Sensitivity analysis of piezoelectric scavenging of vibration energy

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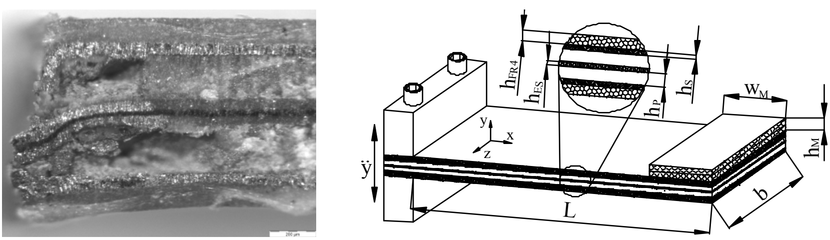
Abstract

In this work a study of the dynamic behaviour of piezoelectric vibration energy scavengers is performed. The output voltages and powers are related to excitation inputs and electrical loads, permitting clear tendencies to be outlined. The coupled electromechanical behaviour shows a noteworthy hardening for increasing loads. Optimal peak powers and their dependence on system's parameters are determined.

1 Introduction

Self-powered wireless sensor networks and other pervasive systems have gained recently increased research and industrial attention [1]. In this frame, piezoelectric energy scavenging devices of optimised configuration have been proposed; particularly advantageous is the usage of "bimorph" configurations aimed at scavenging, via the bending of a cantilever, the kinematic energy of base harmonic excitations [2, 3]. Some of these solutions have already found their way to the market, although their usage can be limited due to lack of relevant data on their behaviour. In fact, the herein considered MIDE vibration energy harvesters [4] have an intricate structure composed of alternating layers of fibreglass reinforced laminate sheets, epoxy adhesive, copper electrodes, piezoelectric material and copper clad polyimide laminates (Fig. 1), thus making the modelling of their behaviour complex.



(a) (b)

Fig. 1: Cross-section (a) and scheme (b) of a MIDE scavenger loaded with a tip mass

In this work, the characterisation of the dynamic performances of the considered devices is performed with the aim of determining the frequency response functions (FRF) and thus establishing the influence of system's parameters on their responses.

2 Experimental set-up

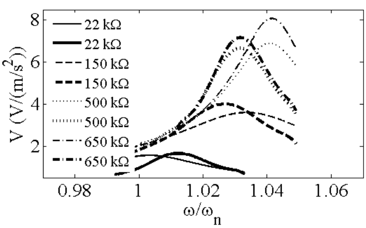
An experimental set-up is developed to determine the voltage and power FRFs around the fundamental resonance frequency of the scavengers with the piezoelectric layers connected in series. Harmonic excitation, generated via a shaker, is swept in the chosen frequency range. The dynamics of the cantilever is measured by using a vibrometer. In a first instance, the response of the V21b and V25w MIDE scavengers [4] is used to determine the value of the mechanical damping ratio as $\zeta = 0.005$.
The FRF functions (the frequencies are expressed in terms of their ratio to the uncoupled configuration of the system) are determined next by varying the applied resistive load R_L in a range between the extremes constituted on one side by an uncoupled (short circuit) condition and on the other by the open circuit condition. A pure resistive load is not necessarily the most realistic condition, but it is simple and useful for estimating the resulting powers and for gaining more intuition about the system's behaviour [3]. The scavengers are loaded with 3 different tip masses each.
The experimental results are compared with those obtained via the recently developed "coupled modal electromechanical distributed parameter model" (CMEDM) [3]. This model is more accurate, in terms of strain distribution, mode shapes and electromechanical coupling, than the previous lumped parameter models [3, 5]. The CMEDM is based on the Euler-Bernoulli beam assumptions and on the consideration of the piezoelectric backward coupling effect. In order to use the CMEDM, the stiffness of the layered MIDE scavenger was calculated by transforming its cross section to an equivalent homogenous cross section as defined by conventional strength of materials theory [6]. The influence of the epoxy adhesive layers was neglected in this frame.

3 Results and discussion

The shown results are those obtained for the V21b scavenger loaded with two M21b MIDE tip masses, but they are qualitatively equivalent to those obtained for other scavenger – tip mass combinations. The obtained FRFs in terms of steady state voltages – to – harmonic base accelerations for varying R_L values allow establishing that:

- there is a good match of the experimental and the CMEDM-based results (Fig. 2a);

- the observed differences are probably due to effects not included in the CMEDM: influence of the adhesive layer, parametric uncertainties, combined influence on the mechanical response given by the anticlastic effect, by the large (geometrically nonlinear) deflections and by the compliance of the constraints;
- there is an appreciable influence of voltage feedback due to the piezoelectric effect (in electromechanical terms equivalent to a transformer) on the dynamic response, i.e. the coupled response is more complex than that of the mechanical dynamic model;
- this influence leads to a nonlinear increase of the voltage amplitudes for increasing R_L values, but also to an increase of the modal frequency where the peak value of the voltage is obtained with respect to the uncoupled modal frequency ω_n (Fig. 2b).



