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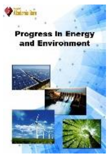

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Short Communication

Preliminary investigation on the energy harvesting of vortex-induced vibration with the use of magnet

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Abstract

The utilization of natural resources as renewable energy is thriving as its innovation brings clean energy, environmentally friendly and also cut down costs. Hence, the purpose of this study is to propose a technique to enhance the output voltage of piezoelectric as an energy harvesting device by applying nonlinear magnetic forces from a phenomenon called vortex induced vibration (VIV). This harvester device is designed with a presence of two magnets that placed at the bottom of a circular cylinder and on the lower base. The mechanical conversion energy that is studied is the vibration from circular cylinder's oscillation through a phenomenon called Vortex Induced Vibration by using piezoelectric transducer. A VIV-based energy harvester has been fabricated and carried out in water flow to observe the optimum output voltage that can be generated. Three different lengths of piezoelectric cantilever plates and two magnet distances are tested to investigate the influence of system's stiffness and the repulsive force to the harvested energy. From the experiment, it is observed that a lower stiffness of the system provides higher harvested voltage. In addition, the presence of magnets shows a greater output voltage due to the action of nonlinear magnetic forces where the position between two magnets able to shift the synchronization region thus, showing a greatly wider synchronization region and increasing the performance of VIV-based energy harvesting system.

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1 Introduction

One of the greatest challenges faced by humanity is to sustain the energy from the natural resources. Non-renewable sources such as fossil fuel are decreasing due to the excessive consumption of energy. Moreover, the production of fossil fuel becomes the main cause of air pollution and greenhouse gas emission which lead to the global warming and causing a large amount of death per year. It is important to switch from better energy consumption to a sustainable energy where it can reduce the pollution and energy waste. Renewable energies such as solar power, water, and wind are the sources that are classified as sustainable energy since they can produce clean energy.

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Energy harvesting device can replace the usability of battery since battery have limited lifespan and the device will become more useful for sensing network especially in places that are inaccessible and unapproachable. To harness kinetic energy from the ambient sources, human has developed new technologies that can be stored, such as microelectromechanical energy harvesting device, operating portable electronic devices, wireless sensing unit, which also can replace batteries due to its unlimited lifespan, low cost maintenance and wearable [1].

In generating energy from the renewable sources, several phenomena are tested for the dynamic response to piezoelectric structure. Vortex Induced Vibration (VIV) is one of the most attractive phenomena due to its capability to generate energy by self-restricted oscillations in the lock-in region or also called as synchronization. Lock-in region occurs when vortex shedding frequency becomes close to the natural frequencies of the structures [2]. However, one of the challenges occurs in vortex induced vibration (VIV) is the narrow synchronization region that result to poor performance of harvested power [3].

In recent years, numerous researches had been conducted to identify the most appropriate method to generate more energy from the ambient vibration through the energy harvester. Due to the fluctuation of ambient vibration in nature and the narrow synchronization region, the resonant harvesters' efficiencies were unsatisfactory [4]. According to Yang et al. [5], there were a few options to widen the range of the harvester such as approaching the performance of resonance, multimodal configurations of energy harvester, nonlinear energy harvester and method in up-conversion of frequencies. To enhance the output performance of energy harvester by widening the synchronization region, nonlinear restoring forces method was developed to increase the vibration responses for energy harvesting [4]. In addition, a few researchers had explored a method in achieving higher range of synchronization region through the nonlinear stiffness of the harvester method [6]. In exploiting this method, a system was performed by Cottone et al. [7] who utilized nonlinear restoring forces for energy harvesting by using two magnets and the effect of bandwidth known as piezomagnetoelastic energy harvesters was observed. A magnifier was proposed by Wang et al. [8] to improve the effectiveness of bistable energy harvester by amplifying the excitations on base. Meanwhile, the performance of an energy harvester was studied by Masana and Daqaq [9] on its monostable and bistable conditions. They reported that ultra-wide lock-in region can be achieved by introducing the bistable configuration through higher acceleration. Focusing on the energy harvesting using the concept of VIV, Naseer et al. [4] was one of the earliest studies that use the magnetic force to harvest the vibrating energy. In the study, hardening effects were observed in all tested spacing distances.

