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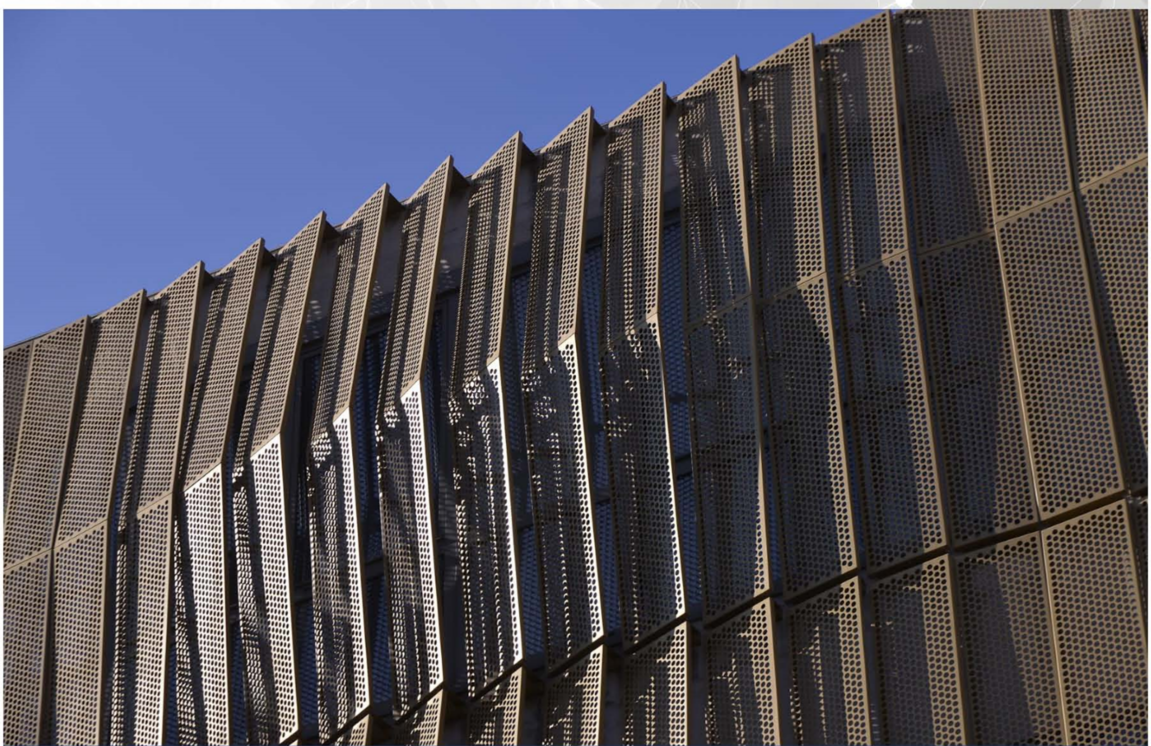

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Modelling, optimization and application of piezoelectric vibration energy harvesting devices

P. Gljušćić,[1,*] S. Zelenika[1]

[1] *University of Rijeka, Faculty of Engineering & Centre for Micro- and Nanosciences and Technologies, Vukovarska 58, 51000 Rijeka, Croatia*
E-mail: pgljuscic@riteh.hr, sasa.zelenika@riteh.hr

1. Introduction

Energy harvesting is the process of collecting low-level ambient energy and converting it into electrical energy used to power miniaturised autonomous devices, sensor networks, wearable electronics or Internet-of-Things components. The considered ambient energy sources comprise solar/light energy, waste heat, kinetic energy and radio-frequency. Especially interesting is the use of the pervasive kinetic energy that can be converted into electrical energy via the electromagnetic effect, the electrostatic principle or the electro-mechanical piezoelectric effect. The latter proves to be advantageous due to design simplicity, miniaturization and integration potential and high energy density [1].

This work focuses on analysing the possibility to use vibration energy, converted via the piezoelectric effect, as a viable power source. Devices used in this frame are generally based on bimorph piezoelectric cantilevers (Fig. 1). The main goal in designing such devices is achieving maximum powers for the given excitation and volume constrains.

