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Generating Characteristics of a Theta-type Piezoelectric Energy Harvester

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A theta-type piezoelectric energy harvester was proposed to increase the power generated by energy harvesters. The generating device consists of a rectangular piezoelectric ceramic plate and two hat-shaped elastic bodies. Both ends of the ceramic were clamped by the two elastic bodies at the upper and the bottom sides of the ceramic, and this structure converted vertical vibration or pressure on the device to a horizontal extension of the ceramic plate. This structure also lessens the stress of the ceramic because it can protect against direct pressure being applied to the ceramic. The theta-type generating device can generate electrical power by using the lower frequency vibrations that can be found easily in our lives. The generating characteristics of the piezoelectric harvester depended on the length and the width of the ceramic and were determined by using a finite-element-method program.

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I. INTRODUCTION

The environmental pollution and global warming caused by greenhouse gases have been worldwide issues for the last decade. Instead of fossil fuels, which are the main source of the pollution, needs for the development of various new alternative energy sources have been continuously increasing. Especially, attention to small energy sources for small sensors and electronic devices is increasing. A battery can be easily used as an energy source for small electronic devices, but a battery must be replaced periodically. As solutions of this problem, various energy-harvesting techniques have been proposed [1–5]. Energy-harvesting techniques generate electrical energy from natural energy sources such as sunlight, wind, pressure, vibrations and heat. Among these techniques, interest in developing piezoelectric harvesters has been steadily increasing. The piezoelectric harvester uses the direct piezoelectric effect to generate electric power by transducing a mechanical force [6–9].

In this work, a theta-type piezoelectric generating device that can be used in the low-frequency range is proposed. The structure of the proposed device is simple and easy to fabricate. Also the stress in the ceramic is lessened because direct contact to the ceramic is avoided. The output voltages of devices with different lengths and widths of both the ceramics and the elastic bodies were simulated by using a finite-element-analysis program ANSYS [10]. A prototype of the device was fabricated, and its output voltages were measured under various conditions. Then, the measured results were compared to the simulated results.

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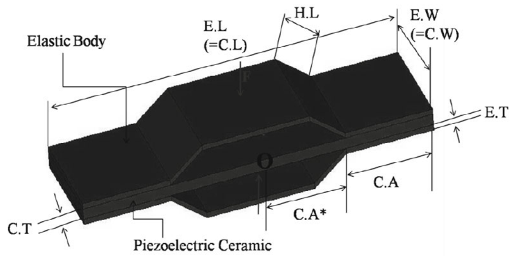
II. FINITE ELEMENT ANALYSIS AND EXPERIMENT

To find the generating characteristics of the theta-type generator, we used a finite-element analysis program ANSYS. Figure 1 shows the structure and the parameters of the piezoelectric generating device. After modeling, a modal analysis was done to find the best vibrational mode for which the vibration and the force at the center of the structure would be effectively transferred to the ceramic. Among the several vibrational modes from the modal analysis, one vibration mode was chosen, which was symmetrical, and the contraction and relaxation were took in the low-frequency range at both ends of the piezoelectric generating device as shown in Fig. 2.

Figure 3 shows the result of a harmonic analysis for the voltages generated by the piezoelectric generating device for various values of the clamped area:non-clamped area (CA:NCA ratio). In the analysis, the vibrating force (F) was 1.5 N, and the length (EL), thickness (ET), width



Parameters			
EL, CL	Elastic Body (ceramic) Length	**NCA**	Non-clamped Area
ET	Elastic Body Thickness	**O**	Origin
EW, CW	Elastic Body (ceramic) Width	**F**	Force
CT	Ceramic Thickness	**Materials**	
HL	Hypotenuse Length	**Elastic Body**	Brass
CA	Clamped Area	**Piezoelectric Ceramic**	PZT4

Fig. 1. Structure and parameters of the piezoelectric generating device.

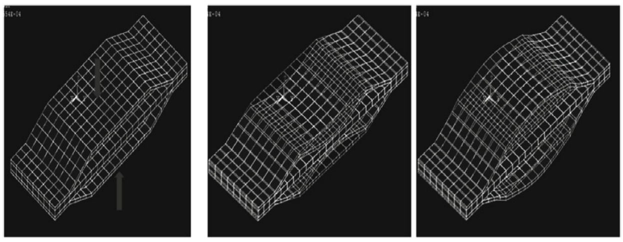


Fig. 2. Vibrational modes of the theta-type piezoelectric generating device.

