SPECTA Journal of Technology
E-ISSN : 2622-9099
P-ISSN : 2549-2713
Homepage jurnal: https://journal.itk.ac.id/index.php/sjt

Piezoelectric Trasducer Based Micro Energy Generator Design for Application in Ceramics

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Abstract

The rapid development of technology causes humans to provide a large amount of energy, especially electrical energy. One of the new renewable energy sources is a piezoelectric-based energy harvester. Piezoelectric is a material that has an electric polarizing effect that occurs when the material is given mechanical stress. The potential difference measured across the piezoelectric material is proportional to the applied pressure. This study aims to examine the prototype of a piezoelectric-based micro energy generator using different loadings on ceramics. This research was carried out by making a prototype on a 30x30 cm^2 ceramic and using a piezoelectric in the form of a PZT type. The method used in this research is measuring the voltage of each configuration variation in the piezoelectric circuit. Retrieval of stress data was done by dropping a load of 3kg, 6kg, and 9kg for each variation. From the test results, it was found the position that produces the greatest voltage is at the center of mass of 4.75V. While the results of piezoelectric configurations in series and parallel, the greatest results are obtained with the series configuration adjacent to the center of mass or load which is most affected by piezoelectricity and using the largest loading. The voltage value obtained is 8.5V. The conclusion obtained from this study is that the distance between the piezoelectric position to the center of mass affects the voltage generated, each additional load will cause an increase in voltage, and a series circuit produces a greater voltage than a parallel circuit.

Keywords: Ceramic, Load, Piezoelectric, PZT, Voltage

Abstrak

Pesatnya perkembangan teknologi menyebabkan manusia untuk menyediakan energi yang cukup besar, khususnya energi listrik. Salah satu sumber energi baru terbarukan yang masih dalam tahap pengembangan adalah pemanen energi berbasis piezoelektrik. Piezoelektrik sendiri merupakan bahan yang memiliki efek polarisasi listrik yang terjadi pada material bahan tertentu ketika bahan tersebut diberikan suatu tekanan mekanis. Beda potensial yang terukur di seluruh material piezoelektrik sebanding dengan tekanan yang diberikan. Penelitian ini bertujuan untuk meneliti mengenai prototipe pembangkit energi mikro berbasis piezoelectrik dengan menggunakan pembebanan berbeda pada keramik. Penelitian ini dilakukan dengan cara membuat sebuah prototipe pada keramik ukuran 30x30 cm^2*, dan menggunakan piezoelektrik berjenis PZT. Metode yang digunakan pada penelitian ini adalah pengukuran tegangan tiap variasi konfigurasi pada rangkaian piezoelektrik. Pengambilan data tegangan dilakukan dengan cara menjatuhkan beban 3 kg, 6 kg, dan 9 kg pada tiap variasi yang akan diuji. Dari hasil pengujian didapat bahwa posisi yang menghasilkan tegangan paling besar berada*

Submitted May 2023, Revised May 2023, Accepted May 2023, Published May 2023
DOI: 10.35718/specta.v7i1.867

pada pusat massa sebesar 4.75 V. Sedangkan hasil konfigurasi piezoelektrik secara seri dan paralel, didapat hasil terbesar dengan konfigurasi seri yang berdekatan dengan pusat massa atau beban yang paling banyak terkena piezoelektrik serta menggunakan pembebanan terbesar. Nilai tegangan yang didapat adalah 8.5 V. Kesimpulan yang didapat dari penelitian ini adalah jarak antara posisi piezoelektrik terhadap pusat massa berpengaruh terhadap tegangan yang dihasilkan, setiap penambahan beban akan menyebabkan peningkatan tegangan, dan rangkaian seri menghasilkan tegangan yang lebih besar dari rangkaian parallel.

Kata Kunci: Beban, Keramik, Piezoelektik, PZT, Tegangan.

1. Introduction

In the early 20th to 21st century, technology in various industrial sectors developed very rapidly along with many discoveries, such as communication, electronics technology, and so on. From the rapid development of this technology, humans are required to provide a large enough energy, especially electrical energy. Energy generation capacity in Indonesia installed is 64,924.80 MW per year 2018 with electricity produced from primary power plants dominated, such as PLTU (42.34%), PLGU (17.28%), PLTA (8.27%), and others. Meanwhile, the electricity generated from renewable energy plants in Indonesia is dominated by PLTM (0.44%), PLTB (0.22%), PLTBg (0.17%), and others (Directorate General of Electricity, 2019). Primary energy generators are a large contributor of energy than renewable energy generators, so they are classified as primary power plants. Meanwhile, renewable energy generators are classified as supporting power plants because the energy produced is smaller than primary energy generators.

