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Experimental and numerical study of energy harvesting from sloshing of a liquid and its performance on shaper machine

R. Maroofiazar*, M. Fahimi Farzam, N. Pashaei

Faculty of Engineering, University of Maragheh, Maragheh, Iran.

ABSTRACT: In this study, a method for energy harvesting from sloshing of fluids has been proposed. In the first part, voltage and electrical power are measured experimentally. A magnet is floated on the liquid in the coiled container and the system is placed on a shaker table. According to Faraday's law of induction, the movement of the magnet inside the container induces voltage in the coil. The results show that the induced voltage increases with increasing frequency and reaches its maximum value at the natural frequency of the structure and container and decreases again. Also, the inductive voltage has increased with increasing both magnet strength and height of the liquid inside the container. The highest inductive voltage and power output in this study were 850mV and 400μW, respectively. To evaluate the efficiency of the proposed method, the system was installed on a shaper machine and the induced voltage and electrical power were measured. Also, the numerical method is used to simulate and analyze the proposed system. The results show that variations of interface parameters including its pressure, are consistent with experimental data and therefore this method can be used to design and predict the performance of the energy harvester.

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Volume of fluid method.

1- Introduction

Energy harvesting is the process by which energy is harvested and stored from external sources such as solar, thermal, wind and kinetic energy and used for small, wireless devices, such as those in wearable electronics and wireless sensor networks. Therefore, an energy harvester can be used both to charge existing batteries and to replace them, which will ultimately increase the life of the system [1,2]. Mechanical vibrations are among the most important sources of energy that exist in various systems and devices and are usually unused [3,4]. Various methods have been proposed to extract energy from mechanical vibrations, including electromagnetic, piezoelectric, and electrostatic [5]. Among the methods of energy harvesting from vibrations, the electromagnetic method has several advantages [6].

The previous studies show that using ferrofluids in the sloshing phenomenon is suitable for energy harvesting, but this method is not without its drawbacks. Nanoparticles deposition and their absorption to the magnets are the main disadvantages of those systems. In this paper, a method has been proposed for energy harvesting from mechanical vibrations by using ordinary liquid sloshing. In this method, the magnet is floated on the surface of the liquid and the liquid container is wrapped by copper wire. In the second part, numerical modeling has been used to analyze and predict the performance of the proposed system.

2- Materials and Methods

The schematic of the proposed system for energy harvesting is shown in Fig. 1. The liquid is poured into the container at different heights and a magnet is floated on it. In this study, the effect of different parameters on energy harvesting from the proposed system has been investigated. Output parameters are: induced voltage in the coil and harvested electrical power. The input parameters and their range of changes are given in Table 1.

The energy harvesting of the proposed system is based on the oscillations of the interface between the two fluids and the movements of the magnet relative to the coil, which ultimately induces voltage in the coil according to Faraday's law of induction. Therefore, it is expected that parameters

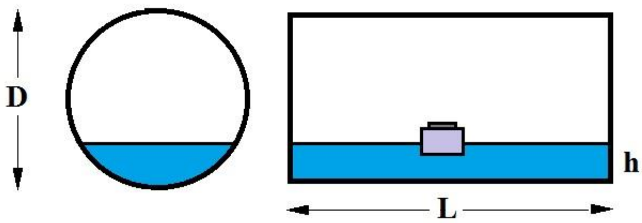

Fig. 1. Schematic diagram of the proposed system

*Corresponding author's email: assem@sharif.edu

Table 1. Effective parameters in this study

parameter	h/L	Magnet strength (G)	Frequency (Hz)	Electrical resistance (Ω)
values	0.2 0.25 0.3	0.05 0.1 0.15	1-3	147 819

Fig. 3. Shaper machine and installed system on it

related to the interface such as pressure, can be used as a parameter to predict the performance of this system. The reason for this is that the greater the fluctuations in the interface, the more energy we should expect. For this purpose, in this study, numerical modeling has been used to simulate fluid sloshing

3- Results and Discussion

The effect of magnet strength and electrical resistance on harvested power is shown in Fig. 2. The values of B and R in this figure are given in Table 1.

It is observed that the highest power harvested in each state is related to the resonant frequency of the system, and between the first and second resonant frequencies, first decreases and then increases the power. Also, with increasing magnet strength, we see an increase in energy harvesting. The important point of this figure is the higher power output with smaller electrical resistance, which is consistent with the data in previous articles, including references [7,8]. The physical reason for this finding is that the electrical resistance is higher than the resistance of the coil itself, which reduces the electrical power.

