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Performance of Linear Vibration Energy Harvesters under Broadband Vibrations with Multiple Frequency Peaks

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Abstract

This paper studies the performance of linear Vibration Energy Harvesters (VEH) under broadband vibrations with multiple frequency peaks. The output power of both electromagnetic and piezoelectric linear VEH is determined when excited by a single frequency excitation and when excited by two frequency peaks, one at resonance and the other at a different frequency (defined as the interference frequency). Experimentally, it was found that when a linear VEH is excited by two-peak vibrations, its output power is lower than in the case of the single frequency excitation. Furthermore, the larger the amplitude at the interference frequencies, the lower the output power of the VEH. Also, for the same interference peak amplitudes, the further the interference frequency is from the resonant frequency, the lower the output power is. These results suggest that when designing a linear VEH for multiple-peak broadband vibrations, the VEH should be matched to the lowest peak frequency and that pure sinusoidal excitation should be avoided when laboratory testing VEH for use in applications with multiple frequencies.

Keywords: Linear vibration energy harvester, broadband vibration, multiple frequency;

1. Introduction

Vibration Energy Harvesters (VEH) are potential power supplies for self-powered systems and have drawn more and more attention over the last two decades [1]. According to their physical behaviour, VEH can be classified into different types such as fixed-frequency linear VEH [1], frequency tunable linear VEH [2], non-linear VEH [2] and bistable VEH [3]. Most existing VEH are linear devices and have one fixed resonant frequency. The most common method to experimentally characterise a linear VEH is to excite it under a sinusoid vibration at its resonant frequency and measure its output power [1]. However,

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the use of a single frequency sinusoidal excitation is not an accurate reflection of practical applications where the vibration spectrum usually contains multiple peaks at different frequencies [4]. Previous research has shown that the charging rate of the storage capacitor is reduced when a linear energy harvester is excited by vibrations with peaks at multiple frequencies (for example the frequency spectrum of vibration of a helicopter shown in Fig. 1) compared to fixed frequency sinusoidal excitation [5].

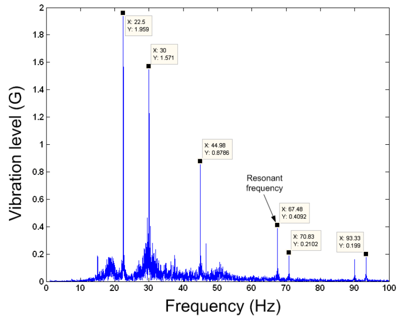


Fig. 1. An example of vibration spectrum with multiple peaks at different frequencies.

This paper presents a comprehensive study of how vibration peaks at frequencies other than the resonant frequency of the VEH affect the output power of a linear energy harvester. Both an electromagnetic and a piezoelectric energy harvester were used in the investigation. Both energy harvesters were excited under vibrations with multiple peaks and their output power into an optimum resistive load was compared to sinusoidal excitation at their resonant frequencies of operation.

2. Test

2.1. Excitation vibration

In the test, the energy harvesters were excited under vibrations with two peaks as shown in Fig. 2. One peak is at the resonant frequency of the energy harvester, f_o, and has an amplitude of $G(f_o)$. The other peak is at frequency, f_i, and has an amplitude of $G(f_i)$. This peak is defined as the interference peak and its frequency is called interference frequency. Various combinations of f_i and $G(f_i)$ were used.

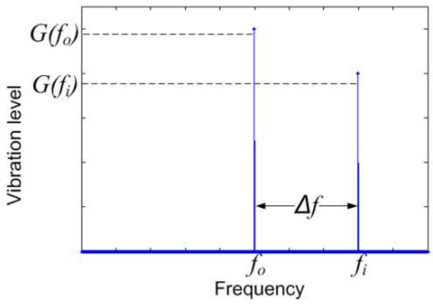
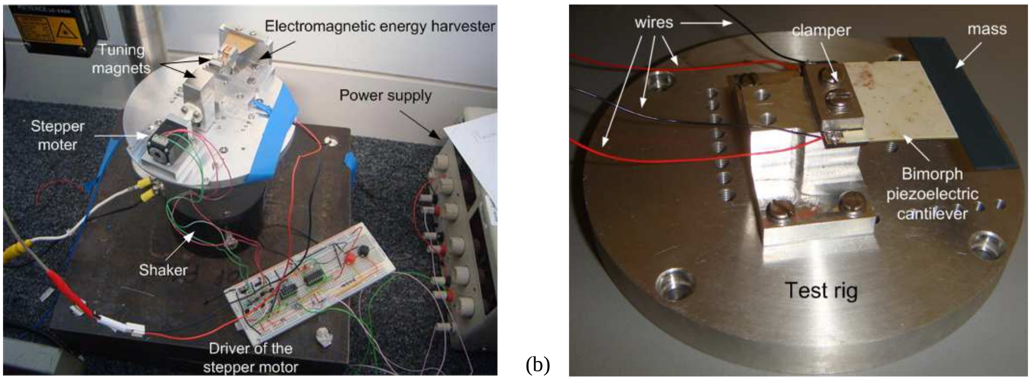


Fig. 2. Vibration with two peaks, the resonant frequency of the vibration energy harvester, f_o and the interference frequency, f_i.