The use of primary energy for electricity generation is regulated in Undang-Undang Nomor 30 Tahun 2009 pasal 6 concerning Electricity. Through this regulation, the government targets that the portion of new renewable energy must continue to increase every year (National Electricity General Plan, 2019). Continuous use of primary energy will cause energy resources to run low and scarcity will occur, therefore the use of new renewable energy sources is an alternative to overcome this problem and as a potential new energy source to replace primary energy sources.

There are two kinds of renewable energy sources, micro and macro energy (Kim, 2011). Macro energy generation utilizes natural assets on an expansive scale and can be utilized continuously, for illustration geothermal, wind and sun powered. Micro energy generators make utilize of waste energy sources from human exercises or machine instruments within the encompassing environment, for illustration, footsteps, mechanical stress, body temperature, mechanical vibrations, and so on (Deenadayalan, 2012). In this paper, the authors researched micro energy by footsteps. Output from micro energy was small so it could not be directly used. If the power need to used, it must be harvested. The harvesting process means extracting, converting, and saving energy from the results of environmental energy (Fredy, 2022).

Based on this, research on new renewable energy generators really needs to be done. One example of a new renewable energy generator is an energy harvester based on a piezoelectric transducer (N. H. bin A. R. Norkharziana Mohd Nayan, 2015). Piezoelectric transducer-based energy harvesters use a source of mechanical energy to be converted into electrical energy (Meriam BA, 2023; E. Yulianti, 2012). Some potential sources of mechanical energy around which can be harvested into electrical energy are transportation movements, industrial noise, human movements, and others (A. Shukla, 2018). Of the several potential sources of mechanical energy that are around us, one of the sources of mechanical energy that has the greatest opportunity to be harvested is human movement (Xin, 2016). Many studies have been carried out on mechanical energy harvesters for human movement based on piezoelectricity, such as contact force (Mitsuhiro S., 2003), but many things need to be observed to produce a large enough voltage such as the distance between the center of mass and the piezoelectric position, the configuration used as an energy harvester, and the output voltage in alternating form (AC) and direct current (DC) (Hong J, 2022).

Submitted May 2023, Revised May 2023, Accepted May 2023, Published May 2023
DOI: 10.35718/specta.v7i1.867

Based on this, it was necessary to carry out further research regarding the utilization of potential sources of mechanical energy for human movement that would be harvested by piezoelectric based energy harvesters. Some of the previous studies in this regard include the floor of the power plant using the balanced cantilever method using LM2596 (Diana Rahmawati, 2021), the prototype design of an energy harvesting system using piezoelectricity that was installed on the floor and generates electrical energy when under pressure using LTC358 (Kusnandar, 2021)

Some crystalline materials such as quartz, Rochelle salts, even human bones exhibit a direct piezoelectric effect. However, there are materials available specifically made to exhibit a direct piezoelectric effect, for example Lithium niobate and Lithium zirconate titanate (PZT) (E. Yulianti, 2012). Piezoelectric energy harvesters are expected to operate in a variety of ambient environments mainly using PZT (R. Ambrosio, 2011).

From the background above, a prototype energy harvester based on a piezoelectric transducer was created using a mechanical energy source to be converted into electrical energy. This study aims to determine the effect of the distance from the center of mass on the voltage generated by the prototype and to determine the effect of the configuration of the number, position and piezoelectric circuit due to varying loading on the prototype. The update used is the ceramic floor which is usually used in homes. From the data obtained, the maximum configuration results are sought to get a large voltage.
he piezoelectric energy harvesters are expected to operate under a wide range of ambient environments. This work considered the energy harvesting system for ambient range oper-
ation, i.e. the use of low frequency resonance of the piezoelectric cantilever.

2. Methods

In this study, the piezoelectric used by PZT made from ceramics is due to its better performance than other materials (Tao Li, 2021). The prototype energy harvester based on a piezoelectric was designed on a ceramic measuring 30×30 cm^2. Prototype testing used 3 different dimensions. This prototype was designed to see the effect of the distance of the center of mass of the system on the generated voltage, and to know the most optimal configuration of the number and position of the piezoelectric in generating the voltage. The stages of the research can be seen in the flowchart of Figure 1.

