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Design and fabrication of a cross-shaped piezoelectric generator for energy harvesting

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Abstract

In this paper, a cross-shaped piezoelectric generator was proposed for generating electric power at low frequency range. The generator has centrosymmetric four elastic body legs which have equivalent vibration mode. The centrosymmetric structure of the generator is able to generate in each elastic body legs at the same time using only one vibration source. Vibration is transferred from center of the generator and is equally applied to each elastic body leg. So each elastic body leg of the generator has the same resonance frequency and vibration mode. Resonance and output characteristics of the generator were analyzed by FEM program. Output characteristics of the generator could be changed by elastic body length, elastic body thickness, ceramic width, ceramic thickness and additional mass at the edge of elastic body legs. Based on FEM result, a generator was fabricated and experimented. As a result, resonance frequency of the generator was verified lower than 35 Hz. So we confirmed generating possibility of the generator at low frequency range.

Keywords: C. Piezoelectric generator; FEM; Resonance frequency

1. Introduction

At present, next-generation energy technologies are developed because of a shortage of energy in the world. One of the next-generation energy technologies is piezoelectric energy harvesting technology. Piezoelectric energy harvesting technology is a technology to harvest electrical energy using piezoelectric ceramics based on the piezoelectric effect. Piezoelectric effect is the phenomenon whereby electrical energy is obtained when mechanical energy is applied to piezoelectric ceramic or conversely mechanical energy when electrical energy is applied [1–4]. Especially, piezoelectric energy harvesting technology is very eco-friendly and useful because of the use of discarded physical energy around our living atmosphere [5,6]. For example, electrical energy is harvested from a pressure and vibration of a road when people and cars go pass the road. For this method, the piezoelectric energy harvesting technology needs proper piezoelectric generator. In this paper, the cross-shaped piezoelectric generator was proposed and studied for use in low frequency range and to get high output characteristics. The generator model is determined considering various parameters based on FEM analysis. Output characteristics of the fabricated generators were experimented by changing frequency and comparing with the FEM result.

2. Structure of the generator and FEM analysis

2.1. Structure of the generator

The structure of the cross-shaped piezoelectric generator is shown in Fig. 1.

The cross-shaped piezoelectric generator is composed of an elastic body and piezoelectric ceramics. An abbreviation is defined for each parameter of the generator for convenience in FEM and experiments. The parameters considered are the elastic body width (EW), elastic body thickness (ET), elastic body length (EL), elastic body material (EM), ceramic width (CW), ceramic thickness (CT), and ceramic length (CL).

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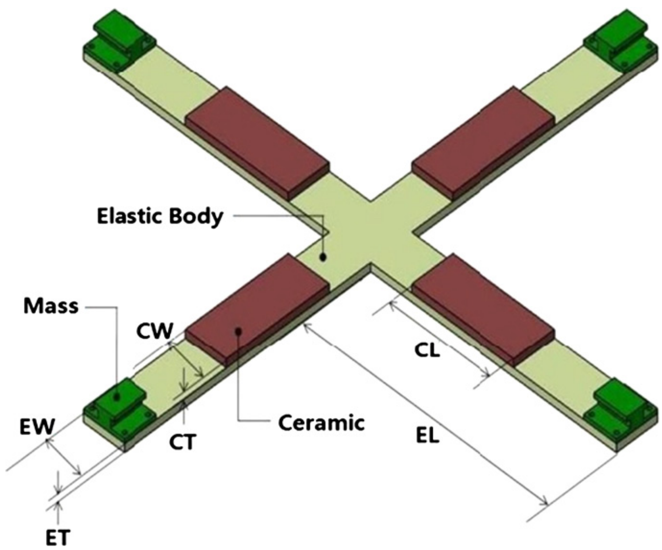

Fig. 1. The structure of the cross-shaped piezoelectric generator.