Based on the literature review, a design to widen the lock-in region of VIV and increase the output performance of energy harvesting device is feasible by exploiting magnet repelling force which can increase the vibration response for energy harvesting. However, very limited resources can be found in the literature. Hence, the purpose of the present study is to investigate the use of magnetic forces to enhance the performance of energy harvester via VIV. Piezoelectric transducers are used as the energy harvester with two magnets to transform the vortex induced vibration (VIV) oscillations of a cylinder to electrical power.

2 Methodology

The experiment takes place at National Hydraulic Research Institute of Malaysia (NAHRIM). The range of water flow speed that is used in the experiment is 0.10 m/s - 0.40 m/s with an interval of 0.03 m/s by using water flume, as shown in Fig. 1. The experiment rig consists of a piezoelectric, circular cylinder, different lengths of aluminum plates and two small circular magnets. The schematic diagram of the setting is shown in Fig. 2. Besides, the circuit used in connecting the energy harvester piezoelectric, which consists of full wave bridge rectifier to convert alternating current (AC) to direct current (DC) energy is shown in Fig. 3. The designation of energy harvesting circuit of the present study is referred to Jian et al. [10].

The supporting structure is made from steel frame with dimension of 0.29 m × 0.29 m × 0.29 m in height, length, and width, respectively. The supporting structure is used to hold L shape steel which acts as connector between the circular cylinder and the supporting structure. A hollow stainless-steel cylinder is used in present study, with the specifications as stated in Table 1.

Since the experiments are carried out in water, the circuit connection is covered with hot glue as waterproofing to avoid any disturbance that can interfere the reading when experiments are running. The end of the plate is attached to a circular cylinder where it acts like a pendulum. The full set up of the experiment is shown in Fig. 4.

Fig. 1 NAHRIM"s water flume.

To identify the optimum voltage produced by VIV-based energy harvesting using piezoelectric transducer, an experimental is done by placing piezoelectric lead zirconate titanate (PZT)-based thin films on three different lengths of aluminium plates (100 mm, 110 mm and 120 mm). Subsequently, plate is of 100 mm is chosen to continue the second experiment. In the second experiment, two magnets are utilized, where one of the magnets is placed at the bottom of circular cylinder while another magnet is located at the lower base of the cylinder to identify the optimum distance between the magnets (1 cm and 3 cm) that can harvest higher voltage (Fig. 3).

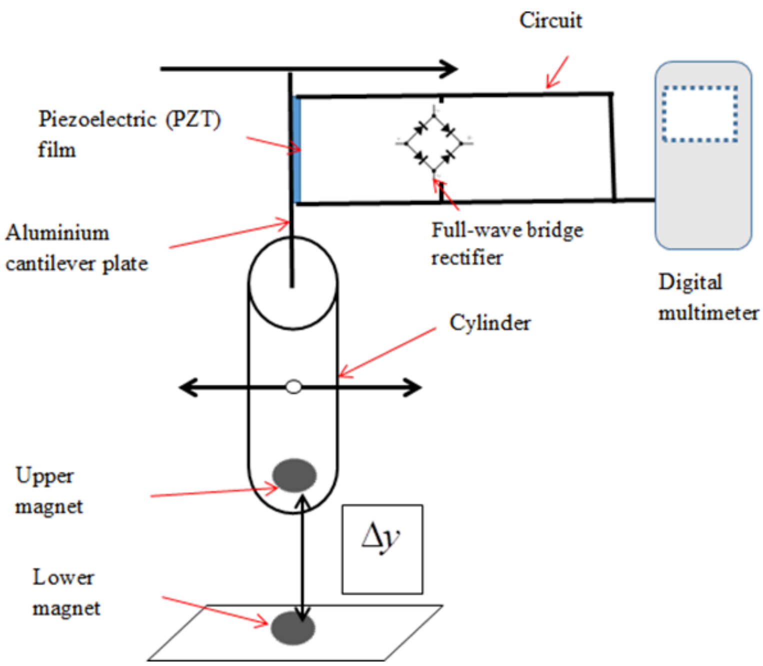

Fig. 2 Schematic diagram of Piezo-magnetoelastic energy harvester.