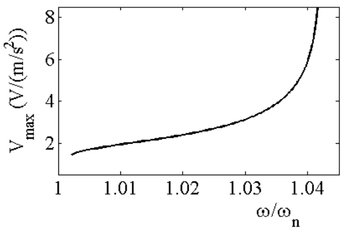
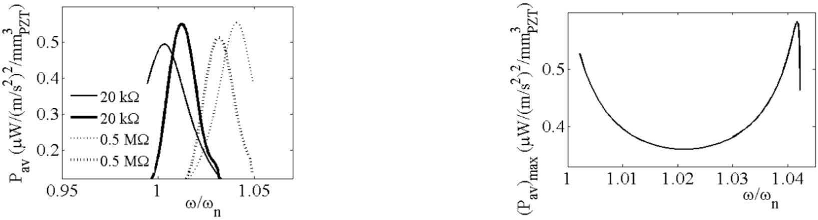


Fig. 2: Experimental (thick lines) and CMEDM (thin lines) voltage FRFs for R_L from 22 to 650 kΩ (a) and CMEDM peak voltages for R_L in the kΩ to MΩ range (b)

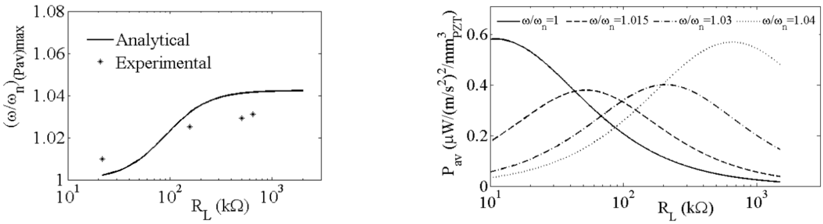
The FRFs in terms of specific powers – to – harmonic base accelerations show that:

- there is a good match between the experimental and the analytical results (Fig. 3a);
- the peak power vs. R_L dependency (Fig. 3b) is complex: initially there is a decrease with increasing R_L, with a subsequent amplification and then again attenuation;
- this dependency allows the optimal R_L, giving the largest output power, to be determined (there could be several R_L values giving the same peak power values!);
- there is a nonlinear hardening behaviour shifting the frequencies where the peak powers are obtained to higher values for increasing R_L values (Fig. 4a);
- there is a variation of the optimal R_L value for varying excitation frequencies (Fig. 4b);
- the lowest loads will thus give a maximal power for frequencies close to the short circuit condition, for the highest loads the peak power is obtained for frequencies corresponding to the open circuit condition, while intermediate excitation frequencies give smaller peak powers even for optimised R_L values.



(a) (b)

Fig. 3: Experimental (thick lines) and CMEDM (thin lines) power FRFs for R_L = 22 kΩ and 0.5 MΩ (a) and CMEDM peak powers for R_L in the kΩ to MΩ range (b)



(a) (b)

Fig. 4: Ratio of frequency where the power is maximal to ω_n vs. R_L (a) and variation of power vs. R_L for different excitation frequencies

4 Conclusions

In this work a thorough experimental and analytical study of the behaviour of commercially available piezoelectric vibration energy scavengers is performed. The study allows establishing the dependence of the voltage and power outputs on harmonic excitation and electrical loads, as well as determining the loads and frequencies where the peak voltage and power levels are obtained. While an increase of the loads has a hardening effect on the dynamic behaviour, the maximal powers have a complex dependence on the loads. The dependence of the power on the loads and excitation frequencies can be used to match the needs and the obtained powers.

References:

[1] Priya, Inman (ed.) (2009): "Energy Harvesting Technologies", Springer.

[2] Anton, Sodano (2007) Smart Mater. & Struct. **16**/3 R1.

[3] Erturk, Inman (2009) Smart Mater. & Struct. **18**/2 025009.

[4] www.mide.com/products/volture/volture_catalog.php

[5] Erturk, Inman (2008) J. Intell. Mat. Sys. Struct. **19** 1311-1325.

[6] Timoshenko (1944): "Elements of Strength of Materials", Van Nostrand.