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Vibration harvesting techniques for electrical power generation: A review

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Abstract. The ongoing demands of using mechanical motion and converting it to electrical power motivated designers to find new sustainable solutions for power generation. In the current article, different techniques of clean power generation are reviewed and discussed. The reviewed techniques use mechanical vibration to produce energy. The techniques using piezoelectric and mechanical design concepts are discussed and compared. The article sheds light on the importance of these techniques and concludes with the advantages and disadvantages of each applied technique.

Introduction

There are increasing demands to find new energy sources to reduce the use of fossil fuels. The new energy source has to be of better sustainability and environmental impact. The use of clean and renewable energy has increasing demands and thus puts a lot of pressure on engineers to find new ways to generate energy. Harvesting vibration energy has obtained a lot of researchers' attention, and that led to the development of new techniques or design concepts [1,2]. The use of mechanical motion in our daily activities and converting it to electrical power has been under investigation and application. This energy harvesting concept can be applied using two main techniques, first, using mechanisms or mechanical concepts, and second, using piezoelectric transducers.

The pendulum mechanism is discussed in [3] for energy harvesting. Different pendulum configurations for energy generation were applied, for example, the multi- or single-pendulum, and modulation-based pendulums. A few combinations of piezoelectric, electromagnetic and hybrid transducers were discussed. An electromagnetic vibration-based energy generator was proposed in [4]. The technique converted the linear vibration to a rotation. Linear motion can be converted to energy using a magnet, where the rotation in the magnetic flux can generate electricity.

Piezoelectric materials can be employed as devices to generate energy from mechanical motion, which is in the form of vibrations, into electrical energy that can power other gadgets. Power harvesting is the technique of collecting energy and turning it into useful power for a system. Portable systems that don't rely on conventional power sources, such as batteries, which have a finite lifespan, can be created by putting these power harvesting devices into use [1]. The vibration energy could come from many sources, such as industrial machinery, transit networks, or even everyday activities like walking or keyboard typing. By capturing and converting these vibrations into useful electricity, we can tap into a nearly unlimited and clean energy resource. Researchers and developers aimed to turn wave energy into power. Power harvesting using piezoelectric materials has been studied for a variety of possible applications. Different power transducer techniques were applied to convert the mechanical motion to electrical energy [5]. Piezoelectric transducers, which are small devices, can be used for energy conversion. The collected energy is usually vibrations which should be converted to electricity to be used in other daily used devices. The mechanical vibration energy is usually wasted as dissipated heat [6] but by applying vibration energy harvesting it can be converted to useful energy. However, conventional vibration energy harvesters can experience the issue of operating close to the resonance frequency and this can affect how efficient the operating range is in generating electrical energy. The overall power that can be used is small. The amount of the resulting power depends on the harvester design and also the amplitude and frequency of the vibration. Therefore, if the collected vibration energy is recorded properly the harvester must be designed and fabricated accurately for the best power results [7].

Researchers and developers aimed to turn wave energy into power. The use of piezoelectric transducers has been investigated for vibration energy harvesting in different applications. Several researchers examined the use of energy dissipated in human activities to generate energy that can power small electronic devices. Proposing Polyvinylidene fluoride films as a material for an implanted physiological power source. The prototype was shown to produce a peak voltage of 18V, corresponding to a power of around 17mW. Many researchers have also researched how to capture energy from mechanical structures. Using a piezoelectric vibrator and a steel ball to convert mechanical energy to electrical energy. Their research evaluated the amount of energy released when a steel ball struck a thin piezoelectric plate. A cantilever beam model was used in [8] for harvesting energy with piezoelectric transducers. The presented model was designed to accurately produce energy by adding the damping effect of power harvesting. A comparison approach to compare different designs and methods for vibration energy harvesting generators was presented and discussed in [9].

The unpredictability of ambient vibrations, the requirement to align the resonance frequency of the harvester with the prevailing vibration frequency, and the effective conversion and storage of the captured energy are some of the difficulties involved in vibration harvesting. Vibration harvesting has a lot of potential for powering low-power electronics, wireless sensor networks, and Internet of Things devices in applications that call for constant or long-term power sources, despite these obstacles. The goal of ongoing research and development in this area is to enhance vibration harvesting systems' scalability, dependability, and efficiency for a variety of real-world uses. The majority of research focuses on a specific technology, making it challenging to compare vastly different vibration-based energy harvesting designs and methodologies [2].

In this research paper, the process of comparing the selected harvesting energy techniques occurs. In our case, piezoelectric technique, and mechanisms technique.

