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Proceeding Paper

Conceptional Designs of the Rotation Mechanism with Antiphase Energy Harvester †

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Abstract: Due to the increased demand for a sustainable source of energy, the research on energy harvesting has increased in the last twenty years. Energy harvesting aims to gain energy from the ambient environment and converting this energy into electrical power. There are different kinds of renewable energy sources and vibration energy harvesting (VEH) is the most promising source owing to its low maintenance cost. This paper focuses on an electromagnetic vibration energy harvester based on the concept of rotational energy harvesting. The proposed device uses a rotating rotor with permanent magnets and moves the repulsive magnet block up and down. The block is connected to an antiphase harvester, which creates power by cutting the magnetic flux density. The antiphase has been proved to doubling the voltage when the antiphase is moving. To improve the vibration amplitude of the magnet block and the antiphase, springs are added to the proposed design. In the concept, four configurations with and without different spring positions are proposed. The experimental results showed that when the spring is placed in the upper and bottom part of the moving part or spring at the bottom would generate the largest vibration amplitude. Based on Faraday's Law of Induction, the voltage is proportional to the velocity or vibration amplitude. Hence, for both cases, at least six times the voltage is generated compared to the design without added springs.

Keywords: rotation energy harvester design; antiphase motion; repulsive magnetic

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1. Introduction

According to the IDTechEx's latest report in energy harvesting, most of the data are targeting in improving people life, especially in the smart cities. A smart city with rich of information will help people to increase the efficiency and productivity. Each information is connected wirelessly through wireless sensor nodes (WSNs). All the sensors' node requires battery to operate, and the battery power will be dissipated over the years. This will increase the challenge in replacing battery, especially in the rural area or deals with thousands of wireless sensor nodes. The vibration energy harvester (VEH) is one of the options in replacing the battery. Hence, the concept design in this paper presented one of the alternatives' designs to be used in the future.

As decades of research into the scope of energy harvesting increases, so also is the improved methodology to harness vibration from non-unidirectional sources alone, but also the use of rotational sources. The general background for such as the endeavor is to convert the slow rotational of any mechanical device whose health is to be monitored such as fan blades, rotors, and stators, crankshafts, rotating wheels, etc. into a unidirectional up-down vibrational motion or vice versa. Previous and current research endeavor has deployed these methods of vibration energy harvesting in both piezoelectric, electromagnetic, and hybridized mode depending on the operational requirement and the operating environment.

An approach of an electromagnetic energy harvester that recycles low-frequency vibration for bicycle rider application is proposed as an example. The input of up-down motion of the rider's sit is converted to unidirectional rotation by the rotating motion rectifier from the bidirectional rotation by the transmission part [1]. In a search for tapping the low-frequency vibration and human motion, [2] reports a uniquely different approach for constructing high-output rotational harvesters using a novel string-suspended and driven rotor that uses only two strings to suspend and actuate a rotor. In an attempt to improve the harvester's efficiency, [3] introduces a cantilever-driven rotor for efficient vibration energy harvesting to convert vibrations to unidirectional. Compared with the conventional cantilever-based harvesters, the rotor-based energy harvester (RBEH) can provide both enhanced output power (1.8 mW versus 0.3 mW) and extended working bandwidth (4.5 Hz versus 1.9 Hz) under a harmonic vibration of 0.8 g. A similar approach is the use of intermittent magnetic force between the rotational driving magnet and the tip magnetic mass to drives the piezoelectric-cantilevered element [4]. A mathematical model for a harvester that using a small gravity-induced disk mounted with a piezoelectric cantilevered beam and a pair of magnets in the wind turbine blades were reported in [5]. An innovative system that offers a direct conversion of ambient vibration to unidirectional rotation through a new plectrum design; vibration-to-rotation conversion mechanism is reported [6]. Design modeling and experimental investigation of a magnetically coupled vibration energy harvester using two inverted piezoelectric cantilever beams for rotation motion was mention by [7] and producing large amplitude in a low-speed range.

This paper presented the concept design of a rotational antiphase vibration energy harvesting through experiments. The works will focus on the effect of the springs on the different locations and the speed variation that affect the voltage output.

2. Working Principle on the Propose Concept

The working principle of the propose rotation energy harvester is ultilise the rotation to generate the vibration through the repulsive magnetic force as shown in Figure 1.