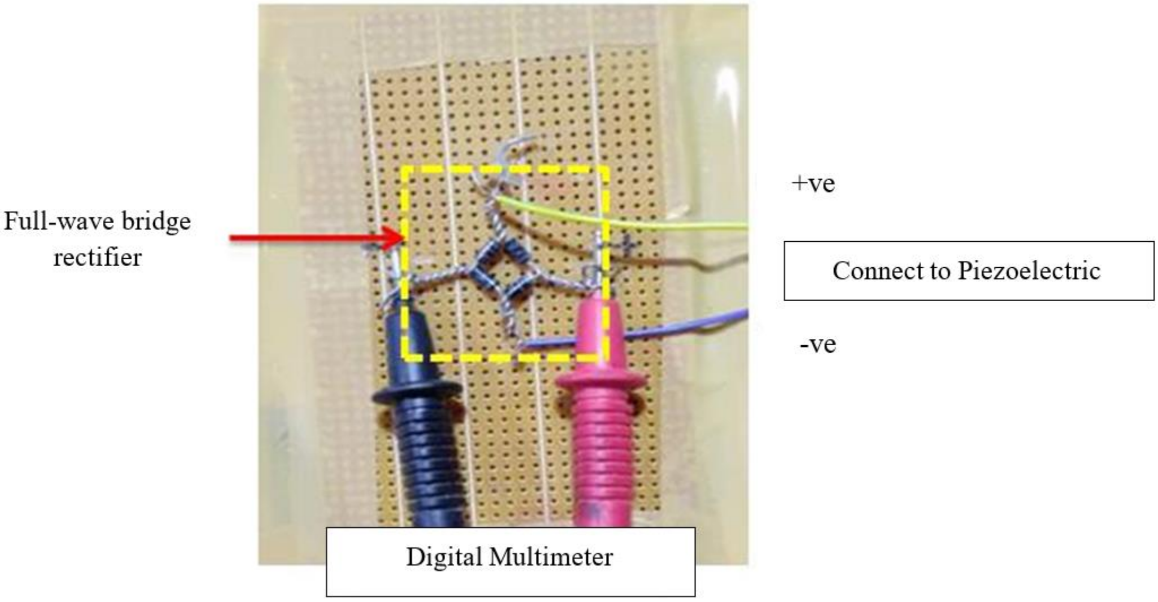

Fig. 3 Circuit of VIV-based energy harvesting.

Table 1 Specifications of the circular cylinder

Items	Measurement
Length (m)	0.1 m
Outer Diameter (m)	0.025 m
Thickness (m)	0.01 mm
Weight (kg)	0.095 kg

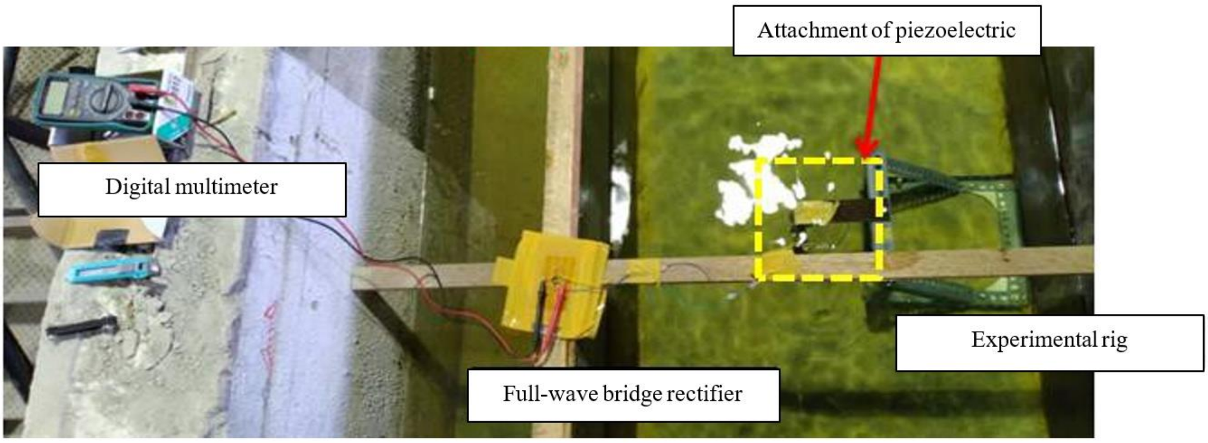

Fig. 4 Full set up of VIV-based energy harvesting device.