Piezoelectric technique for vibration harvesting energy

Many scholars have looked into the possibility of harvesting energy from mechanical structures' ambient vibrations. The concept of a generator is examined by using a steel ball and a piezoelectric vibrator to convert mechanical energy to electrical energy. Their research measured the energy released upon the collision of a steel ball on a thin piezoelectric plate [10]. A power harvesting system model was developed and included a cantilever beam with piezoelectric patches fastened to it. Although the model's construction allowed for any combination of boundary circumstances and the piezoelectric material's position, it was tested on a cantilever beam that was suffering a base excursion from the clamped state. It was discovered that the model was accurate in estimating the energy produced and that it was also useful in illustrating how power harvesting damps energy [11]. The research that is presented in this article will concentrate on the piezoelectric techniques for vibration harvesting energy as well as utilizing the harvested energy. Fig.1 (a) demonstrates that it is based on an actual tile with a 150 × 150 mm2 area. Fig.1 (b) demonstrates that the piezoelectric tile is made up of four supporting springs, a bottom plate, a middle plate where the piezoelectric modules are installed, and an upper plate that must be physically walked on. The upper plate is linked to the piezo-installed layer in the middle plate. The thickness of the top and bottom plates is 10 mm apiece, and the length of the four springs is 40 mm. Fig.1 (c) provides a thorough illustration of the centre section's cross-section, showing the locations of the modules. The piezoelectric material, measuring 47 × 32 × 0.2 mm3, is positioned on a stainless steel plate substrate, measuring 62 × 37 × 0.2 mm3. PZT-PZNM, produced by TIOCEAN (Korea), is a thick film piezoelectric material. Fig.2 shows the experimental setup of the piezoelectric technique. The system efficiency for converting the mechanical motion to electrical power was obtained in [12]. FEA calculations were made and the results show that a bigger conversion efficiency value could be obtained with a thinner and shorter beam of a higher resonance frequency.

Different vibration harvesting energy concepts were applied for generating energy from machines, heat exchangers, compressors and motors by piezoelectric and energy harvesting devices. It was noticed that piezoelectric harvesting of energy was practically good for energy generation from vibration motion but it generated low power amount [13]. Piezoelectric energy harvesting with magnetic coupling promises a more meaningful solution to narrow bandwidth and low energy efficiency [14]. Theoretically, the cantilever beam's resonance frequency depends on its effective stiffness, effective mass, and tip mass [2]. Calculations are demonstrated regarding the beam, both effective mass and stiffness.

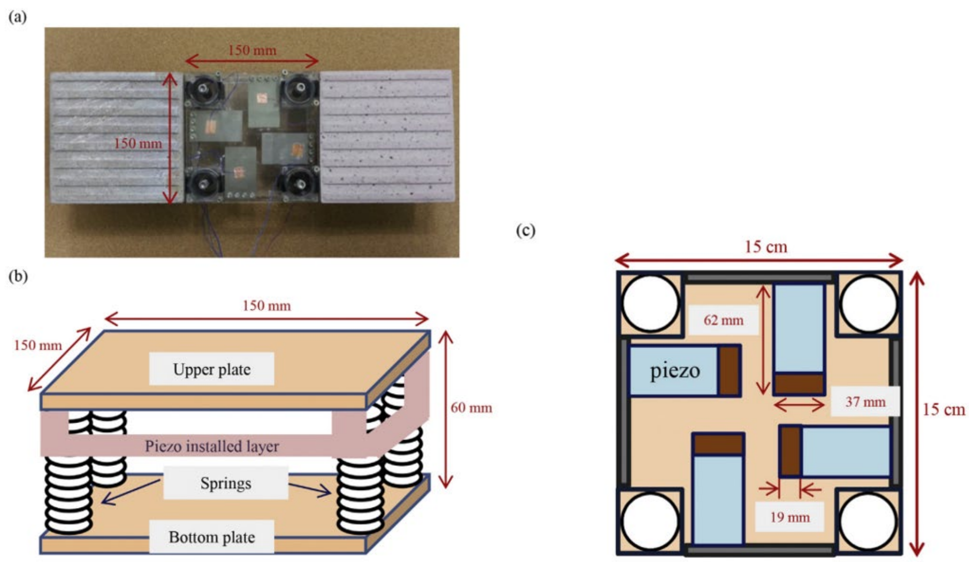

Figure 1: Piezoelectric tiles. (a) piezoelectric tile with a real tile. (b) schematic of the piezoelectric tile. (c) Piezo layer [1]

It had been selected the tip mass whose resonance frequency was closest to the tile's vibration frequency based on the experiment that was detailed [1]. Another research established a general theory containing many specifications where two piezoelectric generators were given the "effectiveness" design concept, and theoretical power outputs were computed. For one design, the power predicted by the effectiveness hypothesis was around 30% higher than the measured power output, and for the other design, it was 10% higher [10]. Three types of generators had been utilised and stated in detail initially and most importantly the piezoelectric generators, the electromagnetic generators, and the electrostatic generators. Familiarity with all types of generators is vital for predicting better alternatives depending on the required outcomes [15].

