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Emerging Advances in Integrated Technology

Vibration Energy Regeneration System Using Piezoelectric Sensor for Wideband Application

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Abstract: This paper presents a method for widening bandwidth by using non-uniform mass which use the concept of center of gravity. Piezoelectric acts as a tool to convert vibration energy to electrical energy. The displacement from the liquid movement plays a role to enhance the bandwidth as the beam bends. The bandwidth is widened 2 times higher compared without tip mass and 1.6 times increased than that of solid tip-mass. High viscosity and density will give a greater effect on the bandwidth at low volume compared to low properties of fluid. Rectangular container can resist the tension of liquid due to high viscosity and volume. The fluid-filled mass technique widened the bandwidth without reducing the harvested power.

Keywords: Piezoelectric sensor, wide bandwidth, non-uniform mass, center of gravity

1. Introduction

Vibration energy regeneration contributes a lot in developing new sources of energy to generate electricity. Energy harvested from vibration sources could power low portable devices at its resonant frequency. This ambient energy is the key solution to resolve power related issue which also recognized as a promising technology. Lately it becomes a highly demanded for harvesting the energy from ambient power source as it can power the Internet of Things or commonly used in replacing batteries in the remote area [1-2]. This energy known for its narrow bandwidth which become the main issue of the energy harvester. This is because narrow bandwidth has high power but not feasible to be implement in real life applications. Therefore, to achieve reliable energy harvester, it is crucial to develop energy harvester with wide frequency bandwidth [3].

Various studies have been done before in widening the bandwidth such as mechanical stoppers, cantilever array of different geometries also electrostatic attractions [4-10]. However, these techniques contributed to lowering the power level of the energy harvester. The complexity in manufacturing the energy harvester which is not suitable to be produce in large scale and need to be individually assessed as introduced in previous research need to be overcome. The technique proposed in this manuscript is using non-uniform mass at the tip of the sensor with the concept of changes in center of gravity. Piezoelectric acts as an energy harvester which generate electricity by applying vibration to it. The deformation of the piezoelectric structure creates electrical energy which able to power low electronic devices [11,12]. The result of shifting the center of gravity at the resonant frequency has been observed and recorded. Fluid-filled tip mass method has been done by the previous researchers which result in bandwidth widening and increasing of power level [13,14].

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In this paper, this method was improved by adding different types of containers and its contribution in widening the frequency bandwidth is observed. Liquids with different density and viscosity were applied for analysis of the results.

2. Experimental Setup

The piezoelectric sensor used in this experiment is a ceramic based and it is in cantilever structure. The dimension of the piezoelectric sensor is shown in Figure 1.

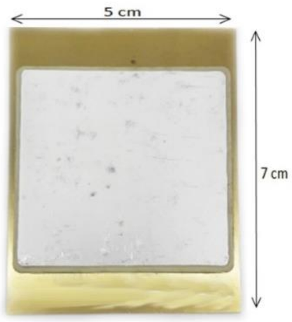

Fig. 1 - Dimension of piezoelectric cantilever

The piezoelectric act as a transducer which convert vibration into electrical energy when ambient sources is applied. Electrodynamic shaker is used as an input source which generate vibration to the piezoelectric sensor. WEDE software is used to calibrate the acceleration of the shaker and voltage output is observed through oscilloscope. The experimental setup consists of piezoelectric sensor, electrodynamic shaker, WEDE software, oscilloscope and resistance box as shown in Figure 2 while Figure 3 illustrated the experimental setup for the frequency bandwidth widening by using non-uniform mass.

