



Modeling of a horizontal asymmetric U-shaped vibration-based piezoelectric energy harvester (U-VPEH)

Shilong Sun, Peter W. Tse*

Department of Systems Engineering and Engineering Management (SEEM), City University of Hong Kong, Hong Kong, China



ARTICLE INFO

Article history:

Received 19 December 2017

Received in revised form 1 May 2018

Accepted 14 May 2018

Keywords:

Energy harvester

Piezoelectric

U-shaped

Vibration-based

Nonlinear

ABSTRACT

In this paper, we present a new horizontal asymmetric U-shaped vibration-based piezoelectric energy harvester (U-VPEH), which collects and converts destructive vibration energy into useful electrical energy. The finite element analysis is conducted on modal shape, the displacement, the mechanical energy, and the strain for both the linear and nonlinear U-VPEH models. Mathematical governing equations are derived to investigate dynamic characteristics of the model. The harmonic balance method and state space form are utilized to conduct the analytical and theoretical analysis. The results show that the first and second eigenfrequencies are 17.167 Hz and 22.951 Hz for the nonlinear U-VPEH model while those are only 17.366 Hz and 25.124 Hz for the linear model. The nonlinear energy harvester model can narrow frequency band gap between the first two resonance modes. Moreover, the maximum voltage response is 8.743 V@16.5 Hz under the up-sweeping signals while the maximum voltage response is 14.18 V@15.41 Hz under the down-sweeping signals. The experimental results demonstrate that the voltage response and the resonance frequency of the U-VPEH agree with the analytical and theoretical analysis. The nonlinear horizontal asymmetric U-VPEH model exhibits a good performance on the energy transfer. This higher energy output, lower resonance frequency, and closer resonance peak can broaden the flexibility and practical usage of the energy harvester.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

In recent decades, the research in vibration-based energy harvester via piezoelectric transducers has been attracting intensive attention in the research sector of sustainable energy [1]. The piezoelectric is widely used to convert the mechanical energy into useful electric energy on electromechanical systems due to its advantages of high power density and easy implementation on mechanical devices [2,3]. The mechanical energy has a broader usage and application in automobiles, buildings, railways, and windmills. The single-degree-of-freedom (SDOF) vibration energy harvester model has been widely studied by numerous researchers because of its simple geometric structure and high efficiency of energy transformation [4–7]. However, the shortcomings of the traditional vibration energy harvester, including the sole resonance mode, narrow bandwidth and insufficient power output, are very common [8]. As the alternative approaches to improve the performance of energy harvesters, the model nonlinearity and multimodality are proposed and studied, such as geometric nonlinear structure systems [9], nonlinear magnetic effect systems [10], and X-stable [11–13] systems.

* Corresponding author.

E-mail addresses: shilosun-c@my.cityu.edu.hk (S. Sun), meptse@cityu.edu.hk (P.W. Tse).

The nonlinearity technology is an effective method to achieve the optimal design of the broadband energy harvester and also shape the resonance frequency spectrum of the energy harvester to better suit the ambient vibration [14,15]. Generally, the technology comprises two parts, i.e., the geometric nonlinear structure and the magnetic effect nonlinearity design implementation. The geometric nonlinear structure technology for a vibration-based energy harvester design has been analyzed and reported recently. The vibration-based piezoelectric energy harvester based on the different geometric structures are classified into the M-shaped [16,17], L-shaped [18,19], H-shaped [20], and also variable-shaped [21]. Erturk [16,17] demonstrated an M-shaped asymmetric nonlinear structure which could be exploited and utilized into the piezoelectric and electromagnetic energy harvester due to its large strain and kinetic energy regions. Asan [22] optimized the piezoelectric beam shape to improve the bandwidth and the power output of the broadband vibration energy harvester. Yang developed an high-efficiency compressive-mode piezoelectric energy harvester (HC-PEH) [23] and an arc-shaped piezoelectric elements energy harvester [24]. The HC-PEH exhibited the favorable nonlinear phenomena at low frequency range and generated a maximum power 19 mW@ 21 Hz. Ansari [25] investigated a fan-folded vibration energy harvester for leadless pacemakers and can generate more than 10 μ W of power per cubic centimeter. Abdelmoula [26] designed a Zigzag energy harvester for low-frequency devices, of which the results opened new opportunities for lower frequency energy harvester design without increasing its geometric dimensions. Zhou [27] developed a flexible longitudinal zigzag structure for enhanced vibration energy harvesting and can improve the energy conversion efficiency at low frequencies. All the aforementioned research works were conducted on the basis of the geometric nonlinear structure field, the system nonlinearity was achieved through the changes of the proposed structure shape. However, it is not sufficient to achieve the broadband energy harvester design only by the structure shape, because the shape of the structure cannot be adjusted once they are implemented on the rotational machines. This is one of the main drawbacks that lead to inconvenience in harnessing the energy from the ambient environment.