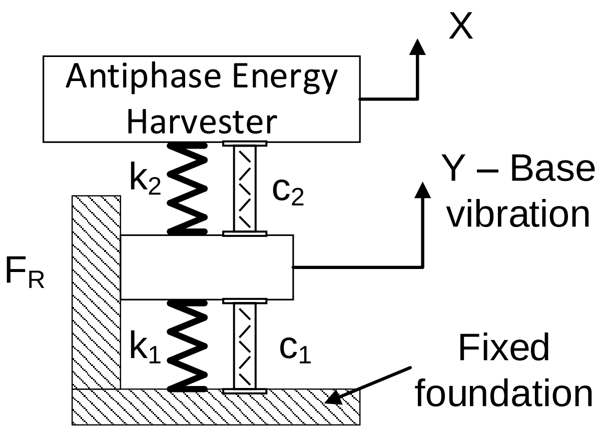

Figure 1. Schemtic diagram of the rotational anti-phase energy harvester.

The overall design can be modelled as two-degree of freedom system (2-DOF) where k is the spring constant, c is the damper, and subscript 1 and 2 represent different system. Y is the base vibration produce from the repulsive magnetic force. Due to the effect of the linear guiderail, the coulomb friction, F_R, is present in the system. The antiphase harvester is well explained in the [8] in author's work. Figure 2 shows that the 3D model of the propose system.

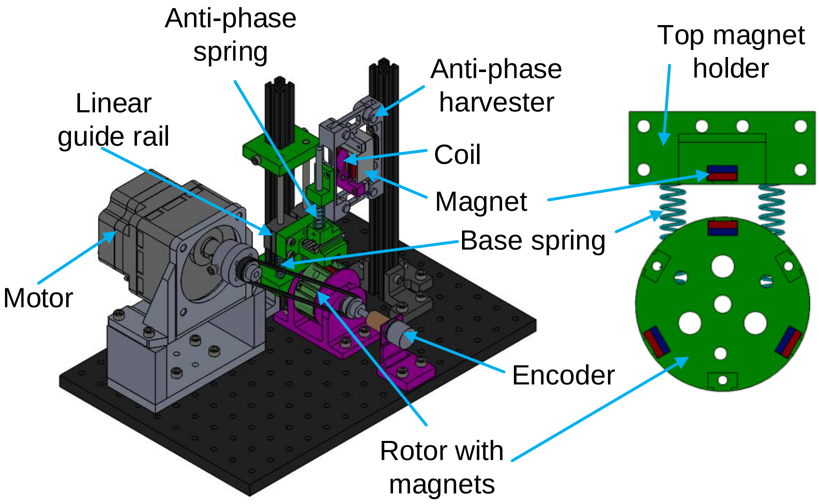

Figure 2. 3D model of the rotational energy harvester (**left**) and rotor with magnets and top magnet holder (**right**).

Generally, the base vibration is produced from the repulsive magnetic force which is present in the rotor. There are three NdFeB permananet magnets (25 mm × 10mm × 5 mm) on the rotor, and another same type of magnet is attached to the upper holder (where the holder is secure to the linear guiderail) to produce a vertical movement. The anti-phase energy harvester also connected to the linear guiderail. There are two springs in the system, i.e., base (two springs in parallel, as shown in Figure 2 right) springs and a anti-phase spring. The springs are connected to the holder with a tight connection. The motor is used to rotate the rotate that mimic the behavior of the real system which connected to the rotor through the same pulley dimensions.

3. Experiment Setup

An electromagnetic vibration energy harvester prototype based on the propose concept of rotational energy harvesting is designed through CAD software and manufactured using 3D printing and aluminium components. Figure 3 shows that the experimental setup.

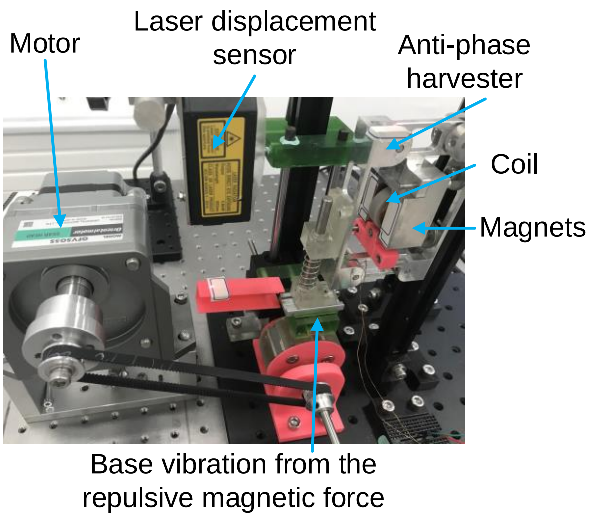

Figure 3. Experiment setup of the rotational anti-phase energy harvester.