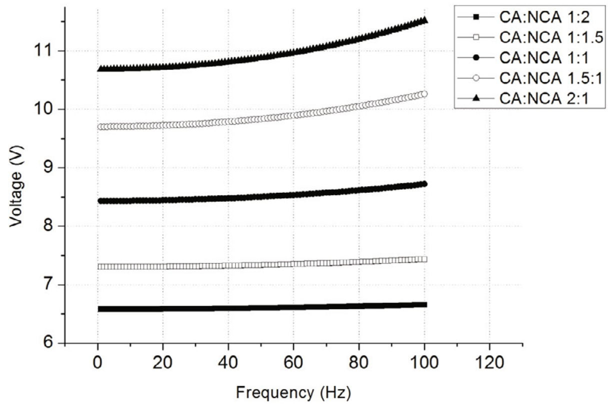


Fig. 3. Generated voltage as a function of the frequency for various values of the clamped area to non-clamped area ratio.

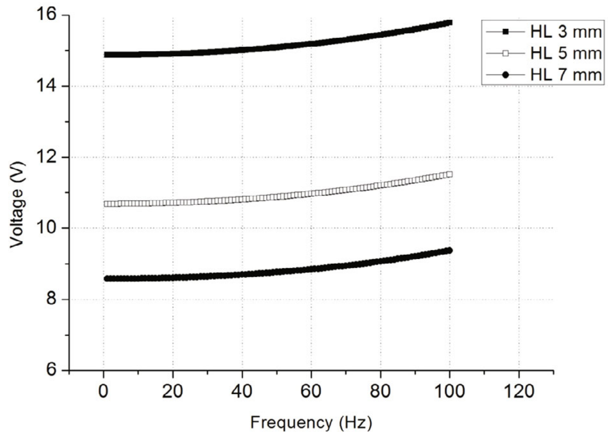


Fig. 4. Generated voltage as a function of the frequency for various values of the length of the hypotenuse.

(EW), and length of the hypotenuse (HL) of the elastic body were 45 mm, 0.5 mm, 15 mm, and 5 mm, respectively. Also, the ceramic's thickness (CT) was 1 mm. The highest generated voltage was obtained at a CA:NCA ratio of 2:1. When the attached area between the elastic body and the ceramic was increased, the transfer of the applied vibrations to the ceramic from the elastic body increased, and the generated voltage increased.

Figure 4 shows the generated voltage as a function of the frequency for various values of the length of the elastic body's hypotenuse. In the analysis, the vibrating force (F) was 1.5 N, the CA:NCA ratio was 2:1, and the length (EL), thickness (ET), and width (EW) of the elastic body were 45 mm, 0.5 mm, and 15 mm, respectively. Also, the ceramic's thickness (CT) was 1 mm. As the length of the elastic body's hypotenuse (HL) was decreased, the distance between the top of the elastic body and the ceramic decreased and the generated voltage increased. This means that the conversion efficiency to transfer vibrations was high when the distance between the top of the elastic body and the ceramic was small. The highest generated voltage was obtained when hypotenuse's length (HL) was 3 mm and longer.

Figure 5 shows the generated voltage as a function of the frequency for a narrow range of values for the thickness of the elastic body (ET). In the analysis, the vibrating force (F) was 1.5 N, the CA:NCA ratio was 2:1, and the length (EL), width (EW), and hypotenuse's length (HL) of the elastic body were 45 mm, 15 mm, and 3 mm, respectively. Also the ceramic's thickness (CT) was 1 mm. Only the thickness of the elastic body (ET) was changed, and it was changed from 0.3 mm to 0.7 mm, incrementally. The highest generated voltage was obtained when the thickness of the elastic body (ET) was 0.3 mm, and the generated voltage increased when the thickness of elastic body (ET) was decreased. These results mean that the transfer rate of vibrations to the ceramic increased when the thickness of the elastic body (ET) was decreased. For the protection of the ceramic, elastic bodies with thicknesses shorter than 0.3 mm were