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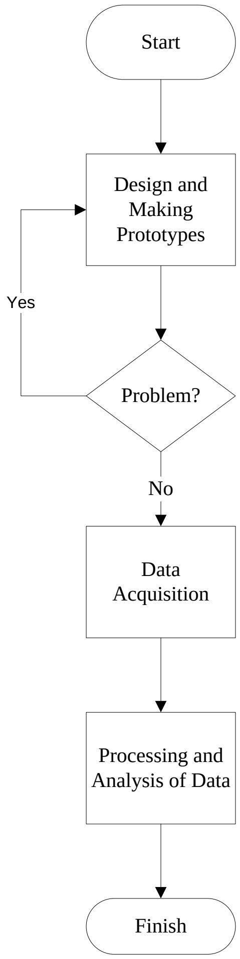
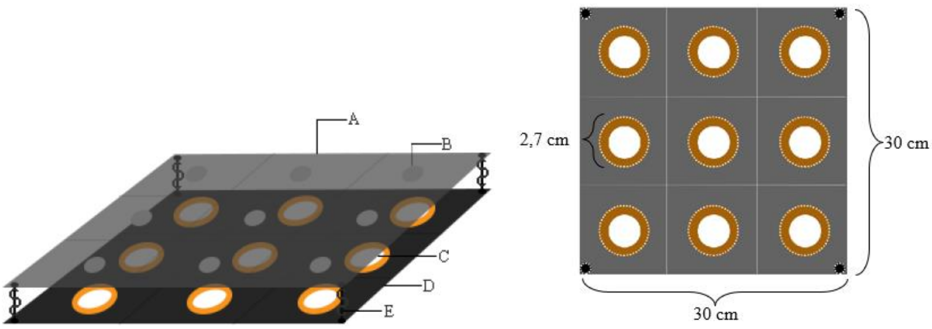


Figure 1. Research Flowchart

2.1. *Design and Making Prototypes*

In harvesting micro-energy from footsteps, a harvester prototype is needed.



(a) (b)

Figure 2. (a) Front View Prototype Design; (b) Top View Prototype Design

In Figure 2, part A is a ceramic part that functions as an area that receives pressure from a dropped object. Part B is the part of silicon that attaches to the bottom of the ceramic which functions as a distributor or connector between the ceramic and the piezoelectric. Part C is the most important part, namely the piezoelectric circuit which functions as the main component in the pressure-to-voltage conversion process (pressure energy harvester). Part D is the part of the plywood that functions as a place for the piezoelectric circuit to be placed. Part E is a clamp part consisting of bolts, nuts and springs which function as a binder between the ceramic and the plywood, as well as a component that will return the ceramic to its initial position.

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The initial step in prototyping was to determine the location of the piezoelectric on the plywood. The size of the ceramic to be used is 30 x 30 cm^2 and was divided into 9 parts. Each part would be placed piezoelectric according to Figure 3. Piezoelectric position no. 5 was the center of the ceramic mass. After that, the piezoelectric circuit was closed using ceramic and given a clamp in the form of a bolt, nut, and spring.

1	2	3
4	5	6
7	8	9

Figure 3. Piezoelectric Assembly Sequence

2.2. *Data Acquisition*

The data collection in this study was divided into 2 parts, namely the stress data collection resulting from differences in the distance to the center of mass and the stress data collection resulting from the influence of the variations used. Retrieval of voltage data generated due to the influence of differences in the center of mass was carried out by measuring the voltage generated by each piezoelectric position using 1 piece of load, the load would be dropped with 3 different dimensions. The first load dimension was 9 cm × 23 cm × 7 cm, the second load dimension was 7 cm × 23 cm × 9 cm, and the third load dimension was 7 cm × 9 cm × 23 cm. The piezoelectric positions to be tested were positions no.1 to no.9 based on Table 1. Each of these positions would be tested for the resulting stress value due to the influence of the distance to the center of mass of the different systems.

