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Invited Paper

An Overview of Self-Powered Energy Harvester based on Vibration

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Abstract. Research achievements in solutions for the environmental and energy problems correspond to the increment of power demand have been reported widely for decades. As a means to solve it, the energy harvesting technology based on vibration has been focused. In this paper, resent piezoelectric energy harvesting for self-powered devices including a newly developed method is reviewed.

1. Introduction

Ambient energy harvesting is far safer to keep the earth from further being polluted because the process will not adversely harm the environment. There are many countries in the world have started the initiative of producing and consuming electric energy from solar and wind. Even though the amount of the electricity that can be generated is dependent on the amount of the ambient energy in the environment, in the long run, it definitely will help us to protect our living place.

Vibration energy harvesting is a topic that has been studied and discussed by researchers all over the world for decades. Generally, vibrations can be found in huge amount in moving mechanical structures, civil engineering structures like highways and buildings, machines and many more.

One of important factors that need to be considered to effectively convert the vibrations into electricity is the type of the transducer. Electrostatic, electromagnetic and piezoelectric-based transducers are among the popular devices for the vibration energy regeneration. They are all having their own advantages and disadvantages. Depending on various factors, designers will choose their devices accordingly.

In the literature [1], in terms of output voltage, it is obvious that piezoelectric device is capable of producing higher than that of the electromagnetic device. However, in terms of their maximum output power, both devices produce almost the same level of output. Our research focus on the application of piezoelectric-based device as the energy converter for the designed power generator. In this paper, design of wide-band vibration-based piezoelectric power generation such as the multi-mode vibration power generation and the impact-mode vibration power generation with its application is described.

2. Multi-Mode Vibration Power Generation

2.1 Development of Multi-Mode and Multi-Axis Vibration Power Generator

Based on the analytical results of the road test, it was determined that multi-mode and multi-axis vibrations are the typical vibration in vehicles. Moreover, its resonant frequencies are only dependent on the measurement location [2]. As a result, power generation using a conventional single-mode PZT device is not effective. Therefore, in this research, a multi-mode and multi-axis vibration power generator that is effective for the vehicle's vibration is proposed.

Fig. 1 shows the geometric construction of the developed device using a three-mass model as an example. The device consists of three masses (m_1, m_2, and m_3) and three plate springs (spring constants k_1, k_2, and k_3 and damping coefficients c_1, c_2, and c_3). PZTs are attached to each plate spring, and the power generation is achieved from the stress generated by the vibration deformation. The physical parameters of the masses and spring plates are designed to match the resonant frequencies at the installed location. Moreover, the attachment point of the PZT to the plate spring is determined based on the results of the stress analysis of the power generation device.

From the results of the stress analysis, it turns out that a two-mass device has two bending modes and one torsional mode. Therefore, a two-mass prototype device was developed. Fig. 2 shows the results of the stress analysis. The computer aided design software CATIA V5 was used for the stress analysis. The attachment point of the PZT was decided to be where the stress was highest (see Fig. 2).

2.2 Construction and Experimental Verification

In this research, a prototype device for the two-mass model shown in Fig. 3 was constructed. Two PZT plates were attached at the location on the plate with the maximum stress. Using the prototype device, experiments were performed based on the vibration analysis. Three-axis accelerometers were placed at the base and on each mass.

In order to verify whether the two PZT devices have generated electricity efficiently, power generation identification experiments were performed. For the input signal, taking the precisely identified frequency region into consideration ¥cite{Ljung}, a sampling time of 1 ms and a pseudo-random binary signal with a period of 511 was applied for a duration of 1.022 s. The identified results are shown in Fig. 4. From Fig. 4, it can be verified that effective power generation can be achieved at the multi-mode vibration frequencies.

Fig. 5 shows the identified results of the PZT power generation experiments for the horizontal-axis vibration. From Fig. 5, the PZT device can generate voltage efficiently at the multi-mode vibration frequencies as the same as the results for the vertical-axis vibration shown in Fig. 4. From the vertical and horizontal vibration tests, it can be summarized that the proposed vibration power generator can generate voltage using not only multi-mode vibration but also multi-axis vibration.

