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Design of an enhanced wideband energy harvester using a parametrically excited array

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ABSTRACT

A wideband energy harvester has been designed, fabricated, and tested based on an array of four parametrically excited cantilever beams; the cantilever beams carry a tip mass at their free end. Piezoelectric transduction has been used to convert between the mechanical and electrical domains. An array configuration in conjunction with parametric excitation generated an enhanced bandwidth of the device (at low frequencies); furthermore, each piezoelectric beam displayed nonlinear dynamical behaviour due to geometric extensibility at the centreline—this behaviour was used to further increase the bandwidth of the energy harvester. An electrodynamic shaker has been used to parametrically excite the energy harvester, and the corresponding voltage of each piezoelectric beam has been measured. It was observed the energy harvester displayed eight resonance peaks that are within close proximity of each other, particularly, for low frequency applications (below 13 Hz); each piezoelectric beam generated substantial power (in the milli-Watt range).

1. Introduction

As the demand for energy increases, research into renewable and sustainable energy technologies is one of the great challenges of today's society; particularly, as the world moves away from fossil fuel technologies to alternate green solutions such as geothermal, wind and solar energy sources [1–4]. However, when scaling down to low power electronics and sensing equipment, a viable solution is to power these smaller devices from ambient kinetic energy—vibration based energy harvesters (VBEHs) can convert kinetic energy into electrical energy; the main transduction methods used to convert from the mechanical domain to the electrical domain are piezoelectric [5–7], electromagnetic induction (EMI) [8–11] and electrostatic conversion [12,13].

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The basis of a VBEH design is for the core element of the device to resonate; however, this leads to a significant drawback with this technology—a larger broadband bandwidth is needed to further improve VBEH technology. VBEH technology can be classified into *transversely* and *parametrically* excited systems, which can be further broken down into *linear* and *nonlinear* approaches, and passive and tuning techniques.

Existing literature for the *first* class (i.e. transversely excited systems) is vast. For instance, William and Yates [14] analysed these systems using a VBEH as a microelectromechanical system (MEMS) to power small electronic devices. Stephen [15] provided a comprehensive linear theoretical analysis for a transversely excited energy harvester, and the system was analysed for both base excitations and direct excitations. Tang and Zuo [16] investigated the benefits of a dual mass linearly resonating VBEH theoretically, and showed that with dual masses the bandwidth had two resonant peaks within close vicinity of each other. Leland and Wright [17] fabricated a linearly tuneable energy harvester which incorporated an axially compressive screw; results showed that the piezoelectric beams resonant frequency shifted with axial compression—this behaviour led to an increased bandwidth of the device. Challa et al. [18] designed a bi-directional tuneable energy harvester with a linearly resonating piezoelectric cantilever beam with a magnet attached, and with an outer tuning magnet. Chen and Jiang [19] theoretically investigated the transverse energy harvested from a coupled internal resonance energy harvesting device; a perturbation technique known as the method of multiple time scales (MMTS) was employed to develop the frequency-amplitude and frequency-power curves—results indicated that a dual softening-hardening response could further increase the effective operating bandwidth of the VBEH. Leadenham and Erturk [20] designed a hybrid M shaped energy harvester, where a bent beam configuration was used in conjunction with piezoelectric bimorphs and EMI. The transversely excited system showed a strong hardening-type behaviour, which increased the effective operating bandwidth of the VBEH.

Literature on the *second* class (i.e. parametrically excited systems), however, is rather limited; for example, Abdelkefi et al. [21] theoretically analysed the energy harvested from a parametrically excited piezoelectric bimorph cantilever beam using the Galerkin discretisation scheme with the MMTS to derive the frequency-response relations; this model also included geometric, inertial and piezoelectric nonlinearities. Daqaq et al. [22] theoretically and experimentally investigated the energy that can be harvested from a parametrically excited cantilever beam using the MMTS for the theoretical component; the system displayed a weak softening behaviour near the principle parametric resonance. In the authors previous work [23], a doubly clamped beam resonator was fabricated using electromagnetic induction for harvesting energy at the principle

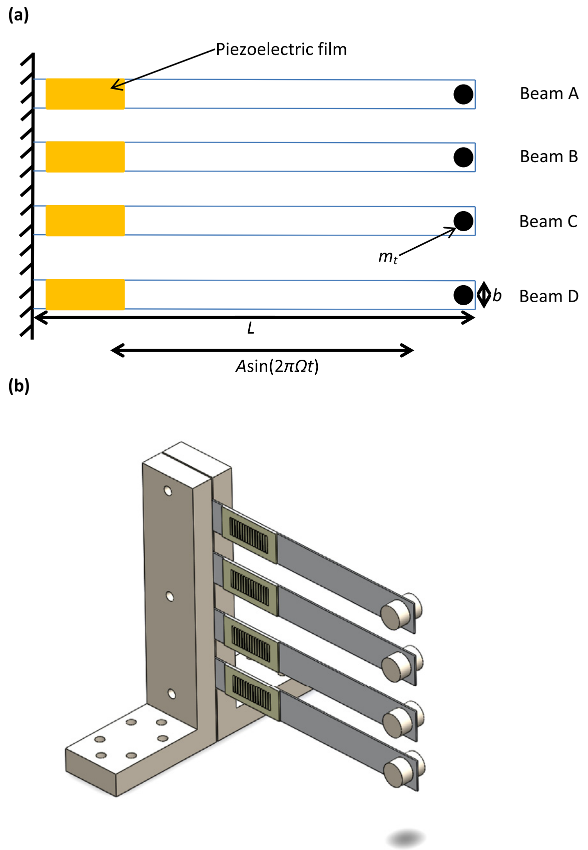

Fig. 1. Schematic representation of the fabricated energy harvester (a) 2-D representation; (b) 3-D representation of (a).