Performance analysis of frequency up-converting energy harvesters for human locomotion

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ABSTRACT

Energy harvesting from human locomotion is a challenging problem because the low frequencies involved are incompatible with small, light-weight transducers. Furthermore, frequency variations during changing levels of activity greatly reduce the effectiveness of tuned resonant devices. This paper presents the performance analysis and parameter study of energy harvesters utilizing magnetic interactions for frequency up-conversion. Ferrous structures are used to periodically attract a magnetic tip mass during low-frequency oscillations, producing a series of impulses. This technique allows resonant structures to be designed for much higher natural frequencies and reduces the effects of excitation frequency variation. Measured vibrational data from several human activities are used to provide a time-varying, broadband input to the energy harvesting system and are recreated in a laboratory setting for experimental validation. Optimal load resistances are calculated under several assumptions including sinusoidal, white noise, and band-limited noise base excitations. These values are tested using simulations with real-world accelerations and compared to steady-state power optimization results. The optimal load is presented for each input signal, and an estimation of the maximum average power harvested under idealized conditions is given. The frequency up-conversion technique is compared to linear, resonant structures to determine the impact of the nonlinearities. Furthermore, an analysis is performed to study the discrepancies between the simulated results and the predicted performance derived from frequency response functions to determine the importance of transients.

Keywords: power harvesting, piezoelectric, broadband

1. INTRODUCTION

In many scenarios germane to structural health monitoring, bio-sensing, and tracking, ambient vibration sources are broadband and time-varying [1–3]; however, until recently, most of the literature on vibration energy harvesting has focused on single-frequency, constant amplitude excitation, i.e. resonance-based energy harvesting. Several experimental efforts have considered stochastic, broadband disturbances with little analysis or predictive results [4–5], although the latter group has demonstrated their charge extraction circuit's insensitivity to changing excitation frequency. Broadband excitation has also been used to develop multi-structure energy harvesters; several research groups have shown an effective increase in bandwidth by combining multiple transducers with varying natural frequencies, most easily accomplished by varying the lengths of each resonant device [6–8]. Yang and Yang [9] have studied a multi-beam system in which the beams are connected elastically, yielding a broader frequency response with a lower peak, i.e. mechanical quality factor. Although these system exhibit a broadband response, only a subset of beams generate power at any given moment, decreasing the efficiency of the device.

Recently, several efforts have focused on applying the theory of random vibrations to the broadband energy harvesting problem. Halvorsen [10] has computed the optimal resistive loads assuming white noise, sinusoidal, and band-limited excitation. The white noise case has been extended to the case of a resistor and inductor load model by Adhikari et al. [11]. Scruggs [12] has applied broadband regulation techniques, which are concerned with minimizing a stochastic, quadratic cost function, to energy harvesters with active power electronics.

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