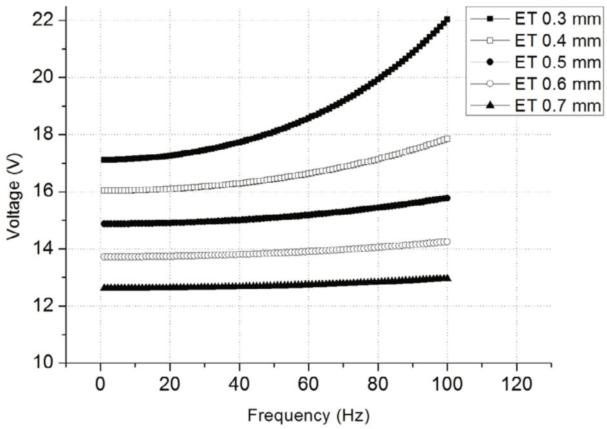


Fig. 5. Generated voltage as a function of the frequency for various values of the thickness of the elastic body.

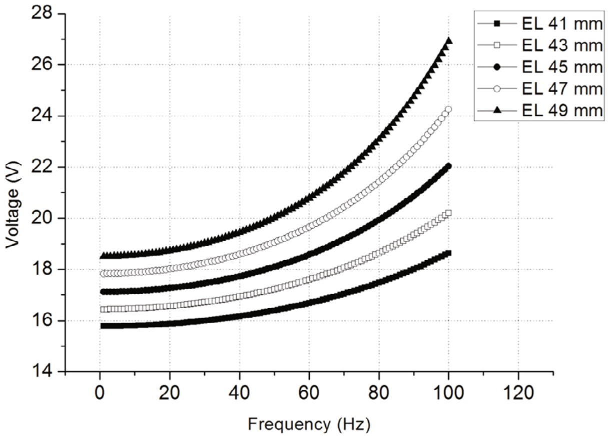


Fig. 6. Generated voltage as a function of the frequency for various values of the length of the elastic body.

excluded.

Figure 6 shows the generated voltages as a function of the length of the elastic body (EL). The lengths of the elastic body and the ceramic were the same. In the analysis, the vibrating force (F) was 1.5 N, the CA:NCA ratio was 2:1, and the width (EW), hypotenuse's length (HL) of the elastic body were 15 mm and 3 mm, respectively. Also, the ceramic's thickness (CT) was 1 mm. Only the length of the elastic body (EL) was changed, and it was changed from 41 mm to 49 mm, incrementally. The highest generated voltage was obtained when the length was the elastic body (EL) of 49 mm, and generated voltage increased when the length of the elastic body was increased.

III. RESULTS AND DISCUSSION

Selected models, which were defined by using a finite-element analysis, were fabricated. Figure 7 shows the process for fabricating the generating device. As in Fig. 7(a), piezoelectric ceramics were cut into certain sizes by using a diamond cutter. The hat-shaped elastic bodies, which were to be attached at the upper and the bottom sides of the ceramic, were made from brass (Fig. 7(b)). As in Fig. 7(c), the piezoelectric ceramic and the elastic bodies were attached by using glue, and lead wires were soldered on both sides of the ceramic as output terminals. Figure 8 shows the experimental setup for measuring the output characteristics. The signal from the function generator was amplified by using a power amplifier, and the amplified signal was applied to a shaker that was fixed to a holder to generate a vibration with the desired frequency and amplitude. An oscilloscope and a digital meter were used in order to measure the generated voltage and current of the piezoelectric generating device. Figure 9 shows the shaker transferring vibrations to the piezoelectric generating device.

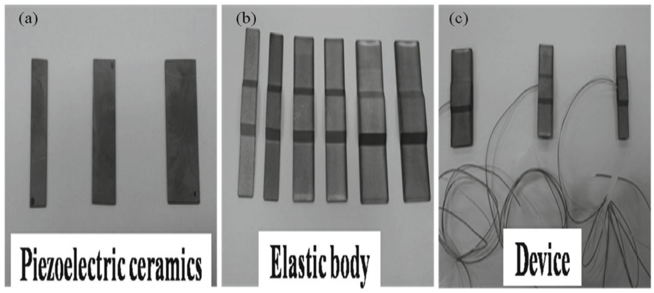


Fig. 7. Fabrication of the piezoelectric generating device: (a) piezoelectric ceramics of a certain size, (b) hat-shaped elastic bodies, (c) fabricated piezoelectric generating device.