Table 1. Variations Piezoelectric Circuits

Variation	Quantity	Position	Connexion
1-1	1	5	-
2-2	2	4; 6	Series; Parallel
3-2	2	1; 9	Series; Parallel
4-3	3	2; 5; 8	Series; Parallel
5-3	3	1; 5; 9	Series; Parallel
6-4	4	2; 4; 6 ;8	Series; Parallel
7-4	4	1; 3; 7 ;9	Series; Parallel
8-5	5	2; 4; 5; 6 ;8	Series; Parallel
9-5	5	1; 3; 5; 7; 9	Series; Parallel
10-6	6	1; 2; 3; 7; 8; 9	Series; Parallel
11-6	6	1; 3; 4; 6; 7; 9	Series; Parallel
12-7	7	1; 2; 3; 5; 7; 8; 9	Series; Parallel
13-7	7	1; 3; 4; 5; 6; 7; 9	Series; Parallel
14-8	8	1; 2; 3; 4; 6; 7; 8; 9	Series; Parallel
15-9	9	1; 2; 3; 4; 5; 6; 7; 8; 9	Series; Parallel

Retrieval of voltage data generated by piezoelectric variations was carried out by measuring using a multimeter which would measure the AC voltage of the piezoelectric circuit. The data taken was in the form of piezoelectric circuit output AC voltage. The load would be dropped without being given any force from a height of 2 cm above the ceramic, then the piezoelectric circuit would respond to the pressure exerted by the load.

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2.3. *Processing and Analysis of Data*

The data analyzed includes the center of mass, the magnitude of the voltage generated by the piezoelectric configuration (quantity, position, and connexion) with varying loading, and the output of the piezoelectric circuit. The processed center of mass data will be used as a reference for determining the distance between the center of mass and the piezoelectric position, placing the piezoelectric at a distance closer to the center of mass will greatly affect the results of the output voltage. Apart from the center of mass, another aspect that is very influential so that the piezoelectric can produce a greater voltage is the piezoelectric configuration (amount, position, and circuit). The output of the piezoelectric circuit in the form of an AC voltage will be compared with the output of the piezoelectric circuit using a rectifier (DC) in order to see the most optimal output. Discussion regarding the influence of the distance between the center of mass and the piezoelectric position, the placement of the piezoelectric at a distance closer to the center of mass, and the piezoelectric configuration will be explained in the next chapter.

3. Result and Discussion

3.1. *Center of Mass*

Ceramics with different dimensional loads have different centers of mass. The ceramic used had dimensions of 30 cm × 30 cm × 0.5 cm. The first load dimension was 9 cm × 23 cm × 7 cm, the second load dimension was 7 cm × 23 cm × 9 cm, and the third load dimension was 7 cm × 9 cm × 23 cm. The coordinate point (0,0,0) was at the upper left end of the bottom of the ceramic as shown in Figure 4 in order to facilitate the calculation of the center of mass of the ceramic and the load.

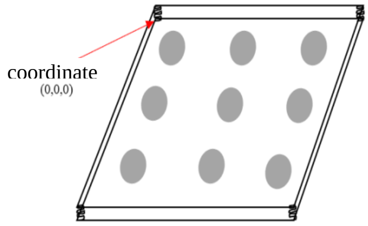

Figure 4. Coordinates (0,0,0) on the Prototype

The results of calculating the distance between the center of mass and the piezoelectric position are presented in Table 2. In accordance with Figure 2 where the center of mass of the ceramic was in position 5, the center of mass between the ceramic and the load both load 1, load 2, and load 3 remains in position 5. This was evidenced by the results from table 2. The smaller the distance between positions 5 in figure 2 with objects (ceramics and loads) it proves that it is getting closer to the object's center of mass

Table 2. Center of Mass of the System to the Piezoelectric Position

Mass	Position (cm)								
	1	2	3	4	5	6	7	8	9
Ceramic + load 1st	14.81	10.45	14.81	10.45	3.06	10.45	14.81	10.45	14.81
Ceramic + load 2nd	14.99	10.70	14.99	10.70	3.81	10.70	14.99	10.70	14.99
Ceramic + load 3rd	17.09	13.49	17.09	13.49	9.06	13.49	17.09	13.49	17.09