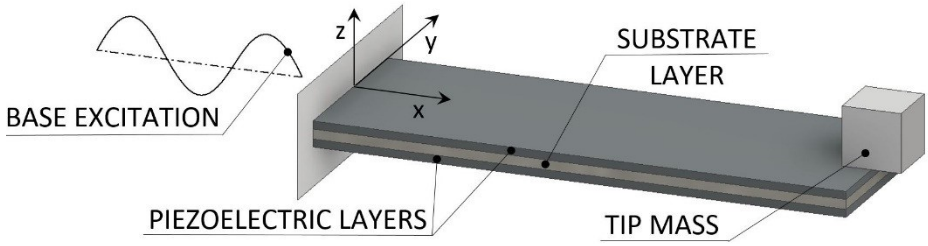

Fig. 1. Typical piezoelectric harvesting device

2. Coupled Electromechanical Analysis

The power output of the piezoelectric device is the highest when the harvester operates at its first eigenfrequency. Since, due to electromechanical piezoelectric coupling, the generation of electric charge in the piezo layers affects the mechanical response of the device, its behaviour must be modelled by employing the rather complex recently developed and validated "coupled modal electromechanical distributed parameter model" (CMEDM) [2]. The amplitude α_s of the output voltage of the harvester is thus:

$$\alpha_s(\omega) = \frac{\sum_{r=1}^{\infty} \frac{j\omega\kappa_r\sigma_r}{\omega_r^2-\omega^2+j2\zeta_r\omega_r\omega}}{\frac{1}{R_l}+j\omega\frac{C_{\tilde{p}}}{2}+\sum_{r=1}^{\infty}\frac{j\omega\kappa_r\chi_r^s}{\omega_r^2-\omega^2+j2\zeta_r\omega_r\omega}} e^{j\omega t} \tag{1}$$

where ω is the excitation frequency close to the eigenfrequency ω_r, κ_r is the forward coupling term, σ_r is excitation's translational component, ζ_r is mechanical damping, R_l is

* Corresponding author

the external load, $C_{\tilde{p}}$ is piezo's capacitance and χ_r^s is the modal coupling term. CMEDM is used next as a benchmark to verify and tune the finite element (FE) numerical model that will allow considering also different harvester geometrical and material configurations, thus simplifying the design process. The regular bimorph of Fig. 1 is thus considered in a configuration without and the one with the tip mass. In the numerical model, proper consideration of harvester's fixture and its excitation has to be imposed [3]. Modal analysis is hence performed to find the mechanical eigenfrequency, followed by the coupled harmonic analysis that allows determining the dynamic response in its vicinity. In the latter case, the consideration of electromechanical coupling is necessary again. This is achieved by connecting the nodes of the piezo layers' finite elements to the ends of a constant-resistance capacitor, having 0 V as the boundary condition on one of its ends.

3. Results and Discussion

The comparison of the CMEDM and the FE results, in terms of voltage outputs around the first eigenfrequency of the considered harvesters' configurations, is shown in Fig. 2.

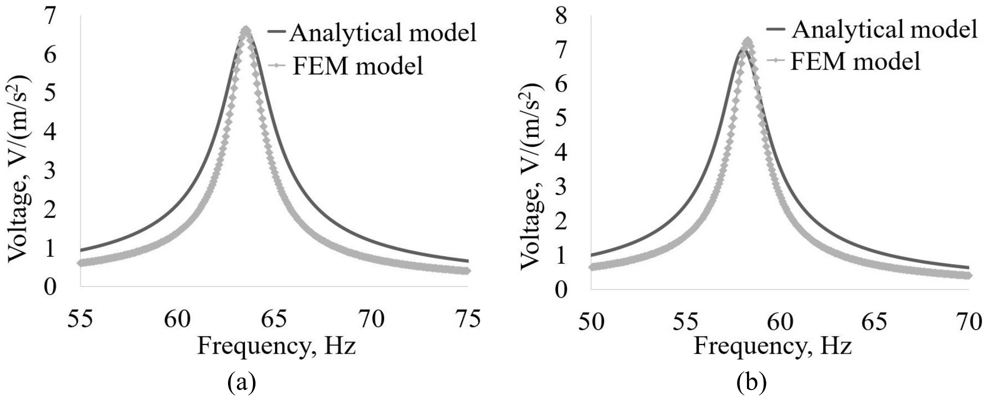

Fig. 2. Comparison of CMEDM and FE results for the harvester w/o (a) and with (b) the tip mass

It can thus be seen that in both cases the FE model allows obtaining results that closely match those obtained via CMEDM. In fact, the FE obtained eigenfrequencies match the CMEDM ones within 0.1 %. In terms of the maximal voltages the FE results are, however, higher by up to 5.5 % than those calculated via the CMEDM approach. This could imply the need for a more detailed tuning of the damping ratios of the FE model.

The given overview of the potentials of energy harvesting principles and of the modelling approaches to be applied to piezoelectric vibration harvesters is thus successfully illustrated. In the prosecution of the work, the developed FE model, extended also to coupled nonlinear transient analyses, will be applied to advanced harvesters' designs aimed at excitations varying in time or multiple excitation sources. This should allow optimising the performances of this class of devices and thus eventually employing it in innovative applications such as e.g. wearable devices for telemedicine.

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