The working principle of the propose concept is explained in Section 2. In this experiment, the different spring position sets on the prototype were studied to identify the best arrangement that harvests the maximum voltage. Four configurations of spring position were identified where the base and anti-phase springs were installed. Four different spring positions are D1—TBS (top bottom springs), D2—TS (top spring), D3—BS (bottom spring), and D4—NS (no spring). The top and bottom springs are referred to the antiphase and base springs, respectively.

The motor was operated at a speed from 200 rpm to 4000 rpm with a gear ratio of 5 at the interval speed of 50 rpm or 100 rpm. The experiments were repeated three times for accurate data. The energy harvester was connected to the external load resistance of 100 Ω. Two laser displacement sensors (LK-H050) captured the amplitude at base spring and the top of the anti-phase spring. An encoder was used to capture the rotation to make sure the vibration is occurred at the correct location. All the data were connected to the NI data acquisition card (NI-USB 6210) and were processed in the LabVIEW.

4. Experimental Results

The data relating to the performance was collected during the experiment. The parameters utilized for the axis labels of plots are rotation frequency, voltage, and base and anti-phase amplitude. Figure 4 shows that the time response in revolutions.

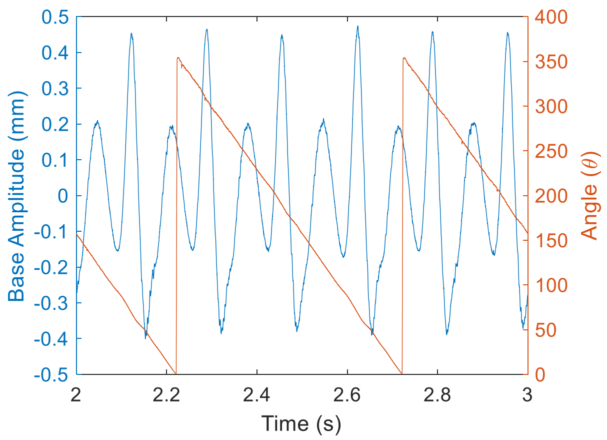

Figure 4. Time response curves of absolute base amplitude and angle for complete revolutions for D1—TBS at 600 rpm.

In a one complete revolution, there is three base vibration amplitude as shown in the Figure 4. This is because the rotor has three equally space permanent magnets, which will cause the repulsive vibration. Figure 5 shows that the graph of the absolute displacement difference of base for four different designs.

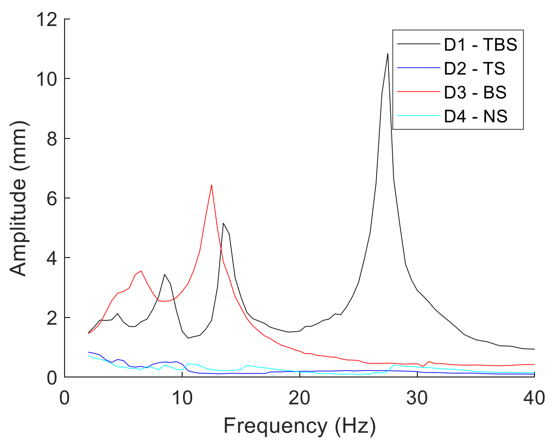

Figure 5. Absolute base amplitude designs 1 to 4 configurations.

The D1—TBS demonstrates three clear peaks, which refer to the resonance frequency of the system when considering the base amplitude. The first peak happens at 8.5 Hz where the amplitude is 3.44 mm, the second peak locates at 13.5 Hz where the amplitude is 5.16 mm, and the last peak is at 27.5 Hz where the amplitude is 10.83 mm. The amplitude drops back to about 2 mm after the peak with the increase of the rotation speed. One of the possible reasons is the springs not properly tight into the holder which cause another resonance. The D3—BS shows two peaks at a smaller frequency. The first peak happens at 6.5 Hz where gives the amplitude is 3.56 mm. The second peak is at 12.5 Hz where the amplitude reaches 6.43 mm. In addition, it is clear to conclude that both anti-phase spring and no spring design yield very little maximum base displacement difference for all frequency ranges, and it is indistinct to identify the peak, especially for the frequency over 10 Hz. To conclude, D1 and D3 could generate relatively obvious resonance when considering the base vibration. Besides, the performance of bottom spring configuration is better than both spring configurations at low-frequency range, i.e., 0–13 Hz.