2.2. Linear vibration energy harvesters used in the test

Fig. 3(a) shows the test setup of a tunable electromagnetic vibration energy harvester. Its resonant frequency can be tuned by adjusting the axial tensile force [6] but for the purposes of this investigation the frequency was fixed at 50 Hz. The excitation level at the resonant frequency was set to be 150m***g*** (1***g*** = 9.8m·s^{-2}). Fig. 3(b) shows the test setup of a bimorph linear piezoelectric vibration energy harvester. Details of this energy harvester can be found in [7]. The resonant frequency of this energy harvester was fixed at 72Hz. The excitation level at the resonant frequency of the piezoelectric device was set to be 300m***g***. Both energy harvesters were connected to their respective optimum resistive loads in the test, which are 700Ω for the electromagnetic energy harvester and 50kΩ for the piezoelectric energy harvester. The benchmark results for these energy harvesters when excited at their resonant frequencies are 2.56mW for electromagnetic energy harvester and 106μW for the piezoelectric energy harvester.

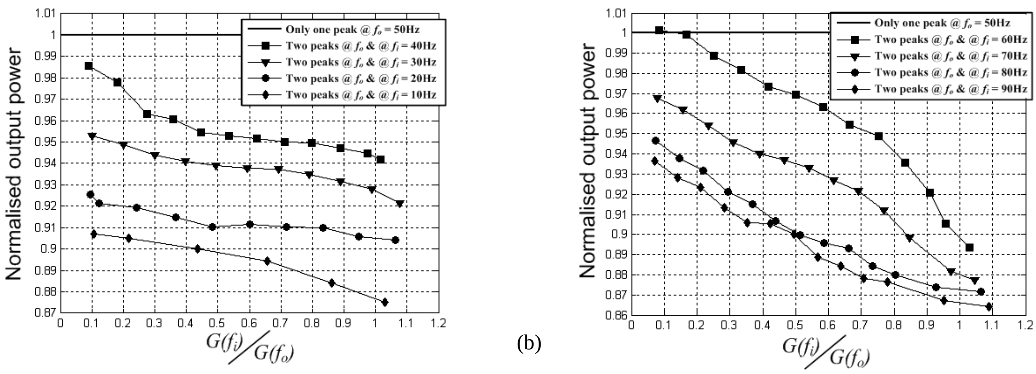


(a) (b)

Fig. 3. Test setup of (a) tunable electromagnetic vibration energy harvester and (b) a bimorph piezoelectric vibration energy harvester.

2.3. Results and discussions

Fig. 4 and 5 compare the normalised output power of the electromagnetic and piezoelectric energy harvesters when they were excited under various two-peak vibrations, respectively. It was found in both cases that for the same interference frequency, output power of the energy harvester reduces with the increasing ratio of $G(f_i)$ to $G(f_o)$. This means that as the amplitude of the excitation at frequency, f_i, increases, the output of the energy harvester reduces. Furthermore, for the same ratio of $G(f_i)$ to $G(f_o)$, the output power of the energy harvester reduces with the increasing difference between the resonant frequency and the interference frequency, Δf. Finally, for the same ratio of $G(f_i)$ to $G(f_o)$ and Δf, interference frequencies below the resonant frequency causes the output power to reduce by 2 to 3% more than interference frequencies above the resonant frequency.



(a) (b)

Fig. 4. Test results of the tunable electromagnetic vibration energy harvester (a) $f_o > f_i$ (b) $f_o < f_i$.

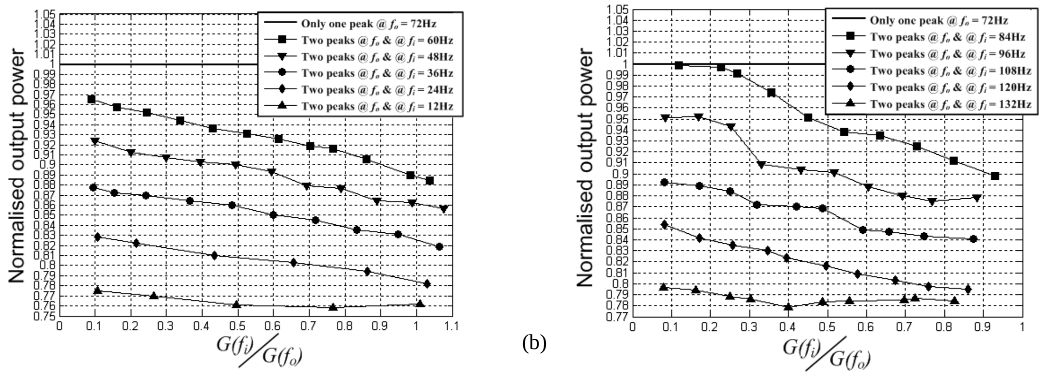


Fig. 5. Test results of the bimorph piezoelectric vibration energy harvester (a) $f_o > f_i$ (b) $f_o < f_i$.

3. Conclusions

This paper studies the performance of linear vibration energy harvesters when they are excited at vibrations with multiple peaks. It was found that vibration peaks at frequencies other than the resonant frequency can reduce output power of a linear energy harvester. The higher the amplitude of the interference peak and the greater the difference between the resonant frequency and the interference frequency, the more reduction in output power will be. These results suggest that when designing a linear vibration energy harvester for multiple-peak broadband vibrations, the energy harvester should be designed to match to the lowest possible peak frequency. Furthermore, when experimentally testing VEH, they should be excited by the actual vibration spectrum from the chosen application since a basic fixed sinusoidal excitation is likely to exaggerate output powers.

Acknowledgements

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