3 Results and Discussion

3.1 Free Decay Test

Free decay test is done by recording the free vibration of circular cylinder in calm water to obtain the natural frequency for all the cylinders. Table 2 shows the recorded value of natural frequency from the free decay test. Based on the Table 2, 100 mm plate has the highest natural frequency value compared to others.

Table 2 Natural frequency from Free Decay Test (FDT)

Tested condition	Natural Frequency (Hz)
Plate: 100 mm, without magnet	1.32
Plate: 110 mm, without magnet	1.31
Plate: 120 mm, without magnet	1.17
Plate: 100 mm, distance between upper and lower magnet, Δy = 1 cm	1.43
Plate: 100 mm, distance between upper and lower magnet, Δy = 3 cm	1.22

The reduced velocity range involved in the present study is from 3 to 13.7, correspond to 0.10 – 0.40 m/s. The range is selected based on the occurrence of lock-in region. Lock-in is defined as the synchronizations because of the vibrating frequency of a structure (due to VIV) closed to the natural frequency of the structure. The reduced velocity can be calculated using Eq. (1),

$$V_r = \frac{U}{f_n D} \tag{1}$$

where f_n is the frequency of the structure, D is the outer diameter of circular cylinder (0.025 m) and U is the free-stream velocity of the flow.

3.2 Different Lengths of Plate

Three different lengths of aluminum cantilever plates are utilized to identify the optimum length for energy harvesting. Fig. 5 shows the result of the harvested voltage of various plate lengths. Based on Fig. 5, plate of 120 mm is found to generate the highest output voltage. The lock in region is the widest, starting from V_r=7.5 until 13.5. On the other hand, plate of 100 mm generates the lowest output, with narrower lock-in region. The lock-in range of the present study is in agreement with the synchronization ranges reported by previous studies [11,12]. The longer the plate length, the lower the stiffness of the system, the larger the vibration, and hence, the higher the harvested energy. The outcome of the present study is consistent with Zahari et al. [13], where a lower stiffness of the system provides greater effect on vortex-induced vibration. To perform the next experiment with the presence of magnets, 100 mm plate is chosen.

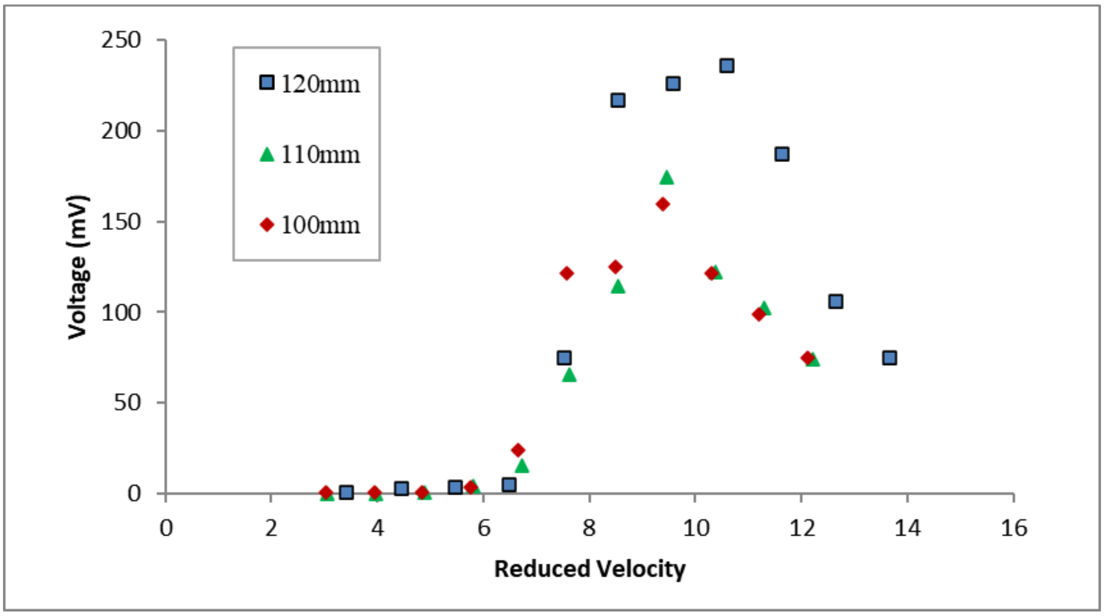

Fig. 5 Voltage versus Reduced velocity for experimental work without magnet.