When considering the absolute amplitude at antiphase from Figure 6, the conclusion can be partially different compare with the previous scenario. The overall trend demonstrates that magnitudes of the antiphase displacement difference of all configurations are descending with the increase of rotation speed. Specifically, the D1—TBS also creates three peaks but the location and the magnitude change. The first peak locates at 4.5 Hz with an amplitude of 4 mm, the second peak, which is the largest one, locates at 8.5 Hz of rotation frequency with an amplitude of 8.17 mm, and the last peak happened at 27.5 Hz with the displacement difference of 2.31 mm. This is due to the effect of the frictional that cause the smoothness movement of the linear guiderail and the harvester. Next, the number of the peak is two for D3—BS as well; the first peak is at 6.5 Hz, and the amplitude is 3.67 mm, and the second peak is at 12.5 Hz, and the amplitude is 6.58 mm. Finally, both D2 and D4 do not provide a plain peak for the analysis. Hence, it will not be considered in the design as the voltage is related to antiphase amplitude. A brief observation can be drawn is the resonance performance of D1 is generally better than other designs when the frequency is lower than 10 Hz and larger than 21.5 Hz. The D3 takes advantage when the frequency is between 10 and 21.5 Hz.

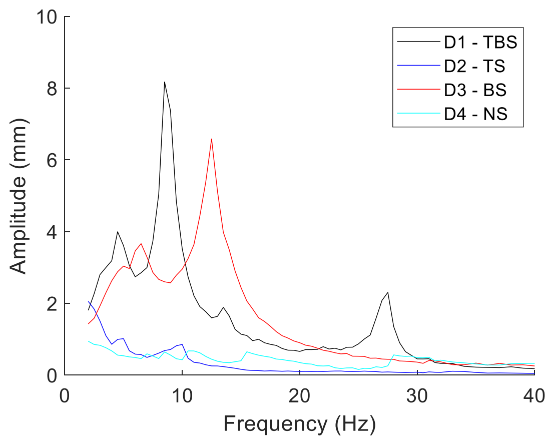

Figure 6. Absolute amplitude at antiphase for designs 1 to 4 configurations.

Figure 7 demonstrates the voltage generated by the vibration energy harvester for different frequency and design configurations. The voltage could be an intuitive reflection of the energy harvester performance. The general observation can be drawn that the no spring configuration can generate about 0.5 V of electricity on average, but the drop can be noticed when the frequency reaches 25 Hz. However, the top spring is not contributing to the enlargement of electricity generation for all frequencies, because the voltage for all frequencies is smaller than no spring configuration. In contrast, the utilization of the bottom spring can magnify the voltage significantly for a certain frequency range. The maximum voltage could reach 1.78 V at the frequency of 12.5 Hz. If add both top and bottom spring, the trend of the curve is similar to the overlap of both single spring conditions.

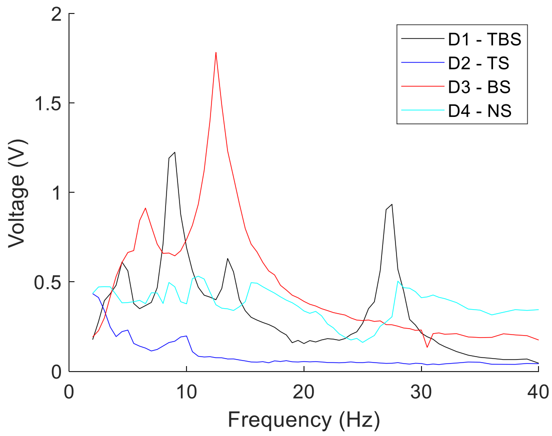

Figure 7. Voltage versus frequency for designs 1 to 4 configurations.

5. Conclusions

In conclusion, the addition of the bottom spring has a significant effect on the amplitude and voltage amplification, but the top spring might contribute inversely and impact the performance to some extent. However, the combination of top and bottom springs can produce a better performance at a certain frequency range. Thus, if the vibration source frequency is known, the design can be changed based on the condition but this always an challenge for random vibration.

In this paper, conception designs using an anti-phase energy harvester have been proposed. The experiment can be improved with multiple materials that have better magnetic flux can be considered for the design of the rotation part, so that the repulsive force can be maximised. In addition, the proposed concept designs are useful for low rotation frequency and provide voltage for the wireless sensor nodes. The energy conversion and storage will be considered in the future works.

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