Another common technique of the realization of nonlinearity into the vibration-based energy harvester design is exploiting the magnets interaction. The nonlinear magnets interaction coupling is popular in the employment of achieving the broadband energy harvesting. Cao [28] investigated the nonlinear dynamic characteristics of a magnetically coupled piezoelectric energy harvester, where the angle of the magnets was adjustable and the rotating magnets could produce nonlinear adjustable magnetic force. Besides, Deng [29,30] also reported a nonlinear electromagnetic energy harvester with various magnetic orientation and Zhou [31] investigated a broadband piezoelectric energy harvesting using rotatable magnets with altering the angular orientation of the external magnets. The results indicate that adjust the magnets orientation and the magnets angular can achieve the broadband frequency. Fan [32] addressed a compact bi-directional nonlinear piezoelectric energy harvester (PEH) which composed of two magnets coupling cantilevered beams at two orthogonal directions. The results showed that the introduction of the magnetic nonlinearity could not only enable the energy transfer between two beams, but also improve the efficiency of the PEH at low-level excitation. Salaudin [33] proposed a new design of hybridized electromagnetic energy harvester which collected the human-body motion energy efficiently. Wu [34] reported a broadband nonlinear two-degree-of-freedom piezoelectric energy harvester and achieved a significantly wider bandwidth. Wang [35] proposed a bi-stable two-degree-of-freedom energy harvester with magnetic coupling to improve the performance of operating bandwidth. However, the nonlinearity of the magnet effect is inflexible in practice, especially when the excitation is under the low-level amplitude. Therefore, the combination of the nonlinearity of geometric and the magnetic effect needs more efforts to be explored with the aim of shifting the resonance frequency and expanding the power output bandwidth by designing the piezoelectric energy harvester.

In addition to the nonlinearity methods, the multimodality can broaden the bandwidth and enlarge the power output frequency range. Most multimodal energy harvesters are designed on the basis of the cantilever beam theory which can produce close vibration resonance mode to make the frequency bandwidth enlarged. Han [36] and Tang [37] both proposed a multi-degree-of-freedom piezoelectric vibration energy harvester which showed that such systems could extract more energy than the single-degree-freedom energy harvester. Meanwhile, they can also offer close resonance frequency and keep the power output at large amplitude with nearby resonance frequencies. Wu [38] designed a 3-DOF resonance energy harvester studying the dynamic characteristics of human motion and collecting an average generated power of 2.28 mW. Mohamed [39] conducted the research on the multimodal vibration energy harvester on the plate structures and the natural frequencies were in the range from 8 to 19 Hz. Sun [40] also presented a multimodal vibration-based energy harvester model for the low-frequency rotational machines which covered a frequency range from 18.18 Hz to 26.8 Hz. The aforementioned studies mainly focus on the linear multimodality implement application when designing the piezoelectric energy harvester.

In this paper, we present a new horizontal asymmetric U-shaped vibration-based piezoelectric energy harvester (U-VPEH), in which the nonlinearity is incorporated with multimodality. The mechanical part is designed based on the traditional cantilevered vibration energy harvester which exhibits multimodality characteristics when it is vibrating. This multimodality can produce a close multiple resonance frequencies band which cover the low range rotational machines' frequencies and maximize the power output at the corresponding resonance frequency. The electric part consists of the piezoelectric and magnets. The piezoelectric material is used to collect and store the energy transferred from the mechanical fields. The magnets will exert the magnetic effect and can enhance the nonlinearity of the whole structure's nonlinear performance further. Therefore, compared with previous research works on vibration-based piezoelectric energy harvester, this proposed U-VPEH exploits the advantages of geometric and magnetic nonlinearity and multimodality.

The reminder of the paper is organized as follows. Section 2 describes the design of the proposed U-shaped vibration-based piezoelectric energy harvester (U-VPEH) model. Simulation results through the finite element analysis, including

Download English Version:

<https://daneshyari.com/en/article/6953662>

Download Persian Version:

<https://daneshyari.com/article/6953662>

[Daneshyari.com](https://daneshyari.com)