3.3 Experimental Work With Magnet

For the experiment attached with magnet, two distances between magnets ((Δy=1 cm and 3 cm) by using 100 mm plate has been conducted to identify the harvested energy. The data of 100 mm plate without magnet is also included for comparison. Based on the Fig. 6, the distance between magnets with 3 cm (Δy=3 cm) has the highest output voltage value. The larger the distance between the magnets, the higher the output voltage that can be harvested from the oscillation. However, there is a limitation on the distances between the magnets. It is when the repulsive effect between magnets is not functioning due to the extremely large distance. On the contrary, when the distance between magnets is too short, the strong repulsive force will cause the cylinder to vibrate at one side only, where the cylinder could not pass through another side, and thus the output energy is smaller, as indicated by the present study of 1 cm distance.

Comparing with the case of without the magnet, the presence of magnet contributes significantly on the harvested voltage, where the increment percentage is 380.68% and 540.79% for 1 cm and 3 cm, respectively. Therefore, the use of magnet shows the potential in increasing the VIV energy harvest. Nevertheless, further investigation should be conducted to examine the details of the nonlinear restoring forces, as the present study is only a preliminary outcome.

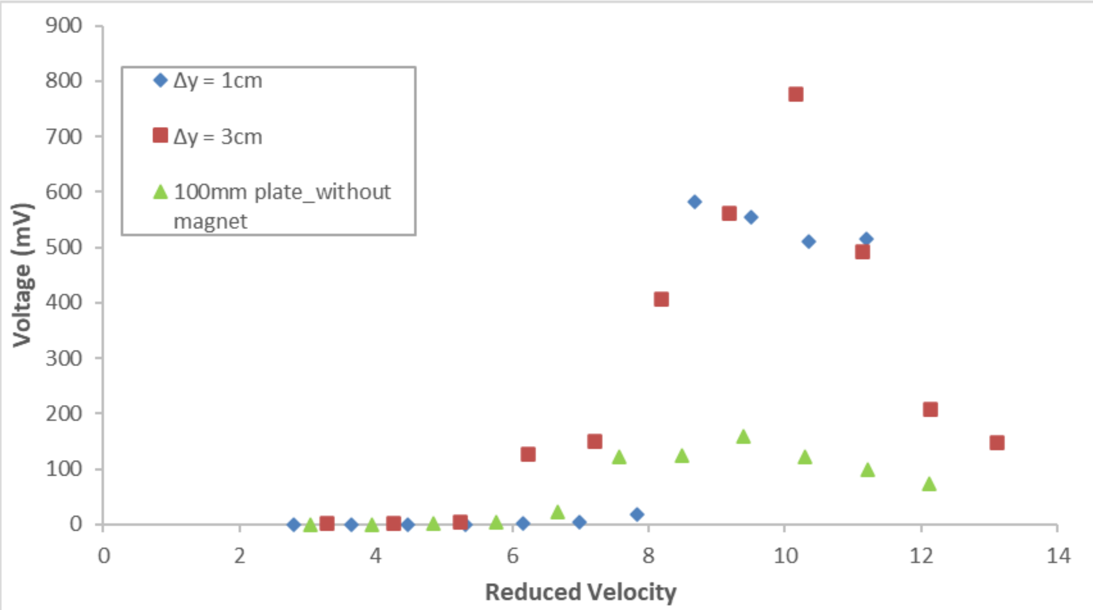

Fig. 6 Graph of Voltage versus Reduced velocity with distance between magnets.

4 Conclusion

This experimental study is to identify the performance of energy harvesting device using piezoelectric transducer with presence of two repulsive magnets. This experimental work has been conducted in water flume at National Hydraulic Research Institute of Malaysia (NAHRIM). The generated voltage is measured by using digital multimeter and the data is being recorded and analysed. From the study, the highest output voltage without the magnets is generated by 120 mm plate which is 235.7 mV. For the cases with the presence of magnets, the distance between magnets with 3 cm generates the highest output voltage which is 776 mV. For future work, it is suggested to investigate the non-linear restoring forces caused by the magnets, the bistable and monostable configurations, and its effects on the performance of energy harvesting.

Declaration of Conflict of Interest

The authors declared that there is no conflict of interest with any other party on the publication of the current work.

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