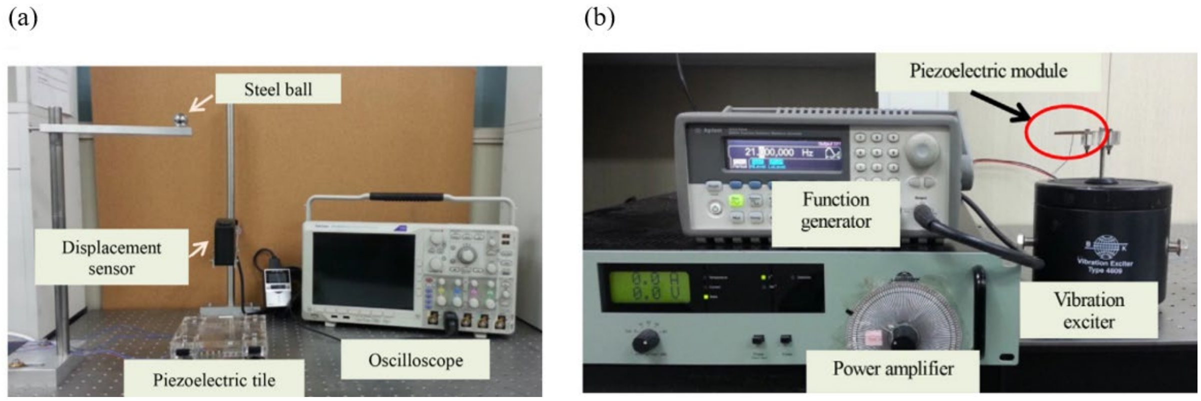

Figure 2: Piezoelectric tile system (a) vibration frequency measurement, (b) resonance frequency measurement (made by TIOCEAN CO.) [1].

While electromagnetic motors and piezoelectric materials have both been applied to vibration energy harvesting, their characteristics differ. Electromagnetic motors are velocity-induced transducers, whereas piezoelectric materials are force- or stress-induced transducers [16]. The active range of amplitude and frequency was studied in [17]. Successful lab and field tools were discussed, and the resulting energy level was compared. Keeping in mind the most recent developments in broadband energy harvesting methods, such as nonlinear methods, multimodal methods, and resonance tuning methods [18]. The application, limitations and advantages of several energy generation techniques were reviewed in [19]. Fig.3 shows a schematic diagram for two types of piezoelectric. Piezoelectric transducers were used in [20] to generate energy from a tile structure where it can produce energy when a person steps on it. A current of 140µA and power 2.8 µW could be generated. A small amount of power can be generated using piezoelectric transducers.

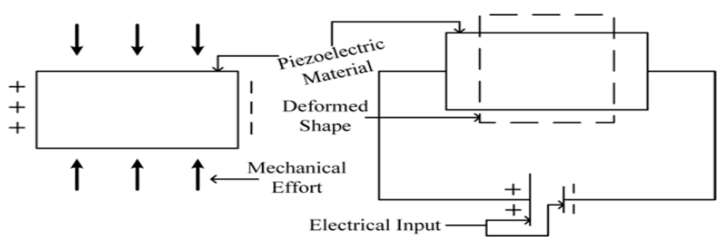

Figure 3: Piezoelectric EH types: (a) direct piezoelectric effect and (b) reverse piezoelectric effect [19].

Mechanisms technique for vibration-harvesting energy

Converting mechanical motion to electricity generation can be done by an electromagnet or a permanent magnet. Because it doesn't require power input, the permanent magnet is a better option for low-power devices than the electromagnet. Ferromagnetic or ferrimagnetic material is present in these permanent magnets. Despite producing a strong electric field, ferromagnetic materials are frequently employed because their increased electrical resistance reduces the influence of eddy currents.