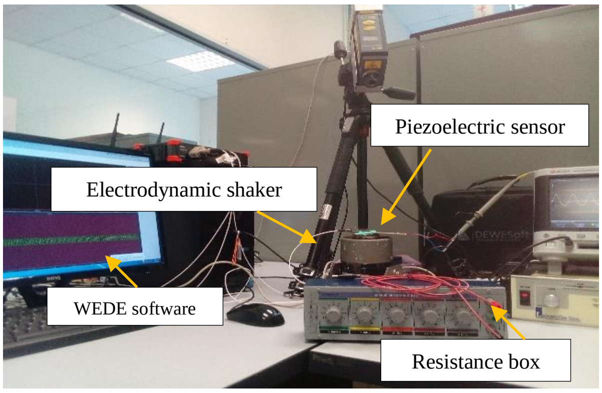

Fig. 2 - Experimental setup 1

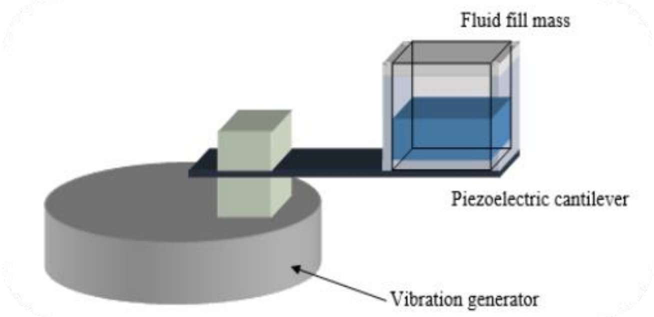

Fig. 3 - Experimental setup 2

To create wide operating frequency bandwidth, liquid proof mass is added at the tip of sensor. Glue is used to secure at the spaces of the lid to ensure no spilling of fluid. The properties of liquid (water, dishwashing liquid and honey) are different in terms of density and viscosity as shown in Table 1. The water has the lowest properties of fluid, in contrast with honey. These parameters will define the impact to the frequency bandwidth. Table 2 tabulated the mass of each container. Figure 4 shows two types of containers used in this project; round shape container (A) and rectangular container (B).

Table 1 - Properties of liquid

Types of fluid	Density (g/cm^3)	Viscosity (Pa.s)
Water	0.9	0.000899
Dishwashing	1.2	0.319000
Honey	1.4	2-10

Table 2 - Mass for both containers

Container	Mass
A (Round)	12g
B (Rectangular)	22g

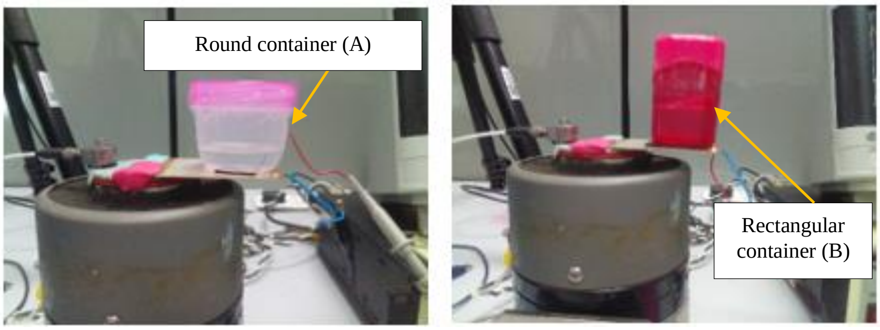

Fig. 4 - Types of containers: Round container (A); rectangular container (B)

Level of volume for liquid used are (10ml, 20ml and 30ml) which represent 25%, 50% and 75% of the container. High volume of liquid generates higher output voltage due to the increment in the mass. However, for high viscosity, the liquid seems to move slower at lower acceleration. The frequency bandwidth of solid proof mass with the same weight as liquid mass is also compared. Figure 5 shows the solid proof mass attached to the tip of the piezoelectric cantilever.

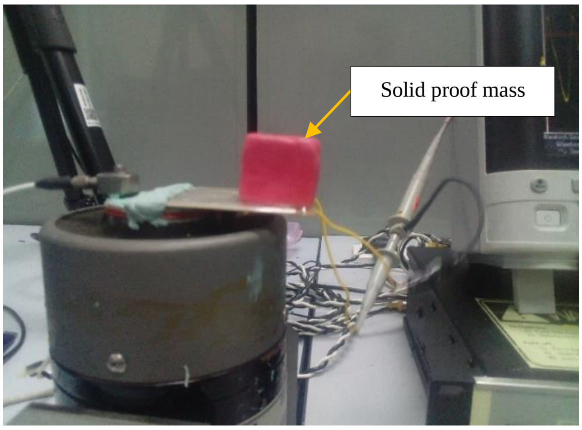

Fig. 5 - Solid tip mass

Full-wave bridge rectifier is used as rectifier circuit in piezoelectric energy harvester to convert AC to DC voltage. It is shown in Figure 6. The output signal will be considered as ripple if the capacitor is not in parallel to the load, which may be unacceptable for powering application with DC voltage. Therefore, the circuit uses a capacitor as a filter to smooth out the effect of variation in load.

