MINIATURIZED WEARABLE BROADBAND ENERGY HARVESTERS

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1. Introduction

Low-level ambient energy, gathered and converted into electrical energy using energy harvesting, can be used to power miniaturized devices such as sensors, wearable electronics and Internet-of-Things components. Kinetic energy, due to its presence in all moving systems, is of special interest in wearable technology applications [1-2]. The replacement of batteries with innovative energy harvesting devices (e.g. piezoelectric or electromagnetic) can result in mass and size reduction, favoring ever-increasing miniaturization of wearable devices, as well as drastically increasing their autonomy. Innovative miniaturized broadband wrist-worn kinetic energy harvesting solutions, primarily aimed for powering ultra-low power devices for medical applications (e.g. telemedicine, drug delivery and health monitoring), are proposed in this work [3].

2. Broadband energy harvesting

The proposed energy harvesting devices are based on an optimized piezoelectric bimorph cantilever design. The main issue in this frame is the narrow area of optimal operation around the eigenfrequencies of a specific device. Within this area, a high voltage level is generated, but it rapidly decreases with the variation of the excitation frequency [1]. When kinetic energy from human motion is used, the excitation of the harvester happens across a wide range of frequencies, thus reducing the maximum possible voltage output. Several approaches to solve this problem, i.e., the broadening of the optimal frequency spectrum, have been suggested in recent literature [1-4]:

- changing the conditions around the cantilever free end (e.g. damping control or active tuning),
- changing the geometry of the cantilever (by using complex geometries with bi-stable or nonlinear responses, or a large number of differently tuned cantilevers) and
- “plucking” the free end of a cantilever and letting it oscillate at its eigenfrequency.

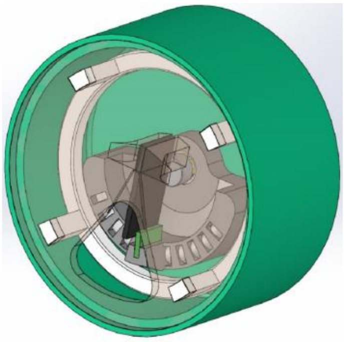

Fig. 1. Piezoelectric energy harvester in a watch-like wearable device [4].

Initial concepts of employing bimorph piezoelectric energy harvesters as wearable power sources, which are studied in collaboration with medical institutions, comprise a watch-shaped device with a flywheel used to transform the energy of hand motion into rotational energy (Fig 1). The attained rotation is used to “pluck” the free end of a bimorph cantilever (or a number of them), thus inducing the excitation of the harvester(s) and generating electrical energy [4]. By modifying the bimorph to an optimized triangular shape (or, due to technological reasons, a more convenient trapezoidal shape), a quasi-uniform stress distribution along its surface can be achieved, thus significantly increasing the specific power output [5]. It was experimentally shown that, by inverting the trapezoidal shape (clamping the cantilever at its narrow end), an even larger increase in specific power can be achieved [5]. In order to overcome the drawbacks of the experimentally validated analytical “coupled modal electromechanical distributed parameter model”, the optimization of different cantilever configurations is performed by employing a numerical ANSYS® model, comprising modal and harmonic analyses [2, 4].

3. Geometry optimization and results

In order to increase the specific power output of a bimorph harvester with a predefined maximum surface area of 20 x 40 mm, the conventional rectangular shape (indicated as “R”) is divided in two trapezoidal (A) and an inverted (B) bimorph (Fig. 2). The considered thicknesses of the substrate and piezoelectric layers are equal in all studied bimorphs, while a 0.5 g tip mass is affixed to their free ends. In this frame, it was experimentally shown [5] that the inverted trapezoidal harvester with a narrow clamped end allows achieving a considerable increase of the output power.

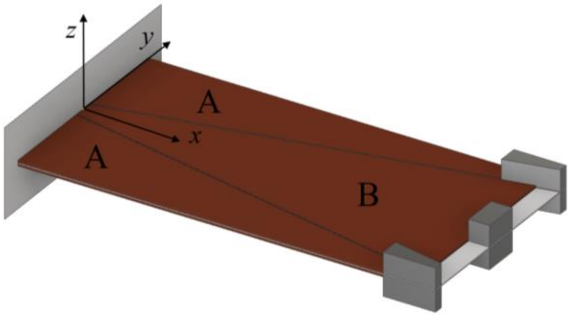

Fig. 2. Optimized usage of the available envelope for the harvester.

As the bimorph is intended to be excited by "plucking", thus allowing each segment to oscillate at its eigenfrequency, the segments are analyzed separately. The optimal load resistance for each segment needs hence to be determined by sweeping through a wide spectrum of load values from 1 kΩ up to 1 MΩ. From the attained data, a power output peak can be observed at a respective optimal load. The specific power output values (Fig. 3) are obtained by normalizing the powers with the segment's surface. It can therefore be concluded that the triangular and inverted shapes result both in higher specific power outputs than the rectangular bimorph. What is more, the optimized configuration allows also matching the maximal power output to a load equivalent to that of a specific wearable sensor, while a variation of the tip mass can be used to vary the respective eigenfrequencies according to the requirements of a specific application.

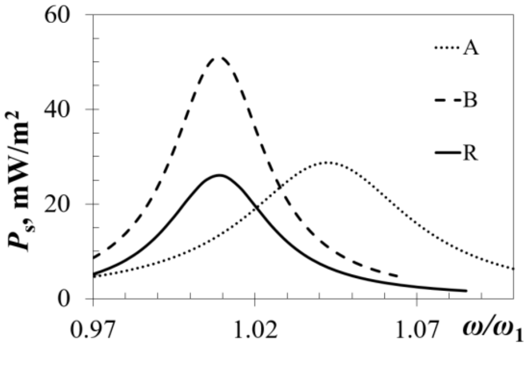

Fig. 3. Specific power output of the analyzed bimorphs.

In order to verify the numerically obtained results, a suitable experimental set-up is developed and will be used next. It is based on a shaker, a piezoelectric accelerometer and a laser Doppler vibrometer. The set-up in interfaced to a LabVIEW-based NI data acquisition system (Fig. 4).

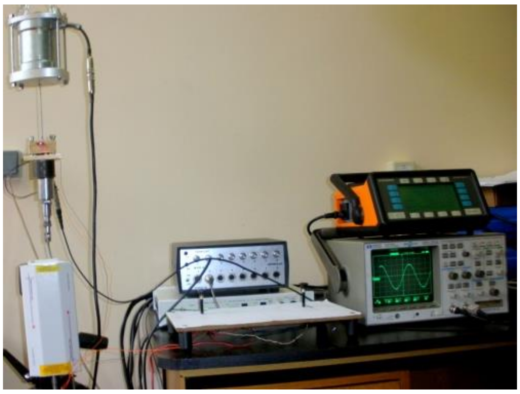

Fig. 4. Experimental set-up.

4. Conclusions and outlook

The specific power output of a wearable piezoelectric harvester can be optimized by varying its shape for a given maximal envelope of the device. By segmenting the conventional rectangular harvester into two trapezoidal and one inverse trapezoidal segment, the power output can thus be significantly increased, providing also a larger flexibility of adapting the performances to the foreseen applications. The segments can hence operate in optimal conditions, maximizing the energy conversion efficiency and, thus, the autonomy of wearable devices. A further experimental optimization of the devised solution is currently being performed.

Acknowledgements

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