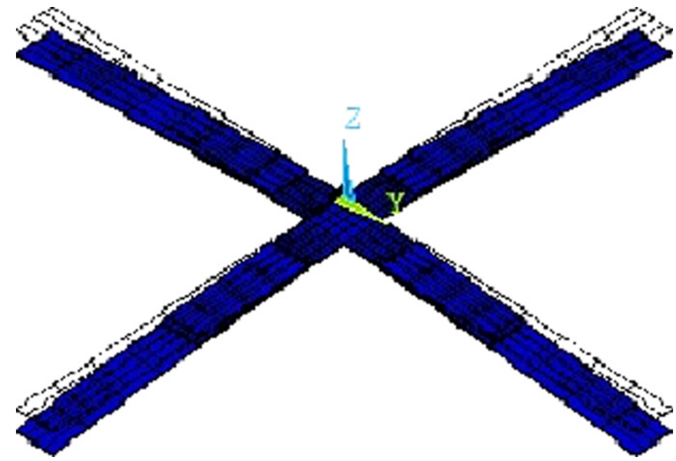

Fig. 2. Modeling of the generator.

The generator has cross-shaped elastic body with centro-symmetric four cantilever type legs and piezoelectric ceramics that were attached on the four legs of the elastic body [7]. The generator shape has no great loss of vibration when vibration is applied to each ceramic through the legs of the elastic body. Vibration source is applied to four legs of the elastic body at the same time. It makes it possible to have the same resonance frequency and maximum displacement of the generator. Also, resonance frequency of the generator can be controlled minutely using additional mass attached at the tip of legs of the elastic body.

2.2. FEM analysis

The cross-shaped piezoelectric generator was analyzed by FEM program to predict the resonance frequency and output characteristics of the generator. The generator was modeled by FEM program. The elastic body and piezoelectric ceramic were determined each as SUS304 and PZT4. Fig. 2 shows modeling of the generator.

Firstly, analysis of the generator was conducted by changing the elastic material which has physical properties as shown in Table 1 [10]. Brass, SUS304 and copper which have different physical properties were selected as materials of the generator. Fig. 3 shows the dependence of the voltage on the elastic body material.

Higher resonance frequencies were found in the order of SUS304, Copper and Brass. This is because the resonance frequency was proportional to the speed of sound in the material [8]. The speed of sound in the elastic body materials is defined as

$$v = \sqrt{\frac{Y}{\rho}} \tag{1}$$

where, Y is the Young's modulus and ρ is the density of the elastic body. And Fig. 4 shows the dependence of the voltage on the elastic body length. The resonance frequency increased with decreasing EL. But the output voltage has no significant change. So it is possible to change the resonance frequency by adjusting the EL [8,9].

Fig. 5 shows the dependence of the voltage on elastic body thickness. With an increase in ET, the resonance frequency increases while the output voltage has no significant changes. Fig. 6 shows dependence of the voltage

Table 1
Physical properties of the materials.

Material	Young's modulus (GPa)	Density (kg/m^3)	Poisson's ratio	Speed of sound (km/s)
Brass	92	8270	0.33	10.547
Copper	110	8920	0.34	11.104
SUS304	193	8080	0.31	15.245

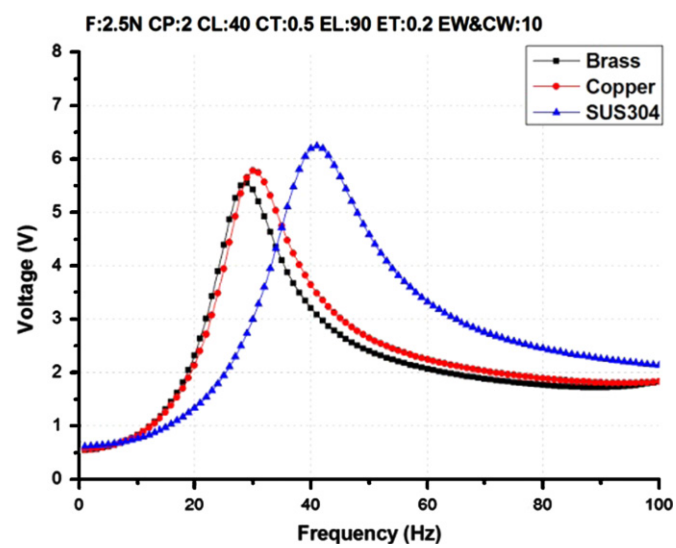

Fig. 3. Dependence of the voltage on the elastic body material.

