Modeling Of The Clamping Fixture Of A Piezoelectric Cantilever-type Energy Harvesting Device

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Introduction

Over the last decade, ambient vibration energy harvesting by piezoelectric materials has been an area of extensive research [1,2]. This technology enables to convert wasted mechanical energy available in our environment into useful electrical energy for autonomous wireless sensors supply[3], in structural health monitoring applications, or implantable medical devices[4].

The most common structure used in vibration energy harvesting is a clamped/free piezoelectric bimorph cantilever beam, which is constituted of two thinned-bulk piezoelectric layers separated with an inner shim material. Firstly, two plates made of hard PZT ceramic are bonded on the two opposite faces of a thin brass layer using epoxy adhesive. Secondly, each face of the bimorph is grinded to the desired thickness. Then, the square bimorph is metallized: electrode materials made of chromium and gold are deposited on each face of the device. Finally, the bimorph is cut into several rectangular bimorphs with desired dimensions. To understand and predict the behaviour of such a cantilever-based mechanical energy harvester, analytical and numerical models are developed[5,6].

In our work, the pursued goal is to build an effective three-dimensional (3D) finite element model (FEM) for the design of a cantilever-based mechanical energy harvester in vibration. To this end, a thinned layer of PZT material is first considered and a particular attention is paid on the clamping fixture modeling issue.

Experimental setup

Before its integration into a piezoelectric bimorph cantilever (Figure 1), the characterization of the 4mm x 39mm x 150.5µm thinned PZT layer has been carried out[7].

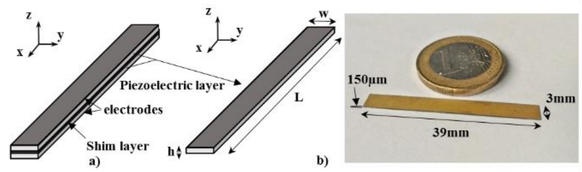

Figure 1. a) Scheme of the bimorph and PZT layer inside the bimorph, b) scheme and photograph of the PZT sample.

The functional characterization of this PZT layer is made using a dedicated vibration test bench composed by a function generator Tektronix AFG3101, an oscilloscope Tektronix TDS3034B, a laser Keyence LK-5000, an accelerometer PCB PIEZOTRONICS 393B and a loudspeaker Dayton audio RSS315HF-4 (Figure 2).

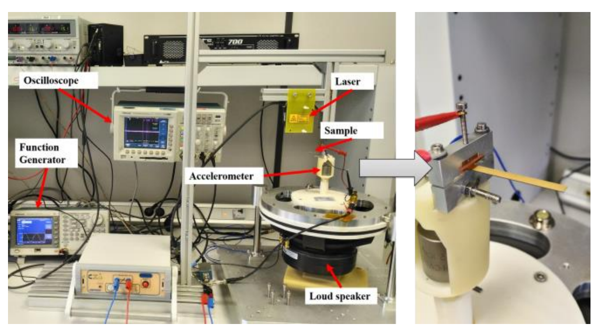

Figure 2. The vibration energy harvesting test bench.

As shown in Figure 3, the clamped cantilever beam is mechanically excited by applying a displacement at its fixed end, generated by the loudspeaker. The vibration amplitude and spectrum are controlled by a function generator. The accelerometer is used to monitor the generated vibration. The displacement at the free end of the cantilever beam is measured by the laser sensor. The signals from the accelerometer and the laser sensor are acquired with the oscilloscope. The whole acquisition chain is controlled by the computer that enables to automatically scan over a wide range of vibration frequencies and amplitudes thanks to a virtual instrumentation developed in MATLAB.

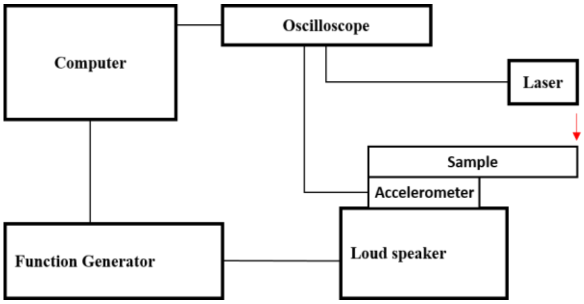

Figure 3. The vibration energy harvesting test bench – interconnection diagram.

Finally, Figure 4 is obtained and presents the amplitude of the displacement at the free end of our device as a function of the frequency. A maximum of amplitude is detected at 65.4Hz.

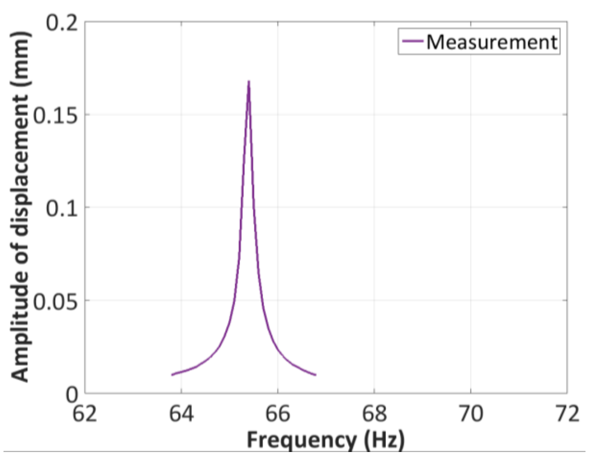

Figure 4. Amplitude of the displacement at the free end of the device as a function of the frequency.

