of PVDF used, the output voltage increased. Fig. 3 shows sandwich structure of piezoelectric energy harvester.

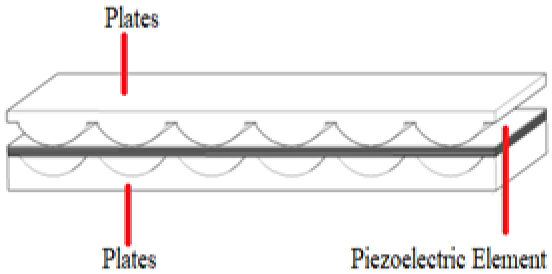

Fig. 3.Sandwich structure of piezoelectric energy harvester.

Study conducted in [11] used PVDF as piezoelectric elements. The experiment done by mounting the PVDF in shoes worn by soldier. The soldier shoes tested by 1 and 6 number of PVDF layers and different level of force. The experiments came to conclusion that higher force and higher number of piezoelectric elements increase the output voltage.

III. METHODOLOGY

In this project, two different shapes of piezoelectric elements, round and square were used in two different shoes. AC voltage was produced when mechanical pressure was applied onto the piezoelectric elements. Next, the AC voltage produced was converted into DC voltage using bridge rectifier circuit that consists of four 1N4001 diodes. The output voltages from the piezoelectric elements were then compared to find out which was more efficient in harvesting energy. The shoes were used for a single step, walking and running simultaneously at the same time to ensure accurate results.

A. Structure of piezoelectric energy harvesting shoes

A round and square piezoelectric element were used in this experiment as shown in Figures 4 and 5. The round piezoelectric element has a diameter of 4.5 cm and the size of the square piezoelectric element is 4.5 x 4.5 cm2. These piezoelectric elements were connected to rectification circuit which in this project was the bridge rectifier. The bridge rectifier consists of four 1N4001 diodes.

B. Experiment setup

A test was done to choose which position of piezoelectric element was the most efficient to harvest energy. A round shaped piezoelectric element was tested at three positions namely, heel, toes and between heel and toes. This setup tested by applying a single step and again, the experiment was repeated thrice to get the average output voltage.

Fig. 4.Round piezoelectric element (diameter = 4.5 cm).

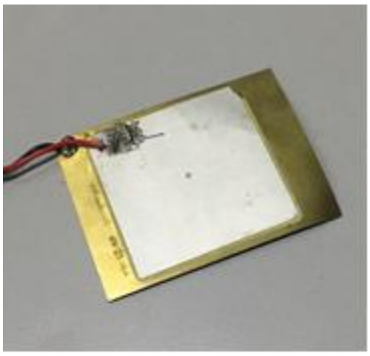

Fig. 5.Square piezoelectric element (4.5 cm x 4.5 cm).

From the result, mean output voltage produced at the heel position was the highest which tells that it was the spot with highest pressure applied by human foots. These results are show in Fig. 6.

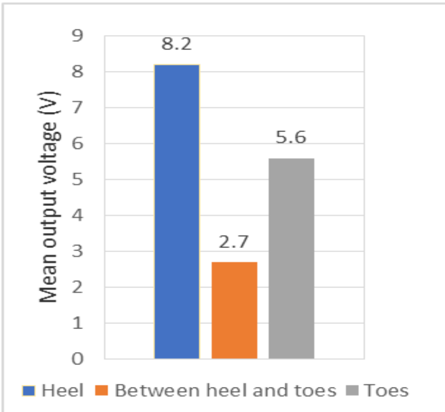

Fig. 6.Mean output voltages at 3 different positions

Next, two circuits were set up initially in the experiment. Each setup contains a bridge rectifier that connected to a multi meter and one piezoelectric element that varied by the shape at each setup.

These circuits were connected on a breadboard at first to test the connectivity and the voltage outputs. Same pressure was applied on each piezoelectric by dropping 3 different test weights with different weight on each piezoelectric element at the same height. Each result was recorded, and the process was repeated to get the mean output voltage. Fig. 7 shows the picture of test weights.

Fig. 7.Test weights.

To prove the hypothesis, two people with weight of 55kg and 73kg were used to compare the output voltage produced by the harvesting shoes with the difference in weight. The shoes were used by walking for 10 steps at the same speed and the maximum output voltage produced was recorded. The experiment was then proceeded with the running test by the same people with same weight. The mean output voltage was calculated by repeating the experiment thrice and maximum output voltage was recorded. Fig. 8 shows the overall circuit design with piezoelectric element and digital voltage meter. Digital voltage meter was powered by a 9V battery.

Fig. 8.Overall circuit design with piezoelectric element and digital voltage meter.

IV. RESULTS AND DISCUSSION

The analyzation was done through three different tests namely, drop test, walking test and running test. This section discusses about the results and the discussion from those tests.

A. Drop test

Table II shows the results from the drop test. From the results, the mean output voltage produced keep increasing as the weight increases. However, the square piezoelectric produced lower mean output voltage than round piezoelectric. Lowest mean output voltage produced by the square piezoelectric using the 1kg test weight which was 1.1V, and highest was 6.3V that produced by round piezoelectric using the 5kg test weight. Fig. 9 shows the graph for the output voltage produced from drop test.