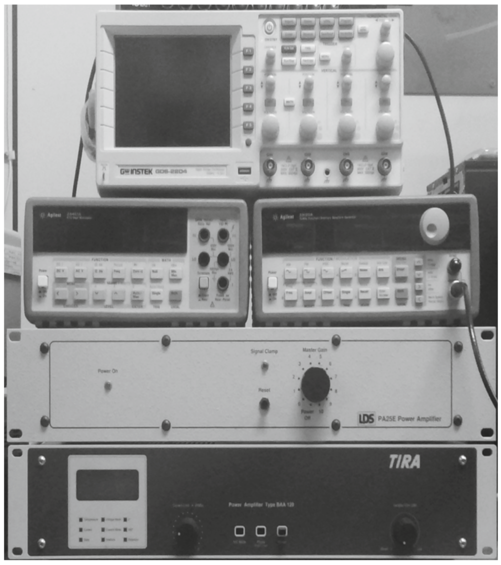


Fig. 8. Setup for the vibration experiment.

Figure 10 shows the generated voltage as a function of the frequency for various values of the width of the ceramic (C.W). The vibrating force (F) was 1.5 N, the CA:NCA ratio was 2:1, and the length (EL), thickness (ET), and hypotenuse's length (HL) of the elastic body

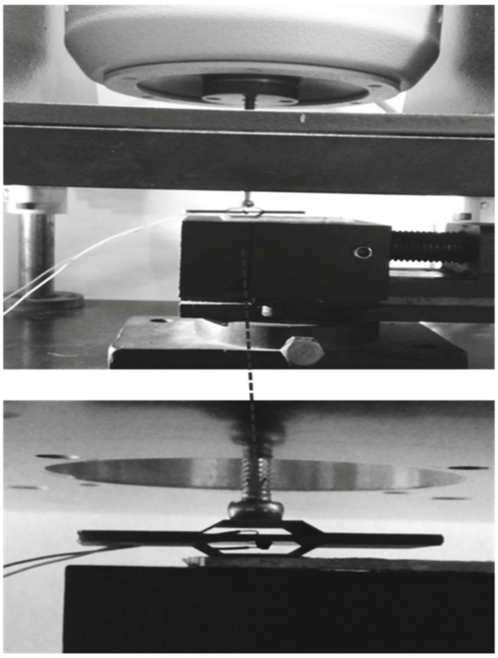


Fig. 9. Photographs of a shaker transferring vibrations to the piezoelectric generating device.

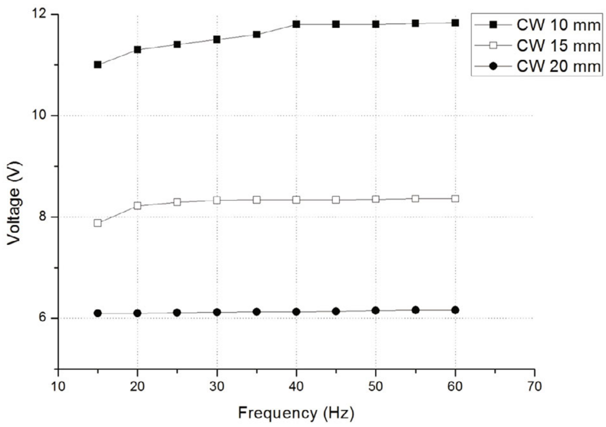


Fig. 10. Generated voltage as a function of the frequency for various values of the width of the ceramic.

were 49 mm, 0.3 mm, and 3 mm, respectively. Also, the ceramic's thickness (CT) was 1 mm. Only the width of the ceramic (CW) was changed, and it was changed from 5 mm to 25 mm incrementally. The analysis showed that the generated voltage decreased when the width of the ceramic (CW) was increased. In order to experimentally confirm this result, we carried out an experiment under the same conditions, and we obtained the same results. The dependence of the generated current on the width of the ceramic (CW) was measured, and the result is shown in Fig. 11. When the width of the ceramic (CW) were 10 mm, 15 mm, and 20 mm, the generated currents were 11 μA, 20.6 μA, and 28.5 μA, respectively. When the width of the ceramic (CW) was increased, the