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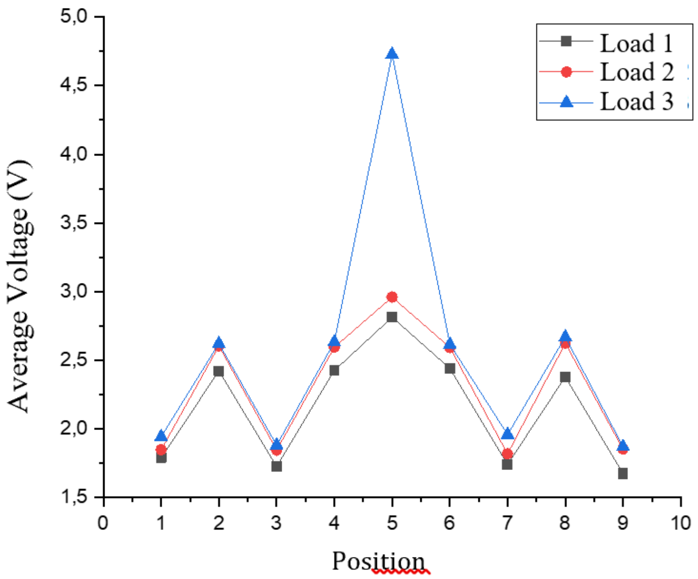

Figure 5. Graph of Average AC Voltage for Each Piezoelectric Position

Both load 1, load 2, and load 3 have a large average stress value near the center of mass (position 5). At position no.5 when dropped by load 1 and load 2 had an average stress that approaches each other because load 1 and load 2 had a similar system center of mass, but when dropped by load 3 the average stress generated by position no. 5 jumped up because there was a difference in the distance between the center of mass and the piezoelectric position which was very far away compared to using load 1 and load 2. The largest average voltage value come from load 3 at position 5. The voltage value was 4.75 V. While the lowest value was 1.75 V by load 1 with the farthest position from the center of mass (position 9). From the results of Figure 5, it was obtained that the ideal load as a harvester was load 3 as evidenced by the large stress results. This is consistent with the hypothesis that piezoelectric energy harvesters utilize energy that comes from inertial (Weipeng Z, 2022).

3.2. *Piezoelectric Configuration*

The magnitude of the piezoelectric output voltage is not constant because it is influenced by several things, one of which is the configuration. In this study, several configurations were tested to obtain the greatest voltage results. Some of these configurations were number, position, and piezoelectric circuit configurations. Configure the number of piezoelectric used at least 1 piece and a maximum of 9 pieces. Configuration of piezoelectric positions used as many as 15 different positions. The piezoelectric circuit configuration used was a series circuit and a parallel circuit.

In a piezoelectric circuit arranged in series and parallel, 3 loads were used. The three loads have different weights, namely 3 kg, 6 kg, and 9 kg. This study uses a different load because it wanted to see the effect of the load on the resulting voltage. In addition, we want to know the effect of the load on the configuration specified in series and parallel circuits.

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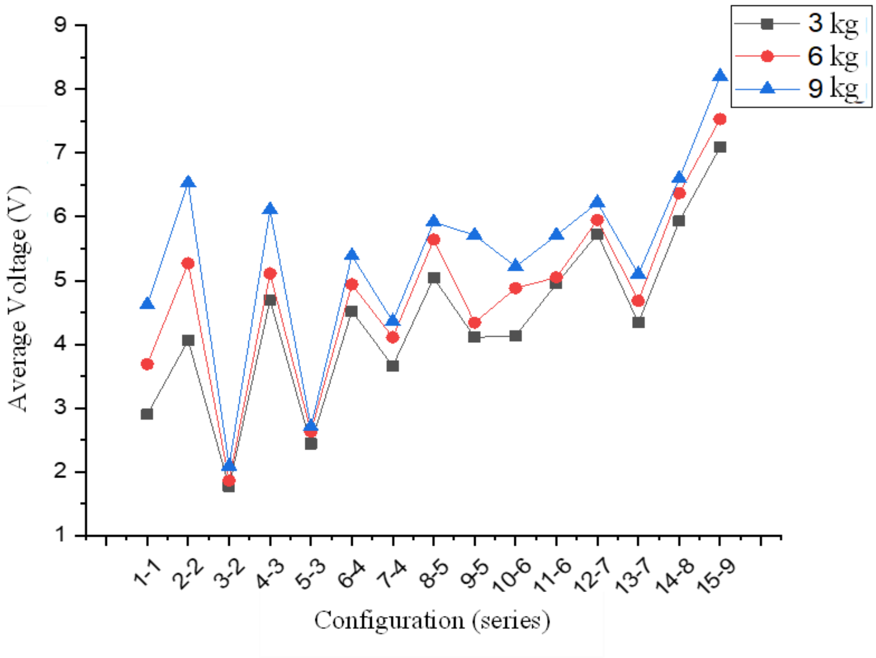

Figure 6. Series Configuration Average Voltage (AC) Graph

Figure 6 shows the average voltage value based on piezoelectric configurations arranged in series according to Table 1. In accordance with Figure 6, the lowest value is in configuration 3-2, this was because this configuration is farthest from the center of mass. While the 15-9 configuration had a large average voltage value because the amount of piezoelectric is exposed to the greatest load (8.5 V). From Figure 6, it can also be seen that the largest load, which is 9 kg, has a large stress value in each configuration.