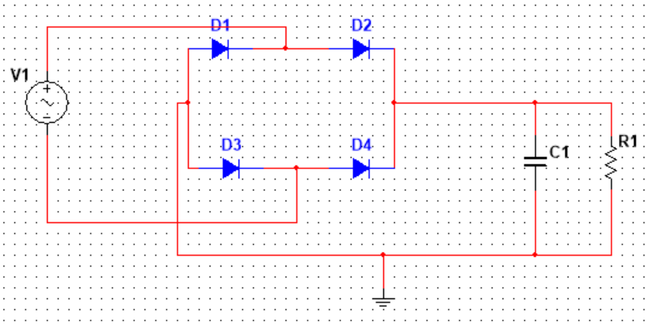

Fig. 6 - Full-wave bridge rectifier circuit

3. Results and Discussion

The output voltage of the piezoelectric cantilever with the characterization setup is set as a control. It has the bandwidth of 4Hz as shown in Figure 7. The frequency bandwidth is captured at 70% of the resonant frequency. The initial bandwidth is then compared with the bandwidth obtained for the liquid proof mass. Figure 8 shows the output power obtained with the optimum resistance of 8kΩ.

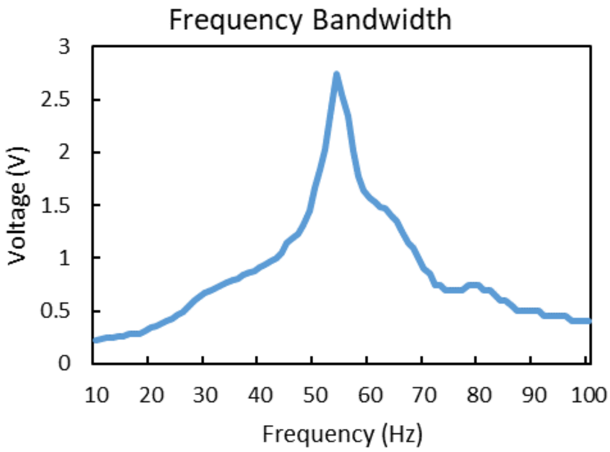

Fig. 7 – Initial bandwidth

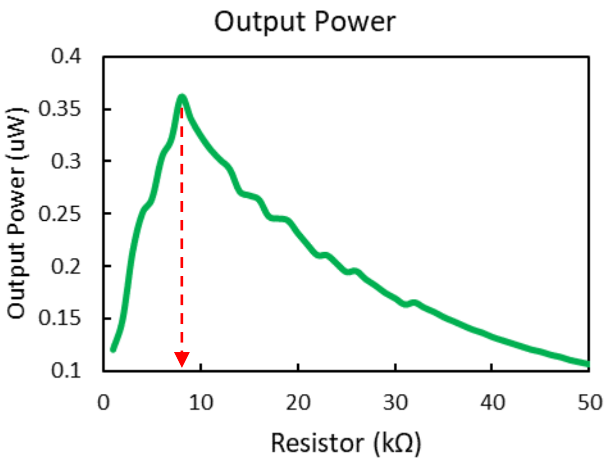

Fig. 8 - Output power

3.1 Frequency Bandwidth for a Round Container

The frequency bandwidth for container A is shown in Figure 9 which include all level of volumes and each fluid. Overall, honey at 10ml shows the widest bandwidth which is 8Hz. The output voltage is increased since the mass of the proof mass is changed depends on the volume filled. At low level of volume for less viscosity liquid, it shows chaotic behavior which reduces the mass along the time.

