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Experimental evaluation of a cruciform piezoelectric energy harvester

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ABSTRACT

This paper describes the development and experimental evaluation of a particular type of piezoelectric energy harvester, composed of four aluminum cantilever blades to which piezoelectric patches are bonded, in such way that electric energy is generated when the blades undergo bending vibrations. Concentrated masses, whose values can be varied, are attached to the tips of the blades. Due to the geometric shape of the harvester, in which the four blades are oriented forming right angles, the harvester is named *cruciform*. As opposed to the large majority of previous works on the subject, in which harvesters are excited at their bases by prescribed acceleration, herein the harvester is connected to a vibrating structure excited by an imbalance force. Hence, the amount of harvested energy depends upon the dynamic interaction between the harvester and the host structure. Laboratory experiments were carried-out on a prototype connected to a tridimensional truss. The experimental setup includes a force generator consisting of an imbalanced disc driven by an electrical motor whose rotation is controlled electronically, a voltage rectifier circuit, and a battery charged with the harvested energy. After characterization of the dynamic behavior of the harvester and the host structure, both numerically and experimentally, the results of experiments are presented and discussed in terms of the voltage output of the piezoelectric transducers as function of the excitation frequency and the values of the tip masses. Also, the capacity of the harvester to charge a Lithium battery is evaluated.

1. Introduction

Energy harvesting from vibration motion, exploring various physical principles, has been intensively investigated lately [1]. Among viable physical principles used for this purpose, piezoelectricity has received great attention, especially in the context of low power applications [1–4,8–11]. However, despite the maturity achieved by this technology, there are still some issues to be addressed in order to improve the effectiveness of piezoelectric energy harvesters (PEH) in terms of the amount of energy generated, and thus to extend their usefulness in practical applications. One of the possible ways to

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achieve this goal is the conception of novel optimized shapes that would enable to explore more favorable vibration patterns.

One of the most popular configurations of PEH consists of a cantilever bimorph, i.e., a metallic plate to which piezoelectric patches are bonded, in such way that energy is generated when the harvester vibrates in bending. Very often, the harvester possesses a mass fixed at the free extremity of the cantilever [1,5,7].

Most of the studies reported in the literature consider the harvester connected to a resistor, which simulates the electrical load, and the vibration is generated by applying prescribed motion to the harvester base (most often by mounting it on an electrodynamic shaker) [5–7]. Although meaningful for many purposes, this situation does not represent a number of practical cases in which the harvester is intended to be attached to a vibrating structure, very often subjected to uncontrolled excitations, and the harvester is to be used to charge a battery, which cannot be modeled as a simple resistor.

Aiming at contributing to the improvement of the performance of piezoelectric energy harvesters in situations closer to those found in real applications, in this paper one proposes a novel configuration of energy harvester, named *cruciform piezoelectric energy harvester* (CPEH) composed of four cantilever blades to which piezoelectric patches are bonded. These later are electrically connected in such way that when the blades undergo synchronized bending vibrations, the energies produced by each of them are added. To increase the vibration levels and facilitate tuning of the natural frequencies of the CPEH according to the excitation frequency, concentrated masses, the values of which can be varied, are attached to the blade tips.

The concept explored here is similar to that developed in references [8,9], which consists in utilizing a piezoelectric energy harvesting beam as a tuned mass damper (TMD), aiming at suppressing a particular vibration mode of a generic host structure over a broad band of excitation frequencies. The device comprises a pair of bimorphs shunted by resistor–capacitor–inductor circuitry, so that the optimal tuning of the TMD is generated by the PEH effect of the bimorphs. Thus, the authors classify the device in the category of "electromechanical" tuned vibration absorbers.

In this paper, on the other hand, the primary focus is energy harvesting and a novel geometrical configuration is proposed. Moreover, the interest is to test the CPEH in conditions that are considered to be close of a range of practical situations of interest. Hence, the harvester is attached to a simply supported, 6 m span truss, excited by an imbalance force produced by a rotating disc driven by an electrical motor, whose rotation speed is controlled electronically. The output voltage of the harvester is used to charge a Lithium battery, after being rectified by a proper electronic circuit.

In the remainder, the configurations of the harvester and host structure are first described. Then, the results of finite element simulations and experimental tests performed to characterize their dynamic behavior are presented. Additional experimental tests are performed aiming at evaluating the capability of the CPEH to charge a battery.

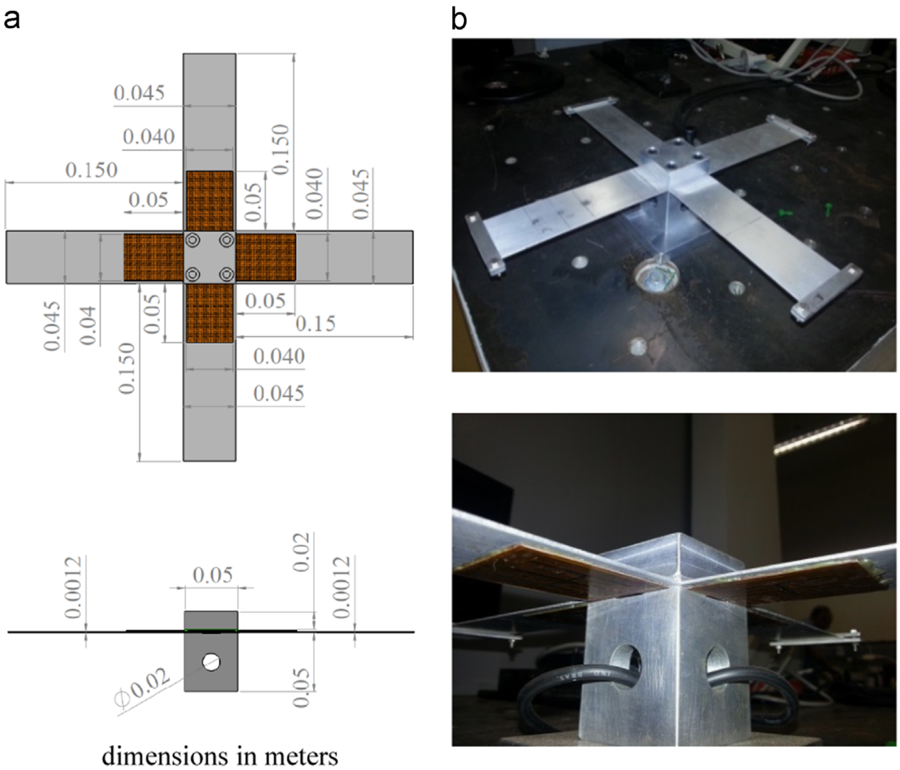

Fig. 1. Illustration of the prototype of the piezoelectric cruciform piezoelectric energy harvester.