Development of a small scale electric power system to extract energy from water fluctuations in a large enclosed water basin

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Abstract

A power generation system using energy from geostrophic fluctuations in water has not been developed yet, because such an energy source has not been well recognized and the applicable methods have not been invented. Recently, we have developed a bench scale power generator to generate electricity from water fluctuations using piezoelectric elements. The applications of piezoelectric power elements are popular for LED displays excited by floor oscillations, remote control power switches, rainfall power umbrellas, and wireless power networks based on oscillations of bridges or roads. Those are realized by the progress of modern technology which requires small power for operation. Our target is to extract electric power from geostrophic fluctuations generated in a large enclosed basin like Lake Biwa. We used piezoelectric bimorph to transform energy of geostrophic fluctuations excited by waves or flows into electricity. Even if each piezoelectric element generate small power, the background energy source in a large lake is huge and, as a water body is flexible in size and dimension, we can set up the system in 3D space and operate it for 24 hours. This is a strong benefit compared with other green natural power energy sources, such as solar and wind power generation systems.

Introduction

We have conducted field experiments in Lake Biwa to measure geostrophic fluctuations from 2010 to 2012. We found that two types of fluctuations occur during the stratified and mixing seasons. Both of them, however, showed velocity fluctuations of 10 to 20 cm sec^{-1} and those are not small compared with mean horizontal flows. The period of fluctuations are between 3 and 4 seconds and the fluctuation intensity is almost constant from water surface to 20 m depth. So, we asked the question: can we use the energy of those fluctuations to produce electricity?

In order to confirm the possibility, we invented a bench scale power generator using piezoelectric elements, which are becoming commonly used for LED displays excited by floor oscillations, remote control power switches, rainfall powered umbrellas, and wireless powered networks based on oscillations of bridges or roads. Our mission was to make piezoelectric elements oscillate with water fluctuations, and generate electricity from water at a practical level.

Generally speaking, piezoelectric elements provide high voltage but low current, and a single unit is not sufficient for societal demands. If we can combine many units of piezoelectric elements, we may extract large power from geostrophic fluctuations in water. Most of energy aggregation mechanism (energy lens) existing in nature on the earth consist of assembles with small scale energy transfer systems like microscale evaporation (Kumagai and Iwaki, 2014). More importantly, is how we can develop such nature-based power generation to solve future energy deficiencies and save the planet.

We needed to develop an in situ power system. To realize this, we may start a field experiment in a small scale water mass of 100 m (L) x 100 m (W) x 20 m (D). Our field data have shown that there might be a power fluctuation of 400 KW (minimum), 800 KW (mean) and 6000 KW (maximum) in this water mass. In a large enclosed basin like Lake Biwa, huge power fluctuations always occur, and these could be converted into heat energy at the final stage. If we can use even a small portion of such huge energy, we can continuously and stably extract natural energy as far as long our solar system is maintained. In this study, we discuss how we can develop a bench scale power system with piezoelectric elements, which can be used in a large enclosed basin in the near future.

Experiments

We performed several laboratory experiments to learn basic characteristics of the piezoelectric element before we adapted it for use in the field. We used commercially available piezoelectric elements of 60 mm (L) x 20 mm (W) x 0.5 mm (H). These elements were inexpensive (300 yen each) and easy to handle. Usually inherent oscillations of piezoelectric elements are quite high (kHz), but the dominant frequency of geostrophic fluctuation is at most 0.2 Hz – 0.5 Hz (period: 2 sec – 5 sec). That is why we examined the output power of piezoelectric elements at around 2 – 5 sec period of oscillations with flexible plates. We mechanically changed the amplitude of oscillation from 5 mm to 30 mm, and measured the output voltage from piezoelectric elements for four different combinations such as (1) 6 series, (2) 2 parallel3 series, (3) 3 parallel2 series, and (4) 6 parallels.

We also conducted afield experiment with different flexible plates attached to piezoelectric elements as seen in Fig.1, where six different lengths of plates (7.5 cm to 20 cm) with two different thicknesses (0.5 mm and 1.0 mm) were used. As the first step, we set up the small scale electric power system and submerged it in water of Lake Biwa. To identify the power generation, we connected LEDs to the piezoelectric elements and confirmed the lights went on and off.

Fig.1 Small scale electric power system with piezoelectric elements (green boards) and flexible plates (transparent acrylic boards). Left side consists of six acrylic boards of 0.5 mm thickness and the right side has another six boards of 1.0 mm thickness. Six plates were spaced from top to bottom with lengths of 20 cm, 17.5 cm, 15.0 cm, 12.5 cm, 10.0 cm and 7. 5cm acrylic boards on both sides. The system was deployed into the water and each output was connected to an LED.

Results and discussion

The output power of a piezoelectric element was depicted against different amplitudes in Fig.2. As expected, the output voltage increased when the amplitude of vibration became greater. The fitting curve is, however, not linear and it follows a 2-D parabola. The output voltage was high (2 V-18 V), but the electric current was low. To evaluate the power of the piezoelectric elements, we tested four cases of the circuit combinations, including a Schottky diode as seen in Fig.3.