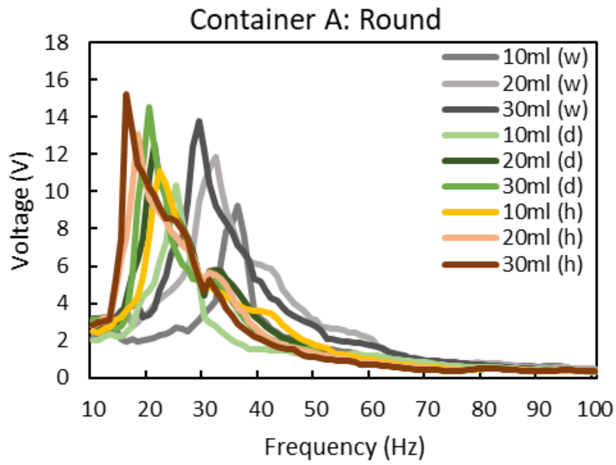

Fig. 9 - Operating frequency for round container

3.2 Frequency Bandwidth for a Rectangular Container

A graph showing the output voltage with the frequency variation from 10Hz to 100Hz for container B is shown in Figure 10. The level of volume is varied at 25%, 50% and 75% of the container. At high viscosity and density of fluid, the bandwidth is still widened by 3Hz. This shows the ability of the rectangular container which has rigid shape to resist the tension of the fluid.

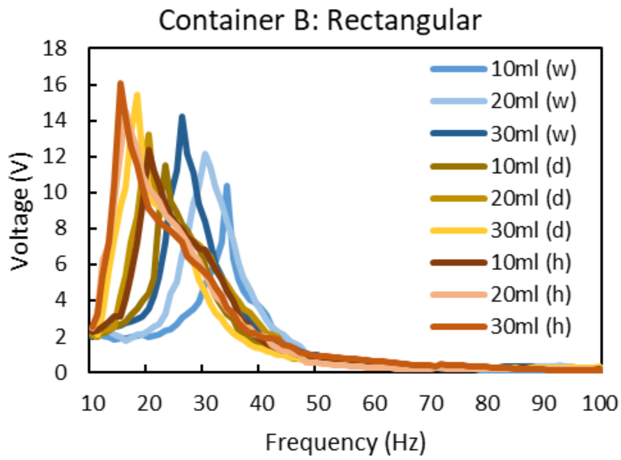

Fig. 10 - Operating frequency for rectangular container

3.3 Frequency Bandwidth for Fluids

The result of container A and B is then compared to observe the differences of the frequency bandwidth of each fluid. For water which has low properties of fluid as shown in Figure 11, both containers show more effective frequency bandwidth widening at 50% volume of the container. While for 25% and 75% of volume, it shows that only a slightly increment can be seen. This happened because at low volume, the liquid behavior is chaotic while at higher volume, there is only little space for the liquid to flows. Therefore, mid-level of volume seems to be steady flow of liquid.

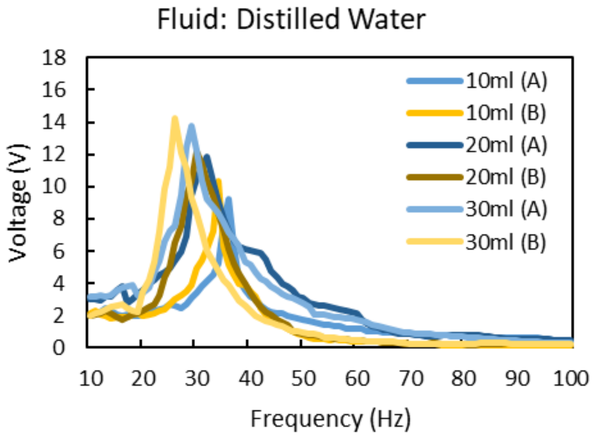

Fig. 11 - Operating frequency for water in both containers

Low volume of dishwashing liquid has not shown chaotic behavior as water. This makes the center of mass is steady which affect to the bandwidth. Container A has shown bandwidth widening of 2Hz for both 25% and 50% in Figure 12. Also, for container B, the increment of volume has shown widening of bandwidth by 2Hz due to the ability of the container to resist the motion of liquid as the viscosity and density become higher.