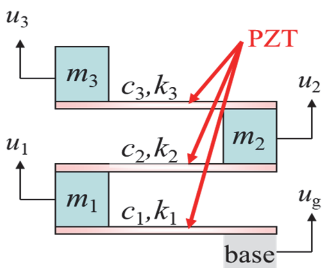
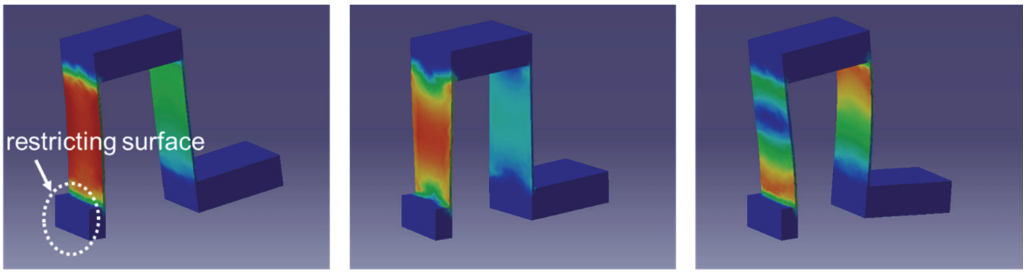


Fig. 1 Construction of multi-mode vibration power generation device.



(a) 1st mode (bending) (b) 2nd mode (torsional) (c) 3rd mode (bending)

Fig. 2 Stress analysis of multi-mode vibration device.

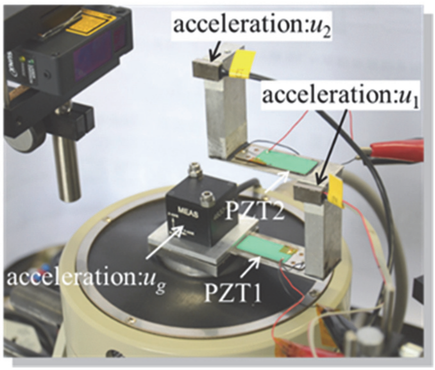


Fig. 3 Experimental setup for multi-mode vibration device.

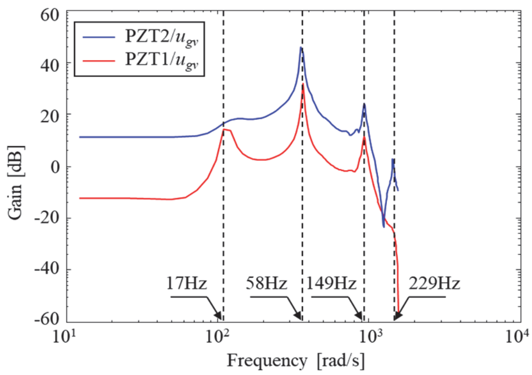


Fig. 4 Frequency responses of PZT generated voltage for vertical-axis vibration.

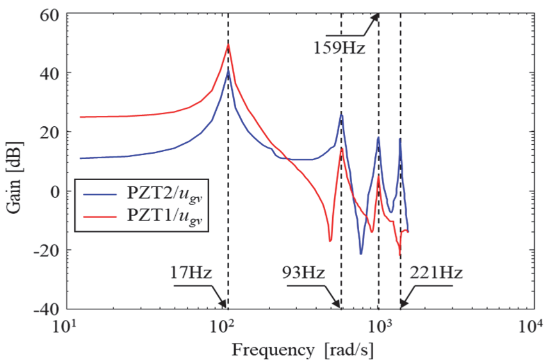


Fig. 5 Frequency responses of PZT generated voltage for horizontal-axis vibration.

3. Impact -Mode Vibration Power Generation

3.1 Construction and Experimental Verification

A work that reports the application of the mechanical impact for the power generation is presented by Halim et al. [4]. The implementation target of the device is to harvest low frequency vibrations such as human motion-related environments. The optimization procedure is based on the matching impedance technique.

