PowerMEMS 2017
IOP Conf. Series: Journal of Physics: Conf. Series 1052 (2018) 012084
doi:10.1088/1742-6596/1052/1/012084

Sound power generation using magnetostrictive power generator

M. Aoki, and T. Ueno
Kanazawa University, Kakuma-machi, Kanazawa-city, Ishikawa, 920-1192, Japan
ueno@ec.t.kanazawa-u.ac.jp

Abstract. We propose a device that generates power from sound using a magnetostrictive material. The device includes a plate for receiving sound. The tendency of the change in the conversion efficiency of the device was confirmed by changing three parameters: its material, size, and fixation position. We also succeeded in generating 1.21 mW of power under a 117 dB environment. We aim to improve the output by enlarging the device.

1. Introduction
Generating electric power from sound is difficult because the physical energy is quite small. For example, the sound pressure level under a girder bridge with running trains is approximately 100 dB. In short, the sound intensity is only $10^{-2}$ W/m$^2$. Additionally, the conversion efficiency of a power generator that changes sound energy into electric energy is generally low. Eventually, we can only obtain small energy; thus, this technology is not practical. On the other hand, if we use a high conversion-efficiency device, we can obtain energy from microwatt to milliwatt level for applications in light-emitting diodes, sensors, and wireless modules. Additionally, we expect that it can simultaneously decrease noise. In the present study, we compared several efficiency properties of magnetostrictive power-generator conversion to improve performance.

2. Device principle
The magnetostrictive vibration power generator consists of a magnetostrictive material plate (iron–gallium alloy Fe$_{81.4}$Ga$_{18.6}$, $4 \times 13 \times 0.5$ mm$^3$), a frame (0.5 mm thick), a coil (485 $\Omega$; 3456 turns), and a magnet (Fig. 1). It can convert vibration energy into electrical energy using inverse magnetostrictive effect. Inverse magnetostrictive effect is a phenomenon in which the magnetic flux that passes through a magnetostrictive material changes because of mechanical stress. Fig. 2, shows that when a device receives vibration power from outside, the magnetostrictive material plate expands or is subjected to pressure because of the frame. Then, it generates electrical power via the coil.

![Figure 1. Device configuration](image1)

![Figure 2. Expanding or pressing force from outside.](image2)
through electromagnetic induction [1]. Here, we place a plate at the tip of the device to receive the sound waves.

3. Experimental method
We conducted three experiments to compare the conversion efficiency characteristics of the plates by varying three parameters: materials, sizes, and fixation positions. In these experiments, input power was provided by a speaker and a function generator. Then, we measured the frequency characteristic of the sound pressure level using a sound-level meter. We assumed that the sound waves from the speaker were plane waves to simplify the input-power calculation [2]. The output was the power consumed by a matching resistance (670 Ω) directly connected to the device. Then, we measured the frequency characteristic of its electric potential difference using a fast Fourier transform analyzer when the device was excited by the speaker (Fig. 3). The frequency range was between 50 and 150 Hz.

![Figure 3. Measurement of the output](image)

4. Experimental results

4.1. Different materials
In the first experiment, we compared four plates made of different materials: thick paper (1.07 g), cardboard (1.06 g), acryl (10.5 g), and aluminium (3.37 g). Their sizes were the same (50 × 50 mm²). The result is shown in Fig. 4. The maximum conversion efficiency values were 0.92% for the thick paper, 1.8% for the cardboard, 0.050% for the acryl, and 1.4% for the aluminium. Comparison of the thick paper and cardboard, which had the same weight but different rigidity properties, showed that the maximum conversion efficiency of the latter with high rigidity was 2.0 times that of the former. Furthermore, the comparison results between the acrylic and other plates confirmed that only the acryl with a large mass had extremely low conversion efficiency. Therefore, we verified that the plate

![Figure 4. Conversion efficiency versus frequency in the comparison of plate materials](image)
should be solid and not too heavy. In particular, the device with a cardboard plate generated 12.6 μW at 105 dB environment.

4.2. Different sizes

In the second experiment, we compared thick papers with three different sizes: small (35 × 35 mm\(^2\)), medium (50 × 50 mm\(^2\)), and large (71 × 71 mm\(^2\)). To maintain the same weight (2.15 g), we added weights to the small and medium papers. The result is shown in Fig. 5. The maximum conversion efficiency values were 0.94% for the small paper, 1.2% for the medium paper, and 0.014% for the large paper. We confirmed that a larger plate does not necessarily generate more energy than smaller ones. Fig. 6 shows each device open-circuit voltages at resonant frequency. Although they were excited by the same sound pressure level (105 dB), the device with a large plate received a lower voltage than the other two devices. We considered that the large plate has lower natural oscillation frequency than the other two types. The plate itself was deformed, and the stress was not efficiently transmitted to the magnetostrictive material plate. By using a material with higher rigidity, we believe that the deformation of the plate can be reduced and the output can be improved.

4.3. Different fixation positions

In the third experiment, we compared the plates at three different fixation positions: Positions 1, 2, and 3 (Fig. 7). We used an aluminium plate (3.37 g), and the size was 50 × 50 mm\(^2\). The result is shown in Fig. 8. The maximum conversion efficiency was values were 0.20% at Position 1, 1.35% at
2, and 0.012% at 3. We confirmed that the conversion efficiency strongly depends on the fixation position.

4.4. Use of a larger device

To drive sensors and wireless modules, power of several milliwatts or more is required, and the output was insufficient for the devices used in these experiments. We increased the size of the device to improve the output. The new device consisted of a magnetostrictive material plate (iron–gallium alloy, \(8 \times 25 \times 1 \text{ mm}^3\)), a frame (1 mm thick), a coil (333 \(\Omega\), 3910 turns), and a magnet. To prevent deformation of the plate itself, aluminium, which has the highest rigidity, was adopted as the plate. Three plates, namely, medium (50 × 50 mm\(^2\)), large (71 × 71 mm\(^2\)), and extra-large (90 × 90 mm\(^2\)) were prepared, and the characteristics of the conversion efficiency were measured between 50 and 200 Hz; the result is shown in Fig. 9. The maximum conversion efficiency values were 3.5% for the medium-size plate, 2.72% for the large plate, and 5.3% for the extra-large plate. Fig. 10 shows the open-circuit voltages of each device at resonant frequency. The use of aluminium with high rigidity reduced the deformation of the plates, and we can see that the outputs improved in proportion to the size of the plates. In particular, the device with an extra-large plate generated 1.21 mW at 117 dB environment.

![Figure 9. Conversion efficiency versus frequency with a large-size device](image)

![Figure 10. Time response of the open voltages in the comparison of the plate sizes with a large-size device (at 105 dB).](image)

5. Summary

In this paper, we have proposed a magnetostrictive sound generator and experimentally verified the change in the conversion efficiency of the device due to the difference in the types of plate included in the device. As a result, the device that used a rigid and lightweight plate tended to have high conversion efficiency. In addition, in the case where a plate with insufficient rigidity was used, we believed that the conversion efficiency could be reduced by increasing the plate size. Furthermore, we confirmed that the fixation position of the plate greatly affected the conversion efficiency. As a result of enlarging the device to increase the output, we succeeded in obtaining 1.21 mW of electric power under a 117 dB environment.

Acknowledgments

This work was supported by JST CREST Grant Number JPMJCR15Q1, Japan.

References

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