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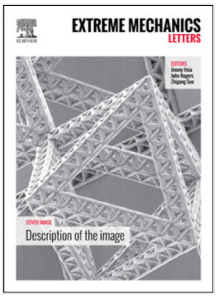

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On the Efficiency of Piezoelectric Energy Harvesters

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Abstract

Energy harvesting is an essential technology for enabling low-power, maintenance-free electronic devices, and thus has attracted a great deal of attention in recent years. A variety of designs and approaches have been proposed to harvest ambient vibration energy, but crucial questions remain regarding figures of merit characterizing the performance of energy harvesters. Of primary importance is the energy conversion efficiency. There are large discrepancies in the definition and tested values of efficiency in the literature. This study is intended to answer the fundamental question for energy harvesters: how to define and calculate the energy conversion efficiency. We first review studies on efficiency and analyze the energy flow in an energy harvesting system. Based on the analysis, we derive an efficiency expression for linear cantilever energy harvesters. The developed efficiency expression transparently and quantitatively reveals the relationship between efficiency and key parameters. Experiments are performed to validate the efficiency expression. Furthermore, nonlinear energy harvesters are tested in both on-resonance and off-resonance conditions. Both experimental and theoretical studies manifest that the energy conversion efficiency tends to decrease as the excitation frequency rises and its value is related to the phase difference between excitations and responses. Around resonance states where the phase difference of both linear and nonlinear energy harvesters is about 90 degrees, the efficiency calculation is much simplified.

Keywords: energy harvesting; piezoelectric, efficiency; energy conversion; vibration

1. Introduction

The dramatic decrease in power consumption of electronic components sets a stage for autonomous operation by using the energy harvesting technology [1-3]. Harvesting mechanical energy from ambient vibration and deformation via the piezoelectric effect has been intensively studied in the past decades. Researchers have recently focused on improving the performance of piezoelectric energy harvesters (PEHs) via high-performance piezoelectric materials [4-8], structure & manufacturing process innovation [9-14] and optimization of dynamic characteristics [15-17].

In order to optimize PEHs' performance, appropriate performance metrics need to be defined first. Taking various structural, material and vibration parameters into account, researchers have proposed several comprehensive figures of merit including normalized power density (NPD) [18], effectiveness [19, 20], volume figure of merit (FoMv) [21] and systematic figure of merit with