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TOWARDS FREQUENCY-INDEPENDENT VIBRATION-BASED ENERGY HARVESTING USING FREQUENCY UP-CONVERSION AND POWER ANALYSIS

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ABSTRACT

Traditionally, vibration-based energy harvesters have been designed for specific base excitation frequencies by matching their natural frequencies. However, harvesting energy from common human motions is challenging because the low frequencies involved are incompatible with small, light-weight transducers, which have much higher natural frequencies. By using the frequency up-conversion method, a vibration-based, nonlinear, magnetically excited energy harvester exhibits efficient, broadband, frequency-independent performance.

A complete model is provided for an energy harvester utilizing the frequency up-conversion method that defines the relationship between the enclosure excitation, the base excitation and the stationary magnets, where the base of the beam is mounted elastically inside an enclosure. The average power output of a vibration-based energy harvester with frequency up-conversion is analyzed using artificial and naturally occurring base excitations such as sinusoidal and walking motions, respectively. Simulations are provided to demonstrate the broadband capabilities of vibration-based energy harvesters with frequency up-conversion, especially for driving frequencies lower than the fundamental frequency, where significant increase in power output are observed when utilizing frequency up-conversion. In addition, the advantages and limitations of approximating a range of natural base excitations with a set of orthogonal basis functions are explored, which provides motivation for Wavelets Analysis. Finally, a procedure is proposed to determine the maximum expected power output.

INTRODUCTION

Natural and artificial environments are full of ambient energy sources that are ready to be harvested. In the past decade, the technologies to harvest ambient wind and solar energy made their mark in the big energy industry. However, there are other sources of ambient energy that have not yet been tapped such as the ambient energy from electromagnetism (local sources, Earth's magnetic field), thermal energy, radio-frequency energy (RF radiation in urban environments), and vibrations (fluid flow, seismic, man-made systems) [3].

Due to an abundance of ambient vibrations in natural and artificial environments, vibration-based energy harvesting has received significant attention. Ambient vibrations are found in bio-motions, the ground, bodies of water, vehicles, machinery, buildings, mobile robots, unmanned systems, and so on. If that energy were tapped, then it could become a simpler means of providing energy to systems that are in very remote areas where a battery may not provide charge for long enough and other means of power supply may not be practical or safe.

The vibration based-energy harvesters under consideration use a cantilever beam that contains one or more piezoelectric layers in a sandwich structure. The energy harvesting beam is typically designed around an expected dominant base excitation frequency. In most applications, such as bio-motions, the dominant frequencies available are relatively low (on the order of 1Hz). To harvest maximum power from low frequencies, the beam should be excited at the same low natural frequency [10]. However, beams with a low first natural frequency (the fundamental frequency) are typically larger and more massive compared to ones with a higher fundamental frequency.

One day, embedded energy harvesters will provide power for the devices in our lives such as personal electronics (GPS, cell phone), personal medical monitoring devices (pedometer, heart rate monitor, thermometer, pacemaker, insulin pump), and so on. Therefore, a heavy energy harvesting design is not practical. However, the dominant frequencies expected in ambient vibrations are much too low to excite a lighter beam around its fundamental frequency. How can an energy harvester be designed such that low frequency excitations (on the order of 1-10Hz) excite the fundamental frequency of the energy harvesting beam (on the order of 100-1000Hz)?

