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Works at AS2M department of FEMTO-ST on optimization for piezoelectric energy harvesting

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***Abstract*—This paper reviews the activities carried-out on piezoelectric energy harvesting based optimization at the Automatic Control and MicroMechatronic Systems (AS2M) department of FEMTO-ST institute. Seeking for a best compromise between the size and the harvested energy, three main approaches were investigated: parametric optimization, hybrid approach and topology optimization. This paper will highlight the principle of each approach.**

I. Introduction

The literature exhibits an amount of works regarding piezoelectric energy harvesting topics. These works can be classified into five categories, all of which have the target to provide better performance in terms of output energy, power density, output voltage or ratio between output electrical energy and input mechanical energy. They are: i) materials improvement and new materials synthesis, ii) multilayered piezoelectric harvesters, iii) hybrid harvesters which combine piezoelectric harvesting with other transduction, iv) multi-frequency (or broadband) piezoelectric harvesters, and v) electrical circuits studies. Since few years, a sixth category has been raising in order to complement with the above five categories: optimization of the harvester structure itself. Our works at the AS2M department mainly deal with optimization of piezoelectric energy harvesting systems for various applications, including animal tracking devices powering [1], sensors powering [2]. Whilst the explored optimization itself falls in parametric and topology optimization approaches, though we also study hybrid harvesting technique. This paper presents these past and ongoing works at AS2M regarding piezoelectric energy harvesting.

II. Parametric optimization

This approach focuses on the optimization of the geometrical parameters of the energy harvesting devices. It is widely used when piezoelectric beams are used to harvest energy. It can be applied to optimize the thickness or the number of layers.

A. *Thickness optimization*

The energy harvester investigated in [3] is based on layers thickness optimization (see Fig.1). Considering a bilayer unimorph piezoelectric cantilever which is composed of two elements: a passive layer and an active PZT layer. A parametric optimization approach is applied to seek for the optimal ratio between these two thicknesses in order to maximize the output charge at the electrodes. For that, a theoretical model of the device, which links the external excitation to the furnished energy, is derived. Then a gradient-based optimization is carried-out to find the optimal thickness ratio (h_1/h_2) that increases the output charge. As a result, the device transmittance is maximized and it allows producing more charge for a given total thickness. Comparison with existing mechanical piezoelectric harvester structure is made which clearly demonstrates that the proposed structure permits to gain up to five times in terms of the output charge and a significant gain in terms of output electrical power for the same condition. Note that interval techniques [4] are also being used in order to find a set of dimensional parameters (thickness, length, width…) that would provide in a guaranteed way a desired quantity of output charge. For e.g. these interval techniques have been used to find such parameters for actuators which would provide desired resonance frequency and displacement [5].

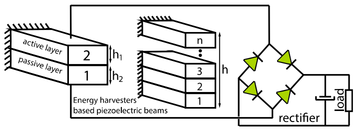

FIGURE 1: Unimorph piezoelectric energy harvester.

B. *Layer number optimization*

In [6], another energy harvester is investigated (see Fig.1). Unlike the previous one, it studies the effect of number of piezoelectric layers on the output charge. Various conditions were used for the study: fixed total thickness, fixed individual thickness, varying length, varying surface… It comes out that the bimorph structure, i.e. a bilayered cantilever all based on piezoelectric materials, would be the best compromise between output charge and sizes.

III. Hybrid approach

In this work, we study structures that can recuperate energy from ambient vibrations and ambient varying temperature nearby cars engines. Based on piezoelectric materials, one major challenge in this work is when the temperature does not vary anymore and, for instance, stays at high value. To reach the target, we endeavor in studying a structure that can harvest as maximal energy as possible during the temperature variation through pyroelectric effect, and that could also exhibit sustained vibration when the temperature is constant and high such that piezoelectric effect could still be exploited.

IV. TOPOLOGY OPTIMIZATION

In topology optimization based piezoelectric energy harvester the goal is to optimize the electrical output of the harvester regarding the mechanical input while respecting constraints on weight, volume and size of the harvester. In this case, we have a design space with predefined boundary condition and loading configuration without any prior knowledge of piezoelectric optimized structure within the design space.

In [7], The algorithm which has been written to optimize the topology of piezoelectric material within the design space, is an extension of 99 line topology optimization MATLAB code written by Sigmund for compliance problems. This code is based on a method called Solid Isotropic Material with Penalization (SIMP) in which design space is discretized by finite number of elements while density of each element is an optimization variable. In SIMP approach, there is a relation between element's density and young's modulus of elasticity of isotropic material. Therefore, optimization algorithm updates the density of each element in each iteration of optimization to find the optimized structure within the designed space to minimize the deflection of the structure due to mechanical force with respect to volume constraint.

The algorithm of Sigmund, solves compliance problem which considers only the mechanical behavior of the system. However, for piezoelectric energy harvesters, electromechanical coupling of piezoelectric material should also be considered in order to optimize the electrical output of the harvester. To do so, first, electrical and mechanical energy of the piezoelectric material due to mechanical input is defined with the help of the piezoelectric constitutive equation. Then, the ratio of the electrical to mechanical energy is defined as objective function to be optimized. Since the piezoelectric materials are not isotropic, SIMP method is modified to relate the density of each element with the piezoelectric stiffness, coupling and dielectric matrices. With the new topology optimization algorithm written for piezoelectric material, it is possible to optimize the structure of piezoelectric energy harvester for different configuration of loads and boundary condition. For example, in Fig.2, the optimized structure under the harmonic force, produced more voltage in comparison to full plate while it has less volume. This is due to the fact that the optimized structure has better strain distribution and displacement in comparison to full plate. Furthermore, the full plate suffers more from charge cancelation due to simultaneous compression and tension in different parts of the plate which is less likely to happen in optimized structure.

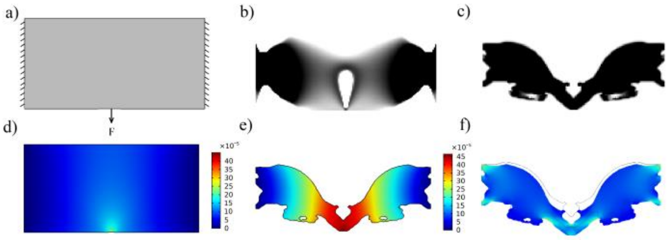

FIGURE 2: a) Design with load and boundary condition b) first iteration of topology optimization c) Finial result of topology optimization d) full plate displacement spectrum e) Optimized structure displacement spectrum f) Strain distribution in optimized structure[7]

The future perspective of topology optimization approach on the piezoelectric energy harvester is to obtain a multi degree of freedom structure that can harvest the energy from different directions.

V. CONCLUSION

This paper gives the approaches carried out at the AS2M department of FEMTO-ST regarding the piezoelectric enegry harvesting. Principally based on optimization of the harvesting structures, the works can be classified into parametric optimization, hybrid structures, and topology optimization. While they are ongoing, some preliminary results mainly on topology optimization was given.

ACKNOWLEDGMENT

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