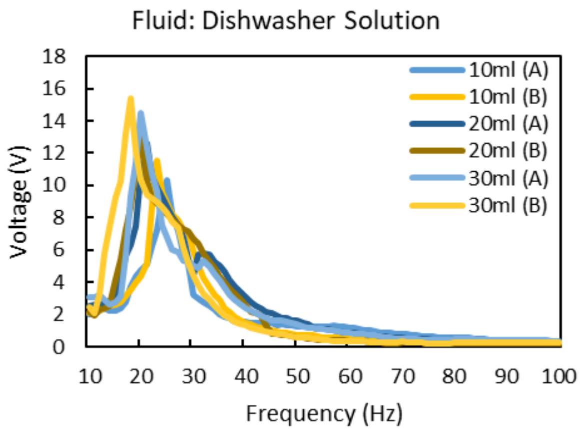

Fig. 12 - Operating frequency for dishwasher solution in both containers

Honey has the highest properties of fluid which also effect to the output voltage and operate at lower resonant frequency. Container A has produced highest bandwidth which is 8Hz at low volume (25%) while container B has lowered the bandwidth by 1Hz. Although container B could resist high viscosity of fluid, however container A shows more efficient at low volume for high viscosity of fluid.

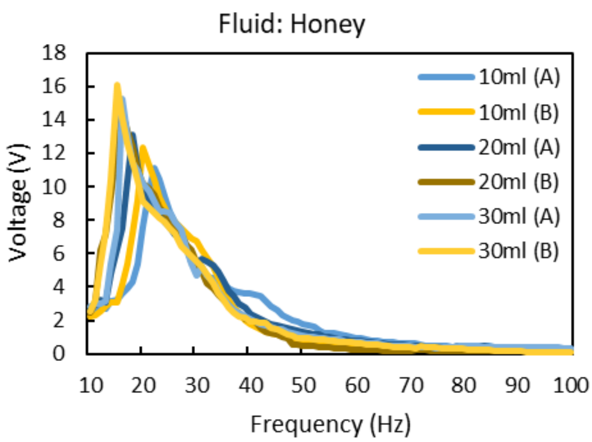

Fig. 13 - Operating frequency for honey in both containers

3.4 Frequency Bandwidth for Tip Mass

With the same weight, solid tip mass and liquid tip mass is compared by taking mass of 10ml of honey for container A. Figure 14 shows that the bandwidth for liquid tip mass is 1.6x higher than solid tip mass. Although both of proof mass has the same weight, the resonant frequency of liquid proof is shifted. This happened because the center of mass is constantly changing due to oscillation of the piezoelectric cantilever. Solid tip mass does not experience changing the center of mass, therefore the widening bandwidth does not effective as liquid tip mass.

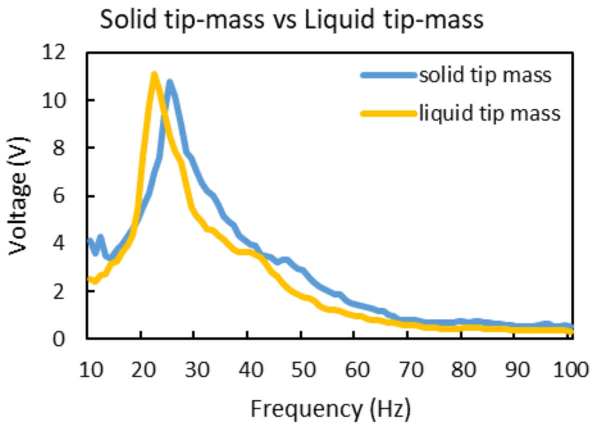

Fig. 14 - Voltage-Frequency characteristics of solid tip mass and liquid tip mass

4. Conclusion

The technique of non-uniform mass approach has results in widening the bandwidth without reducing the harvested power. Constant change at the center of mass when the oscillation occur has alter the resonant frequency. The properties of fluid (density and viscosity) affect the bandwidth along the volume of the liquid. Outcome of the low acceleration (1 g) has shown that higher density and viscosity fluid will determine the displacement of the liquid. Rectangular and round shape has shown that different types of containers will affect the performance of the bandwidth. Also, liquid tip-mass proved that the widening of bandwidth is more efficient compared to solid tip mass. Overall, the properties of fluid with certain volume gives the impact to the bandwidth depending on the acceleration applied to the sensor.

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