In the 2-2 series and 3-2 series variations there is a significant difference in the average voltage. In the 2-2 series variation it is 6.53 while in the 3-2 series it is 2.09 V using a load of 9 kg. The difference in average voltage is caused by different piezoelectric placement, in variations 2-2 the piezoelectric placement is at no.4 and no.6 while in variation 3-2 the piezoelectric placement is at no.1 and no.9.

In the 2-2 series variation, the number of piezoelectric positions that have the closest distance to the center of mass is more than the 3-2 series variation. So that in variation 2-2 the piezoelectric series will produce greater pressure compared to variation 3-2. This also applies to variations that have the same amount of piezoelectricity but different placement of the piezoelectric positions. The variation that has the highest average stress is 15-9 series and the variation that has the smallest average stress is 3-2 series at each different loading.

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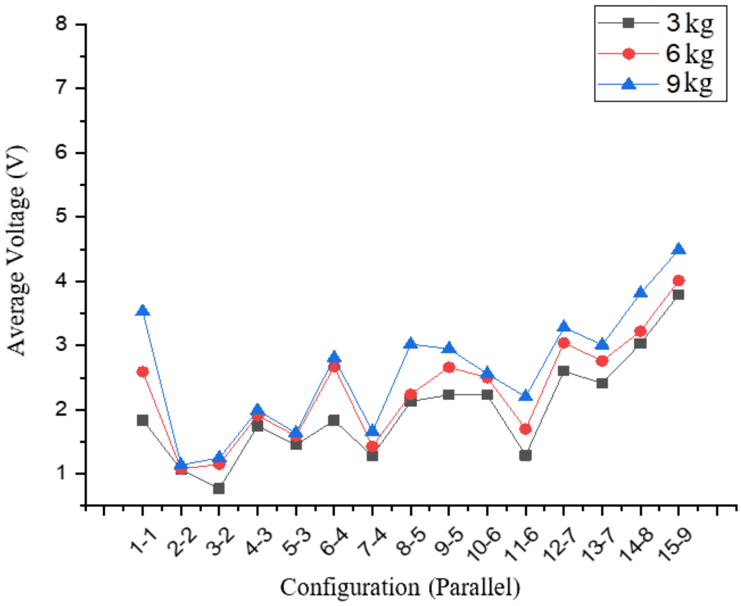

Figure 7. Parallel Configuration Average Voltage (AC) Graph

With the same configuration according to Table 1, the smallest average results are 2-2 and 3-2. This occurs due to the configuration used far from the center of mass and the number of positions that were exposed to the least pressure. The large voltage value is obtained from the 15-9 configuration. This was because the amount of piezoelectric was exposed to the greatest load. From Figure 9, it can also be seen that the largest load, which is 9 kg, had a large stress value in each configuration.

From the series and parallel piezoelectric configurations, when compared to the two, a large voltage value comes from the series configuration. Both of Figure 6 and Figure 7 have in common that the configuration that has the farthest distance from the center of mass and the amount of piezoelectricity affected by pressure will have the lowest average stress. In addition, the 9 kg load produces the highest voltage.

4. Conclusion

From the results of research that had been done it can be concluded that the center of mass is very influential on the voltage. The closer the distance between the piezoelectric positions to the center of mass, the greater the pressure received by the piezoelectric. So that the pressure will be converted into a greater voltage as well. The closer to the center of mass will produce a greater voltage in comparison. The configuration of the number, position, and piezoelectric circuit will result in varying loading. The more the amount of piezoelectricity used, the greater the average voltage generated. The greater the load imposed on the piezoelectric, the greater the voltage generated by the circuit. Besides that, piezoelectric arranged in series produce a greater voltage than those arranged in parallel. Series circuits are more appropriate for piezoelectric-based micro energy generation applications. This is because the voltage of each piezoelectric will be added up to the total voltage.

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Submitted May 2023, Revised May 2023, Accepted May 2023, Published May 2023
DOI: 10.35718/specta.v7i1.867