Comparison between experimental and numerical results

Thanks to COMSOL Multiphysics® FEA software, the 4mm x 39mm x 150.5µm thinned PZT layer is modelled in 3D with a hexahedral mesh made of 500 elements with dimensions 0.8 x 0.78 x 0.075mm^3 using the *Piezoelectric Devices* interface of the *Structural Mechanics Module.*
Ideal clamped-free boundary conditions are applied over a length of 3 mm at one end of the device and a frequency domain study is performed. Then the displacement at the free end of the device can be calculated at a given frequency (Figure 5).

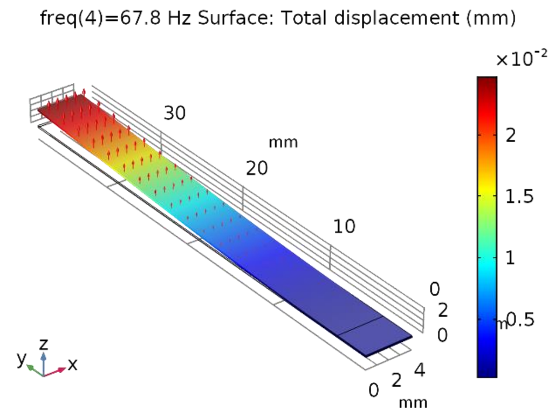

Figure 5. Simulated displacement of the device at 67.8Hz.

Figure 6 presents the comparison between simulation and measurement results on the amplitude of the displacement at the free end of the device. Even if there is a good accordance of the two curves, a gap of 3.67% is observed in frequency, and a difference of 12.98% in displacement amplitude.

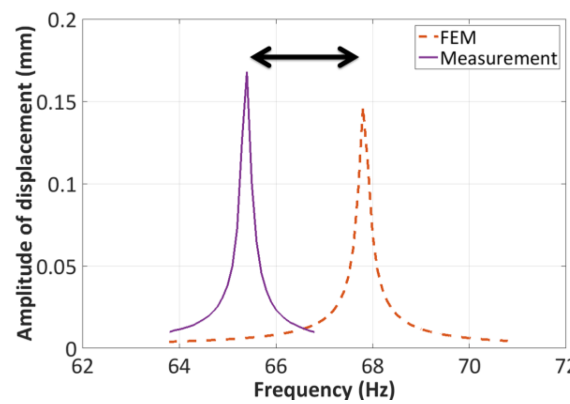

Figure 6. Comparison between simulation and measurement results.

Discussion on the clamping fixture issue

As a discrepancy between simulation and measurement results is observed, different ways of modeling the clamping fixture of the beam are considered.
In modal analysis, the study deals with configurations of increasing complexity, from the ideal clamped-free boundary condition up to the 3D FEM model of the fixture system imported from the CAD CAM integrated software TOPSOLID by using the *CAD import Module*.
Table 1 summarizes the different investigated cases illustrated in Figure 7.

As shown in Table 1, the 5th model presents a discrepancy of less than 0.01% with the measurement results. In this case, the clamping fixture is modelled by a spring in domain with adapted stiffness[8].

Table 1: Comparison between simulation and measurement results for different clamping fixtures of the beam.

Model of clamping fixture	Frequency of the 1^{st} mode of vibration (Hz)	Δ(%)
1. Fixed constraint in domain	68.07	4.08
2. Fixed constraint on two surfaces	68.06	4.07
3. Fixed constraint on bottom surface	67.90	3.81
4. Fixed constraint on bottom surface + top surface load $2.10^7 N/m^2$	67.92	3.85
5. Spring $k=7.3.10^6 N/m$ in domain	65.40	0.003
6. 3D FEM model of the real fixing system	67.96	3.92

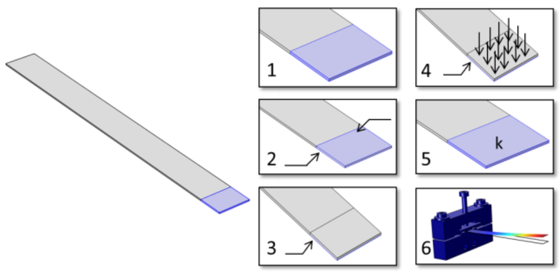

Figure 7. The different investigated clamping fixtures of the beam.

Conclusions

The vibrational response of a thinned layer of PZT has been simulated thanks to COMSOL Multiphysics® FEA software using the *Piezoelectric Devices* interface of the *Structural Mechanics Module* and compared to experimental data.

In order to reduce the discrepancy between simulation and measurement results, different ways of modeling the clamping fixture of the beam have been considered, from the ideal clamped-free boundary condition up to the 3D FEM model of the fixture system imported from the CAD CAM integrated software TOPSOLID by using the *CAD import Module*.

For each investigated fixture model, the comparison of its results and the experiment for predicting the first resonance mode of the piezoelectric samples shows a difference inferior to 5%. However, in the case of a clamping fixture modelled by a spring in domain with adapted stiffness, the gap between numerical and experimental results is reduced to less than 0.01%.

We then recommend the use of this functional design tool to improve the modeling of the piezoelectric cantilever-type energy harvesting device.

References

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Acknowledgements

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