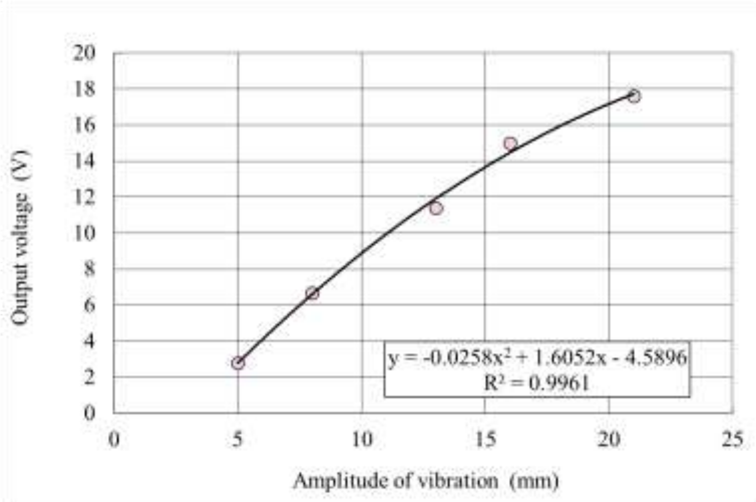

Fig.2 Output voltage against different amplitudes of vibration. Circles show the experimental data, and the solid line is the curve fitted to the data.

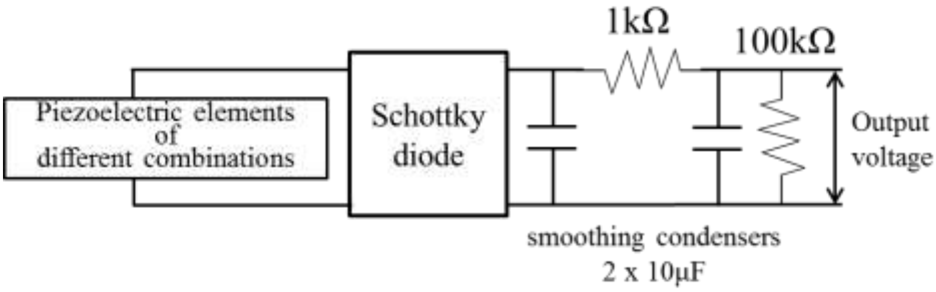

Fig.3 Circuit block diagram for the test cases.

We checked four combinations of piezoelectric elements as given above. The output power against different amplitudes of vibrators are shown in Fig. 4.

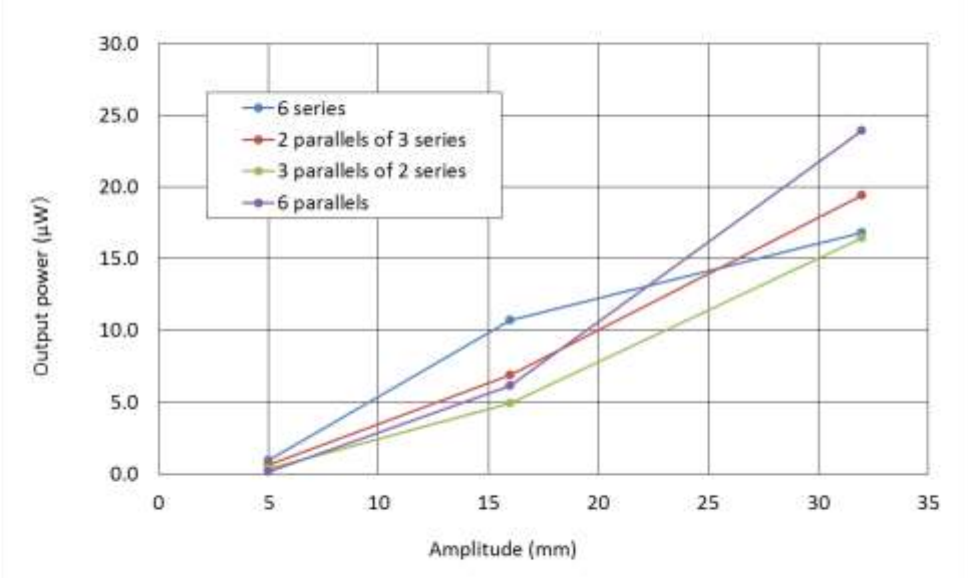

Fig.4 Output power against different amplitudes of vibrators for four cases. As the amplitudes increased, the power of 6 parallel circuits tended to be almost 1.5 times that of 6 series circuits.

As seen in Fig.4, the output power of four combinations of piezoelectric elements were almost the same when the amplitudes of the flexible plates were small, but the parallel circuit outputs became greater when the amplitude were high. That is why we have to find the most efficient combination to obtain high power when we set up this system in a lake. A similar approach with a flexible piezoelectric device (FPED) has been applied to extract energy from ocean surface waves (Mutsuda *et al*. 2010). They suggested a knit-type of FPED generated higher power than a sheet type, because they say that vortex energy or jets caused by broken waves can contribute. We used a hard type of piezoelectric elements, and obtained 10 to 100 times greater power than with the FPED. We are going to invent a more effective system in the near future.

