

Model reduction in stochastic vibration energy harvesting using compressive sampling

A M Wickenheiser

Department of Mechanical and Aerospace Engineering, George Washington University, Washington, DC, USA

E-mail: amwick@gwu.edu

Received 28 January 2013, in final form 8 July 2013

Published 27 August 2013

Online at stacks.iop.org/SMS/22/094029

Abstract

Vibration energy harvesters are designed to gather parasitic energy from the motion of their host structures. In many germane scenarios, this motion is broadband; however, the preponderance of design criteria appearing in the literature for vibration energy harvesters considers sinusoidal base excitation at a single frequency. While this analysis often leads to analytical formulas for estimating power harvested, they fail to account for the contribution of multiple frequency components of the host motion and the excitation of higher vibration modes of the transducer. In this paper, an attempt is made to provide brief, analytical approximation of these additional factors. To wit, the single-mode, single-frequency power formula is extended to multi-frequency inputs and multiple modal excitations by matching each base acceleration frequency component to at most one mode of vibration whose half-power bandwidth that frequency falls within. Then, due to orthogonality, the expected power can be written as the sum of the contributions of the individual frequency components. To demonstrate the accuracy of this approximation, recorded acceleration signals from a car idling and a person walking are used as inputs, and predictions from the approximation are compared to results from full simulations. Approximations using only three frequency components are shown to be more than 80% accurate, with increased accuracy as the base acceleration signal becomes narrower in bandwidth. The effects of charge cancellation in the higher modes are also considered using simulations and the aforementioned approximations. These studies show that rectifying the strain in the higher modes is only beneficial if these modes contribute significantly to the power harvested. The approximate formulas derived in this paper are useful for making this determination.

(Some figures may appear in colour only in the online journal)

1. Introduction

Ambient vibrations tend to be broadband and non-stationary in many practical scenarios for energy harvesting (Roundy *et al* 2003, von Büren *et al* 2006, Wickenheiser and Garcia 2010a). Until recently, much of the literature has focused on harmonic base excitation, which is only a crude approximation of real vibration sources. In order to maximize harvested power, vibration-based generators are designed to match one of their natural frequencies—typically the fundamental frequency—to the base excitation frequency.

Additionally, it has been shown that minimizing the mechanical damping in the system enhances the power harvesting performance (Lefeuve *et al* 2005, Shu and Lien 2006, Wickenheiser and Garcia 2010b). Unfortunately, lightly damped systems, while exhibiting the greatest peak power, also have the least bandwidth. Relatively little analysis has been performed on the broader class of stochastic base excitation compared to harmonic, nor have any general design criteria emerged. There have been several experimental efforts that considered stochastic, broadband disturbances, with little analysis or predictive results (Sodano *et al* 2007, Lefeuve