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Modeling Impact-Based Vibration Energy Harvesting with Application to Frequency Up-Conversion

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Abstract

Many vibration energy sources available in the environment are better approximated by a sequence of impulses, periodic or random, rather than by harmonic motion. Combustion engines, footfalls, and passing vehicles are a few examples of vibration sources that fall under this category. This paper presents a distributed-parameter model of a piezoelectric energy harvester subjected to impacts. A single mode equivalent spring-mass-damper model is developed and shown to be an accurate representation of the impact dynamics. This simplified model is then used to find an estimate of the total energy harvested per impact. To demonstrate the utility of this model, it is applied to the frequency up-conversion technique for low-frequency energy harvesting. This technique uses a magnetic tip mass inside a ferrous enclosure to create a sequence of potential wells. The transition of the tip mass between the wells induces a pluck followed by a free response, similar to an impact. The dynamics of the base motion and the free response are then decoupled by (1) predicting how often the plucks occur and what their initial deflections are and (2) calculating the subsequent free response to each pluck. The frequency response of this method and a purely linear system are compared to the full nonlinear response. Simulations show that the nonlinear response converges to the impact-based approach at low frequencies (compared to the fundamental natural frequency), whereas it converges to the purely linear system in the vicinity of the fundamental natural frequency. Hence, the impact-based approach shows utility for modeling low-frequency energy harvesting using frequency up-conversion.

1. INTRODUCTION

Resonant piezoelectric energy harvesters convert mechanical energy into electrical through the strain induced in the material by inertial loads. Typically, piezoelectric material is mounted on a structure that oscillates due to excitation of the host structure to which it is affixed. If a natural frequency of the structure is matched to the predominant excitation frequency, resonance occurs, where large strains in the piezoelectric material are induced by relatively small excitations. In order to take advantage of resonance, the natural frequency of the device must be matched to the predominant frequency component of the base excitation [1]. For many potential applications, ambient vibrations are low frequency, requiring longer length scales or a larger mass to match the resonance frequency to the excitation frequency [2–4]. This, in turn, reduces the specific power or power density of the device and may make it impractically large or heavy for the application.

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