Table II. Mean output voltage of drop test

Test weight (kg)	Mean output voltage	
	Round piezoelectric	*Square piezoelectric*
1	2.8	1.1
3	4.7	1.9
5	6.3	3.4

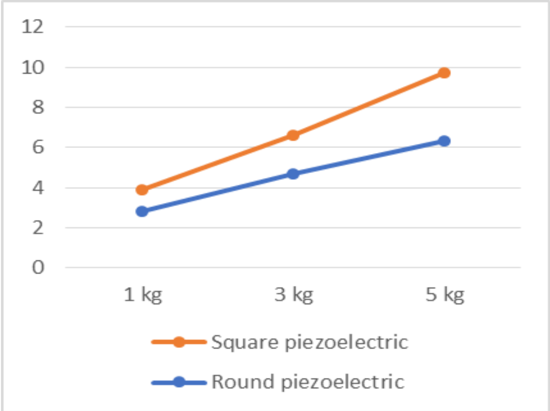

Fig. 9.Output voltage for drop test.

B. Walking test

From the result in Table III, the mean voltage for round piezoelectric is 7.12V which is higher than the one produced on square piezoelectric, 4.81V. The highest maximum output voltage produced by shoes with round piezoelectric element wore by the person with 73 kg. The maximum output voltage goes up to 15.3V. Lowest output voltage produced at 5.7V by the shoes with square piezoelectric. This proves that round piezoelectric is better to be used for energy harvesting as compared to the square piezoelectric and higher pressure enhances it. Fig. 10 shows the mean and maximum output voltage produced on round and square piezoelectric during walking.

Table III. Mean and maximum output voltage produced by walking

Sample weight (kg)		55	73
Round piezoelectric	*Mean (V)*	5.48	7.12
	Max (V)	12.6	15.3
Square piezoelectric	*Mean (V)*	3.23	4.81
	Max (V)	4.3	5.7

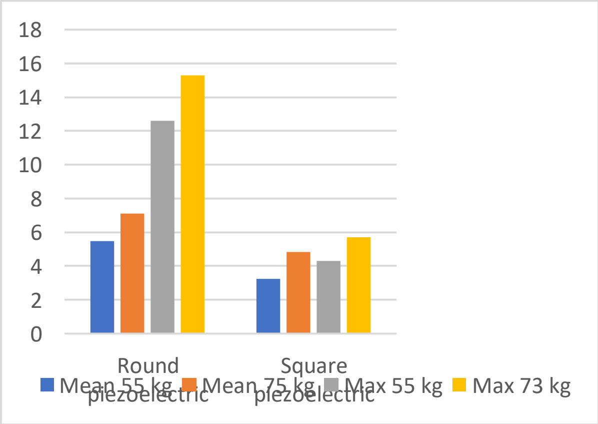

Fig. 10. Graph of mean output voltage for walking test

C. Running test

Table IV shows the result from the running test done on the same individuals. Highest output voltage produced from the running test was 21.7V which produced by 73 kg person using round piezoelectric shoes. The results show that highest mean voltage is 11.56V. This was also produced by the round piezoelectric shoes by 73 kg person. As compared to the results from the walking test, the mean and maximum output voltage produced from the running test were relatively higher. This is due to the fact that more pressure was exerted to the piezoelectric elements during running than walking. Fig. 11 shows the mean and maximum output voltage produced on round and square piezoelectric during running.

Table IV. Mean and maximum output voltage produced by running

Sample weight (kg)		55	73
Round piezoelectric	*Mean (V)*	9.21	11.56
	Max (V)	19.8	21.7
Square piezoelectric	*Mean (V)*	5.47	6.12
	Max (V)	7.0	9.3

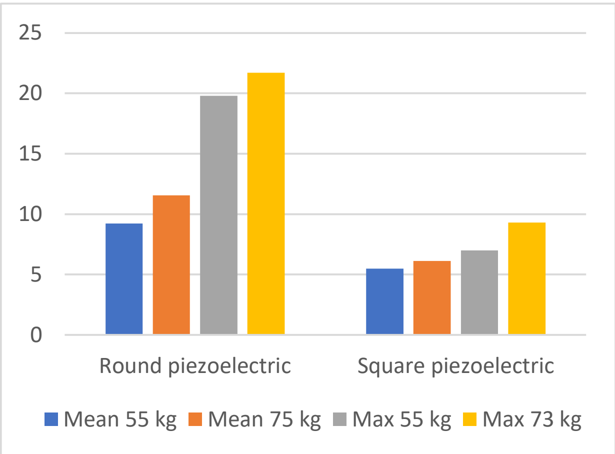

Fig. 11. Graph of mean output voltage for running test

From the results of the tests, it is found that when higher weight is applied onto a piezoelectric element, higher output voltage is produced. This is due to the fact that higher weight exerted more pressure onto the piezoelectric element and thus providing more mechanical force to it. Next, the findings show that round shaped piezoelectric element is more efficient for energy harvesting shoes as compared to the square shaped piezoelectric element. This is because there are some parts on square piezoelectric materials that are not touched by human's foot whereas all spot on round piezoelectric materials era touched during walking and running. Therefore, a more consistent mechanical force is applied to the round piezoelectric materials thus producing higher output voltage.

V. CONCLUSION

In this project, piezoelectric energy harvesting shoes is developed using round and square piezoelectric elements. These elements are suitable to be installed in shoes and work as planned. From the experiment done, round shaped piezoelectric are the most efficient for energy harvesting. The output voltage may go to the highest limit by adding more pressure or vibration on the piezoelectric elements. Piezoelectric energy harvesting shoes is a decent device to harvest energy as piezoelectric element is cheap and small in size that can easily fits into shoes. The piezoelectric shoes can however be improved by connecting more piezoelectric elements in parallel to produced higher output voltages. Besides that, further improvement can be done by adding storage to store the produced output voltages.

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