The experiment in Lake Biwa showed unique results. We used 12 acrylic boards as seen in Fig.1, and six of them had a 0.5 mm thickness and six others had a 1.0 mm thickness. Each piezoelectric element was attached to different lengths of vibrator (20 cm, 17.5 cm, 15.0 cm, 12.5 cm, 10.0 cm and 7.5 cm). Also the output terminals were connected to LEDs. Fig. 5 shows the LED lights when the vibrators were oscillated by current movement.

Fig.5 Activated LED lights due to 12 piezoelectric element power. Unfortunately, one of them did not light up due to disconnection (bottom left), but the others worked very well. The upper lights were excited by the 0.5 mm thickness plates and the lower lights by the 1.0 mm thickness ones.

We checked the LED lightning and classified its intensity as “weak (+1), moderate (+2) and strong (+3)” with the naked eye over about 30 seconds and plotted the results in Fig.6.

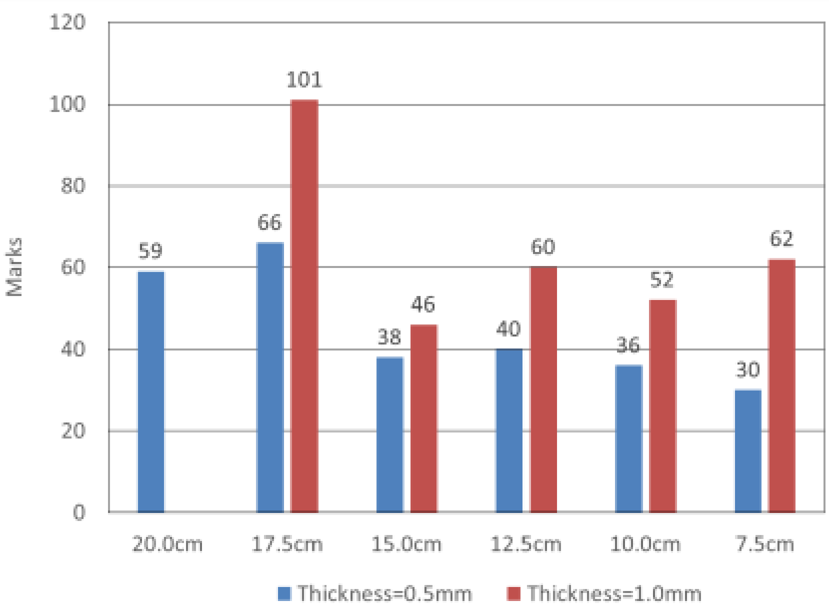

Fig.6 LED light intensity activated by water fluctuations in Lake Biwa. Marks are integrated values of weak (+1), moderate (+2) and strong (+3) lighting evaluated with the naked eye over about 30 seconds.

Apparently, the thick flexible palate of 1.0 mm can produce greater power then the thin plate of 0.5 mm. The difference of length may not be an important issue, but we have to discuss more deeply the shape of a plate rather than its length. This could be the next step.

Conclusion

We developed a small scale electric power system to extract energy from water fluctuations in a large enclosed water basin. This system is basically the application of piezoelectric bimorph, and we succeeded in getting power from water fluctuations excited by waves or flows in Lake Biwa. Even if each piezoelectric element does not generate large power, we can assemble small systems to build up a large system. This could be a suitable approach to use the huge energy fluctuations in a large lake, because a water body is flexible in size and dimension. We can also run this system in 3D space and operate it continuously over diel cycles and throughout the year. This is a very strong benefit compared with other green natural power energy sources.

Geostrophic power generation is our original idea, and it can provide energy as long as the planet system exists and it could be one of the best power systems to be utilized in a low carbon society. We have already shown that there is huge geostrophic fluctuation power in large enclosed basins like Lake Biwa. The problem is how to extract power with high efficiency. We have to optimize the shape, combination and deployment of piezoelectric elements with plates.

The direct ripple effects of a geostrophic fluctuation power system for industry are not only for a stable power supply but also for promoting electric vehicles and realizing a hydrogen-powered society in the future. We believe that this study can be combined with societal demands and develop a new vision on fisheries, environmental business and sightseeing. If a geostrophic fluctuation power system can create 200 KW, we can prevent 4 million tons of carbon dioxide entering the atmosphere and realize a 200 billion Japanese Yen economic benefit.

Acknowledgements

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References

Kumagai, M. and M. Iwaki (2014) Global Warming Impact on Lake Environments:

Challenge of Natural Energy Lens. J. JAP. SCIENTIST. **49**: 12-17 (in Japanese).
Matsuda, H., K. Kawakami, M. Hirata, Y. Doi, Y. Tanaka and D. Yanagihara (2010) Study on Wave Power Generator using Flexible Piezoelectric Device. J. JSC B2, 66: 1281-1285 (in Japanese).