Self-tuning sliding mass electromagnetic energy harvester for dramatic frequency bandwidth enhancement

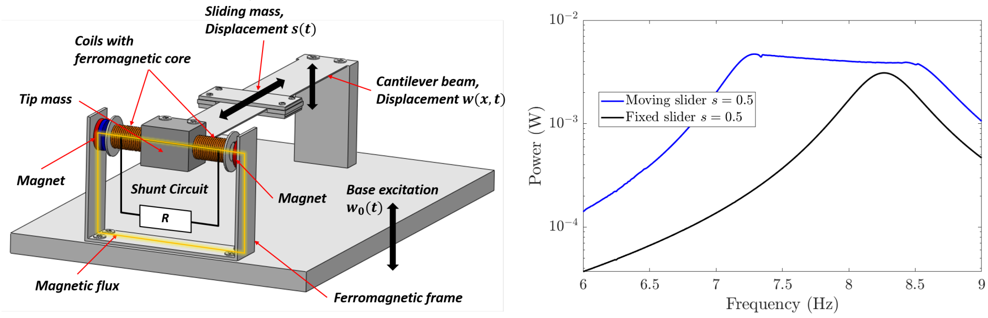
Mohammad Bukhari* and Oumar Barry*

*Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

Abstract. This work investigates a self-adaptive electromagnetic energy harvester using a moving slider mechanism through analytical and experimental methods. The slider moves along a beam with an electromagnetic transducer fixed on its tip, which vibrates within an electromagnetic field. Due to external excitations, nonlinear coupling, because of Coriolis and centrifugal forces, moves the slider along the beam until it settles down on an equilibrium position. This equilibrium position further tunes the harvester to the excitation frequency, and thus increases the harvested power significantly due to resonance. The coupled nonlinear system of equations is analyzed numerically using an adaptive mode shape algorithm based on the instantaneous slider's position. The results demonstrate a dramatic increase in the frequency bandwidth. This further indicates that the current system can be operated over a wide range of frequencies without scarifying any portion of the harvested energy to tune the system.

Introduction

Researchers have recently drawn their attention toward renewable energy sources for clean and sustainable energy conversion and self-powered systems. Vibration energy harvester (VEH) can represent a suitable clean sustainable source that converts environmental vibrations into useful power. These vibrations can be converted into electrical power using electromechanical or electromagnetic VEHs [1]. VEHs are beneficial when tuned to the excitation frequency; however, environmental vibrations have time-variable frequencies, making VEHs effective only at limited frequencies. Increasing the frequency bandwidth can be demonstrated through different passive and active techniques. Although active techniques are effective in tuning VEH, they require scarifying a portion of the harvested energy or external power source. On the contrary, passive self-tuning VEH can be obtained through a sliding mass mechanism [2]. The slider can move along VEH until meeting an equilibrium position, and hence tuning VEH to the excitation frequency. Studies in the literature on self-tuning VEH were limited to electromechanical VEHs, which are beneficial in small scale applications ($\sim \mu$W). Moreover, the investigations of similar dynamical systems used conventional assumed mode through Galerkin's projection, although system mode shapes are time variable and not constant. In this work, we investigate analytically and experimentally the dynamics of a self-adaptive electromagnetic energy harvester for large-scale energy harvesting applications. Unlike techniques in the literature, we employ an adaptive mode shape algorithm to enhance the current nonlinear system's numerical analyses.



(a) (b)

Figure 1: (a): A schematic for the proposed VEH; (b) bandwidth enhancement near the first mode.

Results and discussion

A schematic for the proposed self-tuning VEH is presented in Fig. 1(a). Near each mode, the exact mode shapes and resonance frequencies are determined for each possible instantaneous slider's position. These frequencies range from few hertz to several hundred hertz depending on the mode shape. Next, we continuously feed these frequencies into the numerical simulation to adapt the slider's instantaneous position. The results indicate that the frequency bandwidth of the proposed VEH is significantly wider than that for conventional VEH, as shown in Fig. 1(b) for frequencies near the fundamental mode. This enhancement in the harvested power also holds for higher resonance frequencies and frequency regions in between. Although there is only one equilibrium position near the first mode, several equilibrium positions may exist at higher modes. Therefore, our investigations also reveal that the slider's equilibrium position and the harvested power depend significantly on the initial slider's position and other parameters.

References

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