To evaluate the performance of the system, the harvester was installed on a shaper machine and the harvested energy was measured in different modes of operation of this machine. The shaper machine and the system installed on it are shown in Fig. 3. Experimental data are extracted and plotted in Fig. 4. The results show that the proposed system has worked well on the machine. The inductive voltage has increased with increasing course length as well as the oscillation of the shaper movement. The maximum inductive voltage in the coil is 350mV, which is related to the course length of 26cm and the frequency of 1.25Hz.

To evaluate the efficiency of the numerical model used in this study, the changes in pressure of the interface resulting from the numerical method and the experimental voltage drawn with time have been done and shown in Fig. 5. It can be seen that there are many qualitative similarities between numerical graphs and experimental data.

4- Conclusions

In this study, a method for energy harvesting from mechanical vibrations was proposed. The findings indicated that: 1) The maximum harvested power was 400 microwatts. 2) As the frequency of oscillations increased, the power increased and had the highest value in a frequency called the resonant frequency. 3) Harvested power was higher for lower electrical resistance. 4) The proposed system was used in the shaper machine and an acceptable performance was observed

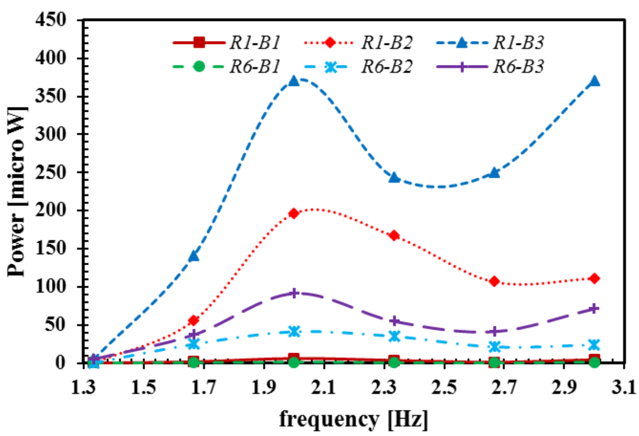

Fig. 2. Harvested electrical power for h/L=0.25

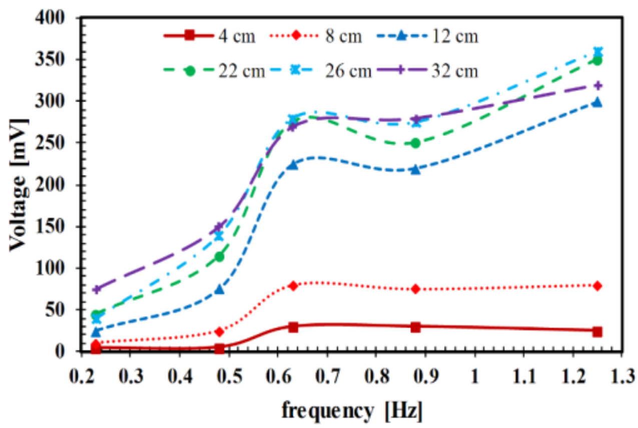

Fig. 4. Induced voltage in the shaper machine

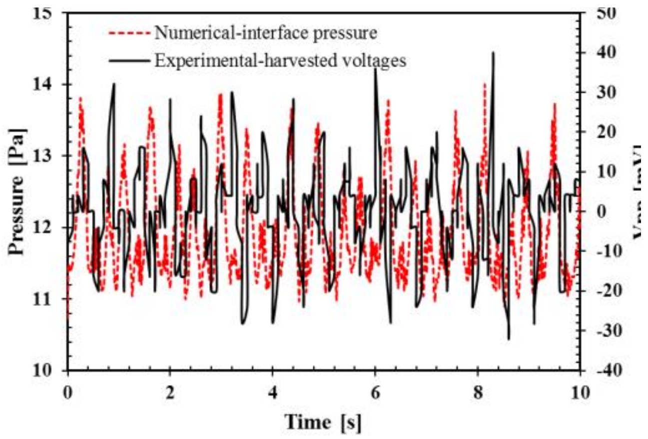

Fig. 5. Comparison of numerical results and harvested voltage variations with time at f=2Hz and h/L=0.25 with R1 and B1: (a) interface pressure

so that this system can be used in wireless sensors to precisely control the performance of this machine. 5) Considering that the main factor of energy harvesting in the studied system is the interface movements due to sloshing, so by numerical modeling, its performance can be designed and analyzed.

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