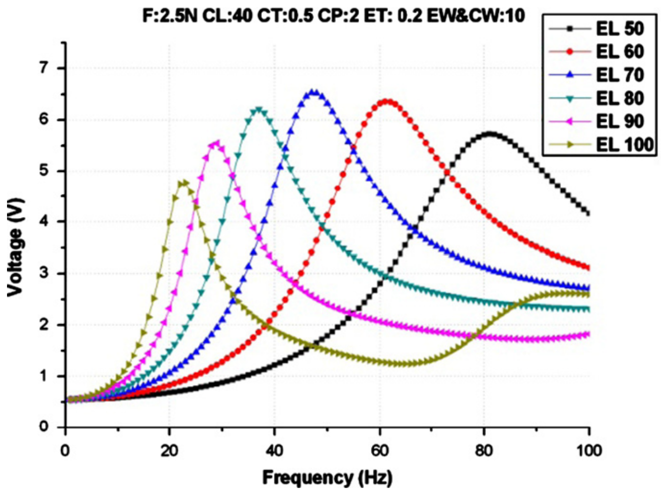

Fig. 4. Dependence of the voltage on the elastic body length.

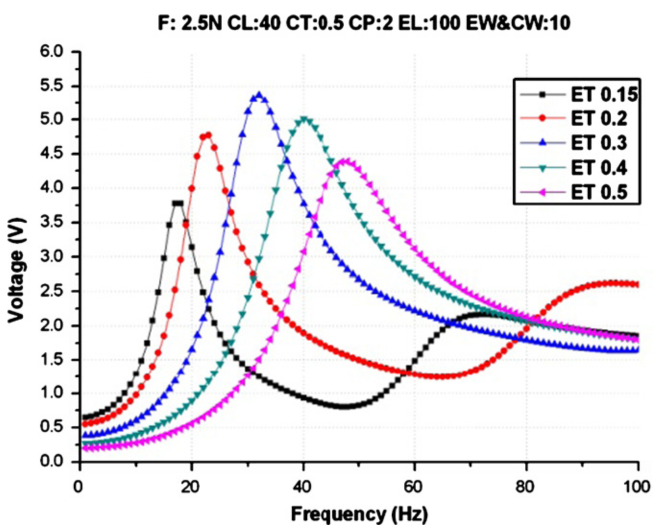

Fig. 5. Dependence of the voltage on elastic body thickness.

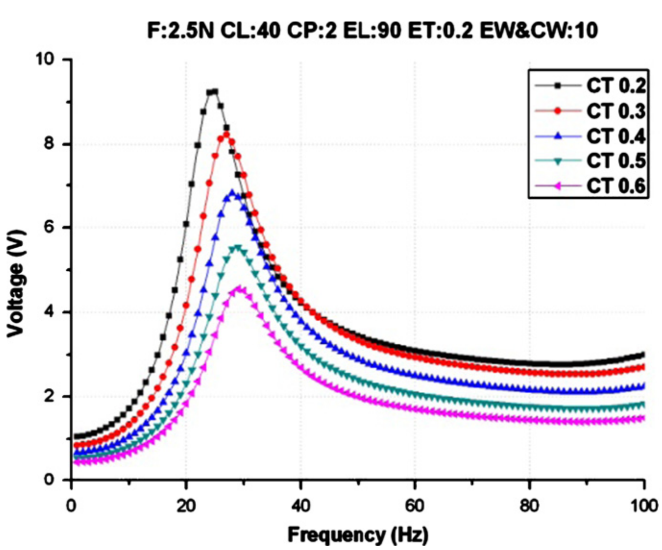

Fig. 6. Dependence of the voltage on the ceramic thickness.

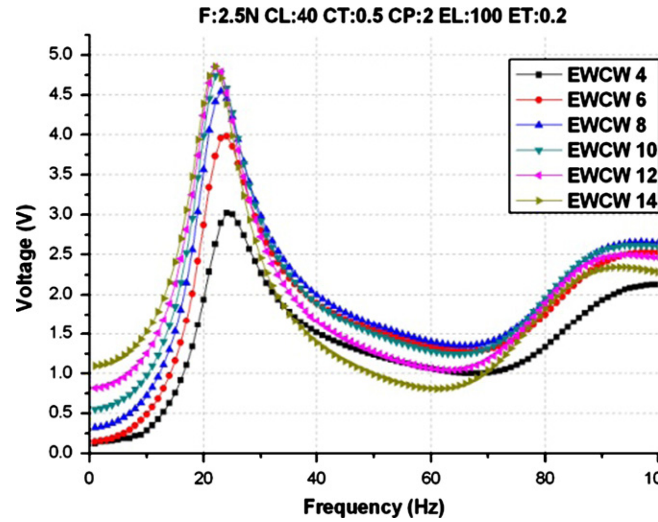

Fig. 7. Dependence of the voltage on the ceramic and elastic body width.