To allow a uniform force transfer from the mechanical impact, we suggest here a new impact configuration. As can be seen in Fig. 6, instead of hitting the device directly, a small piece of shim plate (made of aluminum) can be put on the device. By doing this, the force from the tip will be transferred to the device through the shim plate. Regardless of the configuration, a uniform impact from the tip to device can be applied to the device and therefore, a uniform strain force will be generated on the surface of the piezoelectric device. Subsequently, an optimum output over wide frequency band can be expected from this impact configuration.

3.2 Experimental evaluation

In order to evaluate the output of this new structure, experimental evaluation was carried out. The sim plates have four different sizes with same thickness of 5mm. The purpose of preparing different sizes is to evaluate the effect of the contact area when same force is applied to the shim plates.

In Figs. 7 and 8, it shows the frequency response of the power generator for the pre-load configuration with variation in the shim plate size. Input base acceleration was up to 3.8G. As seen in Fig. 7, the peak voltage of the power generator increases gradually from the frequency of 30Hz up to the frequency of approximately 45Hz. From this frequency onwards, the peak voltage has become relatively stable at the voltage of 22 - 23V before it increased again at the resonant frequency of about 76Hz and 86Hz. Difference in the magnitude of the voltage is not seen at most of the frequency except at the resonant frequency of 86Hz. At this frequency, we can see a significant difference in the magnitude when the size of the shim plate is different. The highest peak voltage is obtained when diameter of the shim plate is 4mm. The next highest output is with the diameter of 6mm, 8mm and 10mm respectively. In Fig. 8, the average output power for 0.5s is shown. It is clearer in this figure the difference of the output power of the power generator when their size of shim plate is different. This can be observed at the output of the resonant frequency.

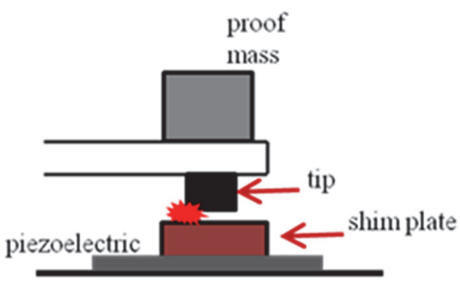


Fig. 6 New impact configuration with shim plate.

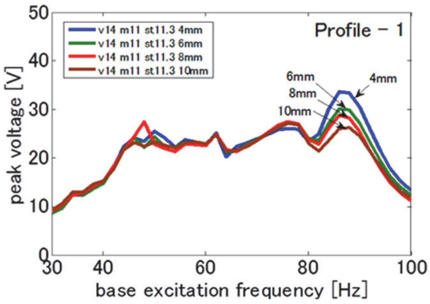


Fig. 7 Frequency response of peak voltage.

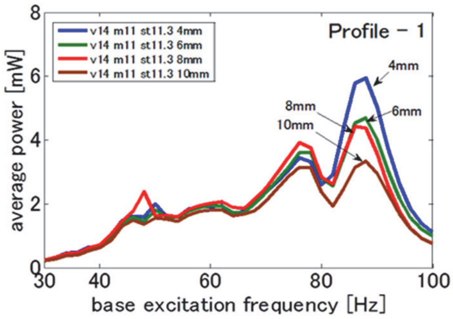


Fig. 8 Frequency response of average power for 0.5s.

4. Conclusion

In this paper, based on the characteristics of the vehicle's vibration, a multi-mode and multi-axis power generator designed specifically for vehicles has been proposed, and a prototype has been developed. The system identification experiments have been performed to evaluate its multi-mode and multi-axis vibration power generation ability.

This paper has also proved that for the designed impact-mode power generator, high efficient vibration based impact mode piezoelectric power generation can be realized by placing shim plate between the hitting structure and the device so that an optimum and uniform force transfer can be achieved. Furthermore, it has also proved experimentally that the effect of the size of the shim plate in the output power. Optimal size can increase the output power of the power generator.

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