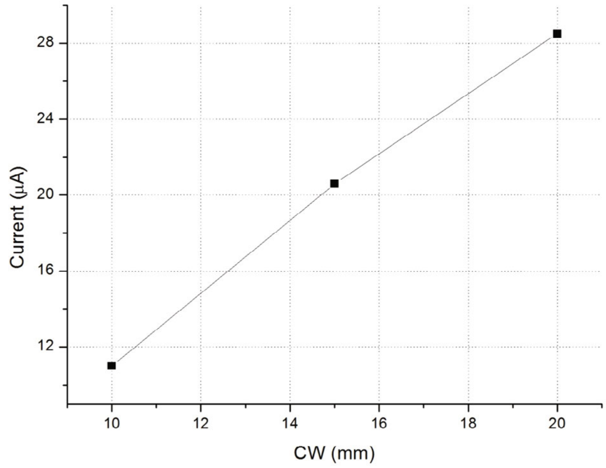


Fig. 11. Dependence of the generated current on the width of the elastic body.

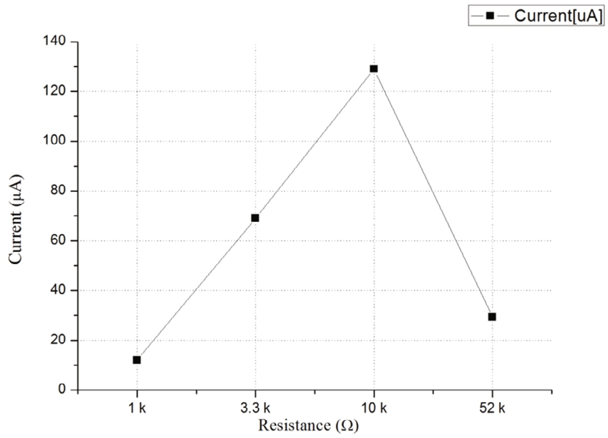


Fig. 12. Dependence of the generated current on the load resistance.

generated currents increased. The generated power was calculated from the measured voltage and current, and the model with a CW of 20 mm generated the highest power. However, difference in the generated power between the model with a CW of 15 mm and that with a CW of 20 mm was not very large, so the model with a CW of 15 mm was selected for reducing the space of one device and increasing the number of arrayed devices in one energy block.

Figure 12 shows the dependence of the generated current on the load resistance after an alternating current voltage had converted the direct-current voltage by using a AC-DC converter. Load resistances of 1 kΩ, 3.3 kΩ, 10 kΩ, and 52 kΩ were connected, and the generated currents were measured. Figure 13 shows the generated power calculated by using the measured currents. The highest generated power of 166 μW was obtained at 10 kΩ, and the generated power could be improved by changing the load resistor.

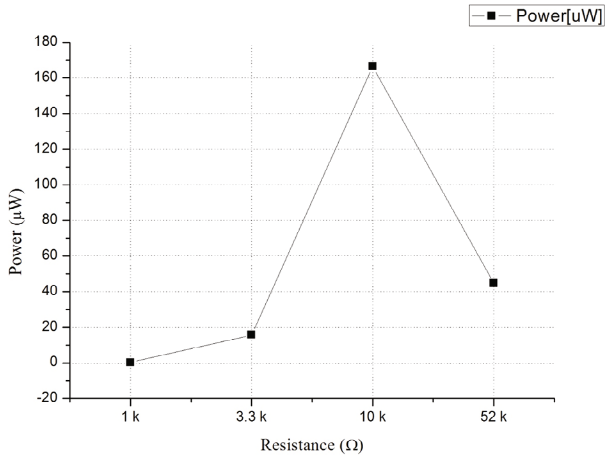


Fig. 13. Dependence of the generated power on the load resistance.

IV. CONCLUSION

A theta-type piezoelectric generating device that can be used in the low-frequency range was proposed. The characteristics of the voltage generated by the device were confirmed through a finite-element analysis. The analysis showed that the generated voltage increased when the attached area between the ceramic and the elastic body was extended and the length of the elastic body was increased. Also, the generated voltage could be increased by increasing the length of the hypotenuse of the elastic body and decreasing its thickness. Both the analytical and the experimental results showed that the generated voltage decreased when the width of the ceramic was increased. The measured generated current also increased when the width of the ceramic was increased. Through the experiments, the width of the ceramic 15 mm model was selected as an optimal width for the devices in an energy block. Also, an improved generating power was achieved by changing the load resistors.

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