on the ceramic thickness. The output voltage increased with decreasing ceramic thickness while the resonance frequency of the generator did not change significantly.

Fig. 7 shows the dependence of the voltage on width of ceramic and elastic body. Ceramic and elastic body width had no significant effect in resonance frequency. Also, there were small changes in output voltage when the width was bigger than EW and CW 10 mm.

3. Fabrication and experiment

The cross-shaped piezoelectric generator was fabricated to use in experiments for verifying the analysis results. The generator was fabricated by using SUS304 and the leg length was 100 mm. The thickness of the elastic body was 0.2 mm. All the ceramics were the same size as CL 30 mm, CT 0.5 mm and CW 10 mm. Four rectangular ceramics were attached to the elastic body legs after the elastic body was cut to have cross-shape. PIC 151 manufactured by PI Ltd. was used as the piezoelectric ceramic and elastic epoxy was used as the adhesive material. For applying vibration, the center of the generator was perforated so that the elastic body could be attached to the shaker. The fabricated generator is shown in Fig. 8.

Fig. 9 shows the experimental equipment used to measure output characteristics of the generator by changing frequency. Signal was applied to power amplifier after frequency and amplitude were set properly through a function generator. Amplified signal was applied to the shaker which generates vibration. Vibration was applied to center of the generator and was measured through 3-axis acceleration sensor. Acceleration was measured approximately to be 1 g. Electric circuit was composed of rectifier diode and ceramic capacitor. Output characteristics were measured through an oscilloscope at output terminal. Also, current was measured through a digital multimeter with connect resister 100 Ω.

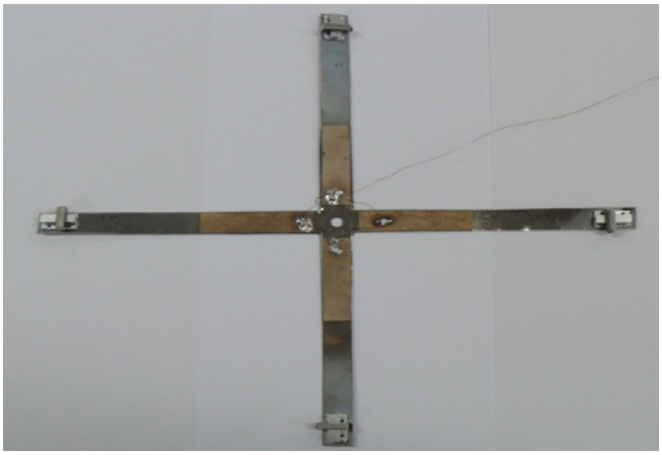

Fig. 8. Fabricated cross-shaped piezoelectric generator.

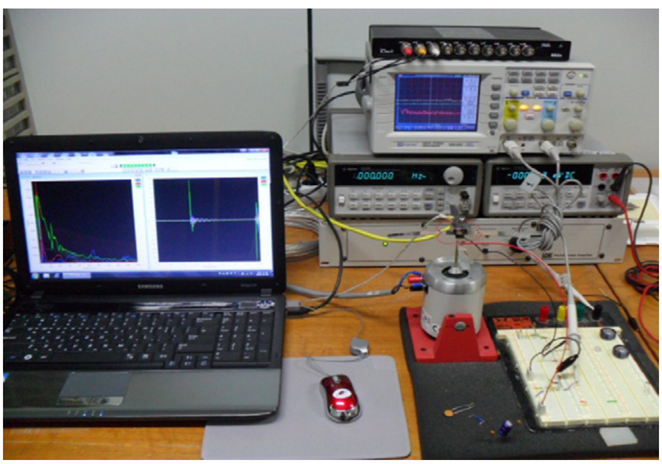

Fig. 9. Experimental equipment used in the vibration experiments.