A multi-degree freedom system can be introduced into an excitation structure to increase the bandwidth of the EH. Different subsystems were combined in the EH design to provide different modes. It was discovered that each resonance's average power generation by the EH differs significantly [19]. Harvesting energy response is discussed in [21], where a harvester of high sensitivity is used for generating energy. A harvesting system, including power electronics for managing the power, an electromagnetic converter and different mechanical parts was used. The system of high sensitivity can produce useful energy using vibration shocks. Energy harvesting techniques using bi-stable systems were reviewed in [22]. Electro-mechanical systems were presented to show the practical benefits of these techniques. The different bi-stable harvesting systems use magnetic repulsion, magnetic attraction and mechanical load to induce bi-stability. Energy generation using vibration harvesting that can be applied to self-powered micro and wireless systems was reviewed in [15]. Maximum harvesting energy is analyzed and optimum results were found in single- and multi-mass systems. The system sensitivity is obtained from the implemented simulation.

Vibration harvesting energy and conversion to electricity was applied in several mechanisms, using the electromagnetic principle [4, 23-28]. As seen in Fig.4, an energy generator using a speed bump that harvests vibrational motion is presented in [23]. The model uses a mechanism of rack and pinion and clutches. The mechanism is tested in the bump impact case and power generation is examined.

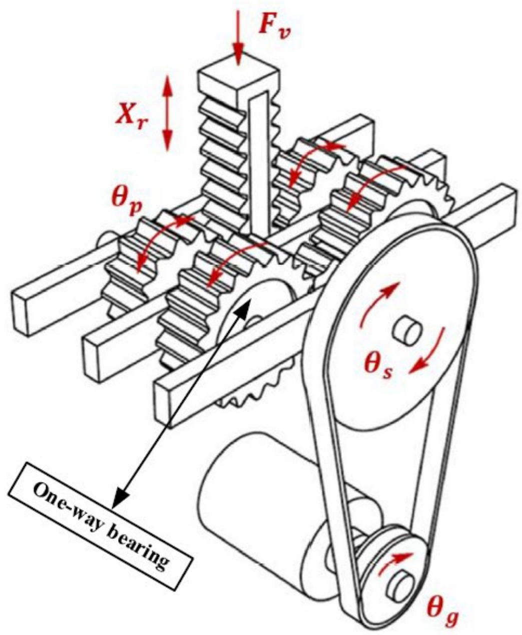

Figure 4: A speed breaker mechanism using one-way bearing [23]

Energy generation was investigated using mechanical concepts. A few mechanisms using spring were reviewed and discussed in [24]. The presented design configurations which are applied and tested work for power generation by using mechanical motion. A speed breaker design was presented and used in [25,26] for power generation. As seen in Fig.5, the mechanism can convert the linear motion of the rack to the rotary motion of the pinion and the rotational motion is converted to electrical energy using the magnetic field concept. As stated in [26], the used mechanism could produce 1.16 V, which is much higher the produced value in case of the piezoelectric. A compact energy harvesting system is presented in [27], which is an efficient, durable, and also feasible device. Modelling and simulation were used to validate the design model.

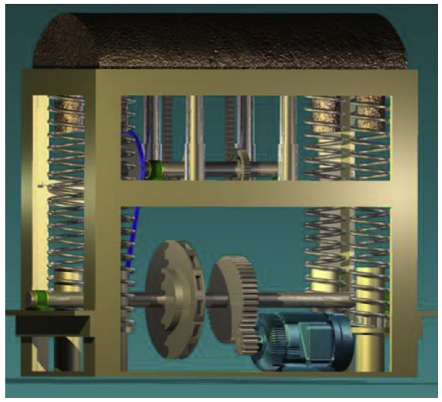

Figure 5: A speed breaker mechanism assembly [25]

Conclusions

Piezoelectric devices, which are small and light transducers, can be used to transform mechanical motion, often vibrations, into electrical energy that can power other devices used in our daily life. There are multiple energy harvesting techniques for converting vibration energy into usable electricity using mechanical design concepts. Power harvesting devices, using both piezoelectric and mechanical concepts, can be applied for vibration energy harvesting without relying on traditional energy sources, which have limited lifespans. Vibration energy is a free and sustainable source of energy that should get more attention to improve the applied techniques for increasing power generation, especially in the piezoelectric techniques. Mechanical concepts generate much higher energy than piezoelectric devices, however, they involve mainly springs, racks and gears which can result in system complexity, heavy weight, and energy losses. Moreover, the applied mechanisms can be a source of noise if the concept is applied to harvest energy from human walking. On the other hand, piezoelectric transducers, which are small and light, can produce energy with a small amplitude of vibration, but it is a much smaller amount of energy.

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