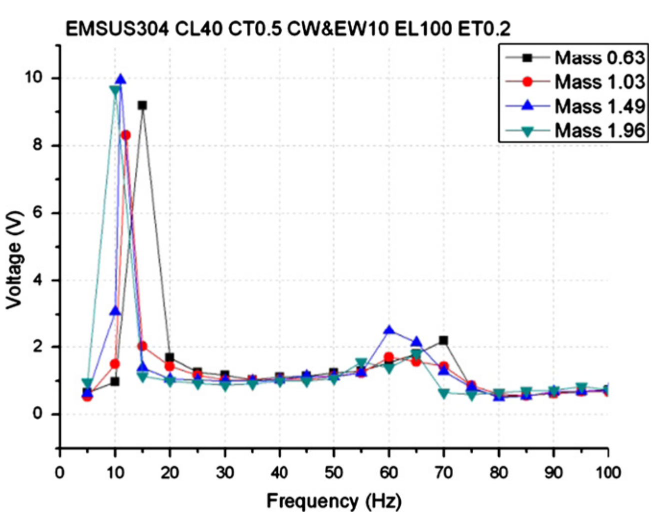

Fig. 10. Dependence of the output voltage on the additional mass.

Figs. 10 and 11 show the dependence of the characteristics on additional mass which was used to optimize parameters of the generator. The parameters of the generator were determined as EM SUS304, CL 40 mm, CT 0.5 mm, CW & EW 10 mm, EL 100 mm and ET 0.2 mm. This optimized generator was experimented with additional mass.

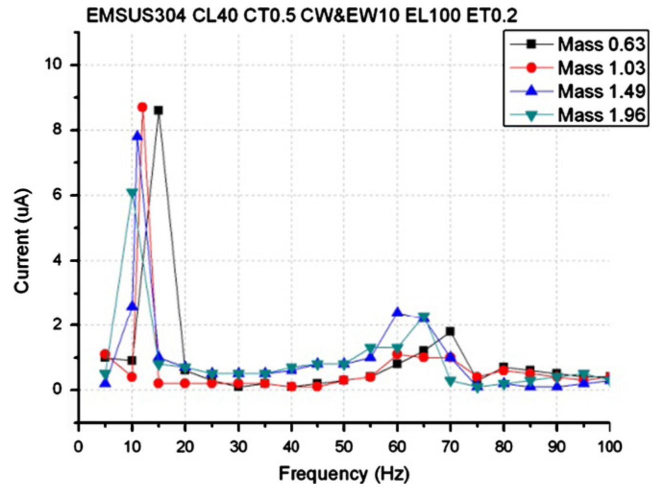

Fig. 11. Dependence of the output current on the additional mass.

The resonance frequencies of the generator were measured at frequency lower than 20 Hz. The output characteristics had no big changes by the mass. But the resonance frequencies were changed by additional mass by about 5 Hz.

4. Conclusion

In this paper, optimal model of the generator which can be used at low frequency range was proposed. The parameters of the generator were analyzed by FEM program and the optimized generator was fabricated and experimented. In FEM analysis, EL and ET could be used to control the resonance frequency of the generator. CT and CW and EW had no big influence to the resonance frequency. SUS304 of elastic body materials had somewhat high resonance frequency but output voltage was higher than other materials. Based on this analysis, cross-shaped piezoelectric generator was fabricated. Also, to control the resonance frequency, additional mass was fabricated. Optimized generator parameters were determined as EM; SUS304, CL;40 mm, CT;0.5 mm, CW & EW;10 mm, EL;100 mm, ET;0.2 mm. Also, additional masses were fabricated as respectively 0.63 g, 1.03 g, 1.49 g, 1.96 g. In the vibration experiments, the output voltage of the generator was hardly changed. Maximum voltage of the generator was 9.66 V at 1.96 g of mass weight. And resonance frequency was 10 Hz. At that time, current was measured as 6.1 μA. Variation range of the resonance frequency of the generator was about 5 Hz. So resonance frequency of the generator could be controlled by adjusting weight of the additional mass. Therefore, the cross-shaped piezoelectric generator shows a possibility to generate power at low frequency range which can be easily found around our living atmosphere.

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