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AN INVESTIGATION OF SIMPLE PIEZOELECTRIC BEAMS[6]

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Abstract: *This paper presents an investigation of vibrations of simple cantilever piezoelectric beams. The theoretical basis is described and applied on software system MATLAB to solve the free vibrations. For charging mobile devices the kinematic excitations are important, so the software system COMSOL is used to study the mechanical and electrical behaviour in this case.*

Keywords: *Piezoelectric beam, Cantilever beam, Vibrations, Kinematical excitation, MATLAB, COMSOL.*

INTRODUCTION

The development of extremely low power electronics and wireless systems has led to a strong interest in the fields of energy harvesting and development of miniature generators. Typically, these devices are used to power sensors and wireless communication systems, enabling standalone wireless sensors that are cheap to deploy.

Lead researches in the field of the energy harvesting with piezoelectric beams are presented in (Mam, K., 2017), (Wang, H., 2019), and (Yang, Z., 2020). One basic model of an energy harvester has to include the major components: a piezoelectric bimorph, a proof mass and, a supporting structure. The piezoelectric bimorph usually consists from a ground electrode embedded within it (coincident with the neutral plane of the beam) and two electrodes on the exterior surfaces of the cantilever beam – Fig. 1 (Y. Shoko, 1998).

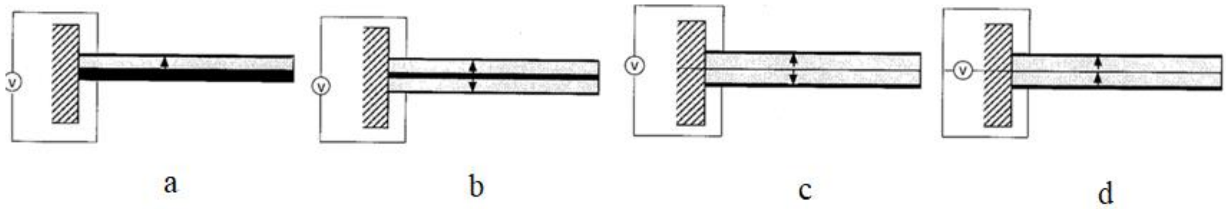

Fig. 1. Kinds of bimorph layers and connections: a – unmorphed layer; b – triple layer; c – bimorph in series connection; d – bimorph in parallel connection

Piezoelectric materials deform under an applied voltage. Conversely, deforming a piezoelectric material produces a voltage. Therefore, analysis of a piezoelectric part requires the solution of a set of coupled partial differential equations with deflections and electrical potential as dependent variables. In (The MathWorks, Inc., 2018) the software system *MATLAB* and the *Partial Differential Equation Toolbox* is used for modelling a two-layer cantilever beam, with both layers made of the same polyvinylidene fluoride (PVDF) material. A voltage has been applied between the lower and upper surfaces of the beam and the beam deflects because one layer shortens and the other layer lengthens. This the elastic behavior can be described trough the equilibrium equations (Hwang, W., 1993):

$$-\nabla \cdot \sigma = f \tag{1}$$

In (1), σ is the stress tensor, and f is the body force vector. Gauss's Law describes the electrostatic behavior of the solid:

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$$\nabla \cdot D = p, \qquad (2)$$

where D is the electric displacement, and ρ is the distributed free charge. Combine these two PDE systems into this single system, one can obtain:

$$\nabla \cdot \begin{Bmatrix} \sigma \\ D \end{Bmatrix} = \begin{Bmatrix} f \\ -\rho \end{Bmatrix}. \qquad (3)$$

For a 2-D analysis, σ has the components σ_{11}, σ_{22}, and $\sigma_{12} = \sigma_{21}$, and D has the components D_1 and D_2.

According to the introduced above, and evolving the investigations in (Stoyanov, S., 2017) and (Stoyanov, S., 2018), the aim of this paper is to present an investigation of vibrations of simple cantilever piezoelectric beams with the help of the contemporary software systems.

EXPOSITION

Simple unimorph piezo beam as an energy harvester

The first study in this investigation is conducted modifying the presented in (The MathWorks, Inc., 2018) study. Instead of applying a voltage and determining the deformations, in this paper an initial deformation is applied and the generated voltage is obtained. In other words, it is thus obtained a simple energy harvester. After applying the initial deformation, a free damped vibration occurred – Fig. 2.

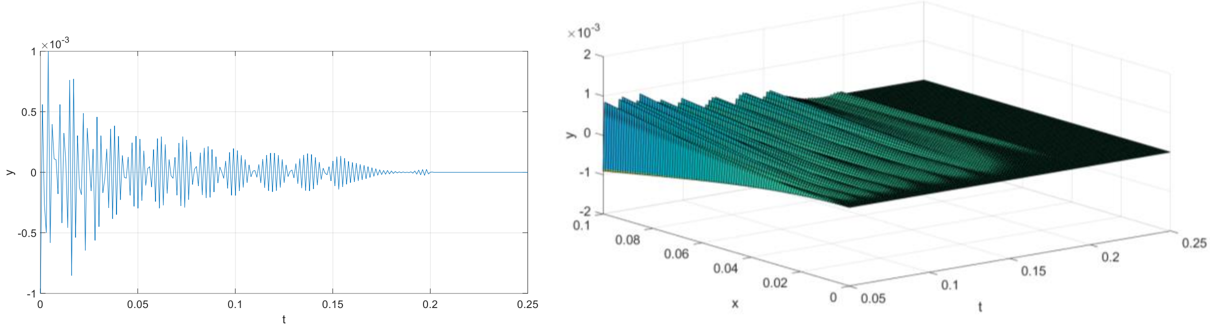


Fig. 2. The vibrations of a point of the beam (left), and the vibrations of the entire beam (right)

Triple layered piezo beam as an energy harvester

This investigation is inspired by (Shah, R., 2015), and conducted with the help of the software system *COMSOL*. The *COMSOL Multiphysics* software enables the simulation of designs involving coupled physics. A one project can include simulations from the fields of mechanics, electromechanics, acoustics, fluid flow, heat transfer, chemical reactions, etc.

Model description

The models investigated are shown on Fig. 3. The series connection electrical scheme is used (Fig. 1c). The piezoelectric layers are connected through a resistor with 12 kΩ resistance.

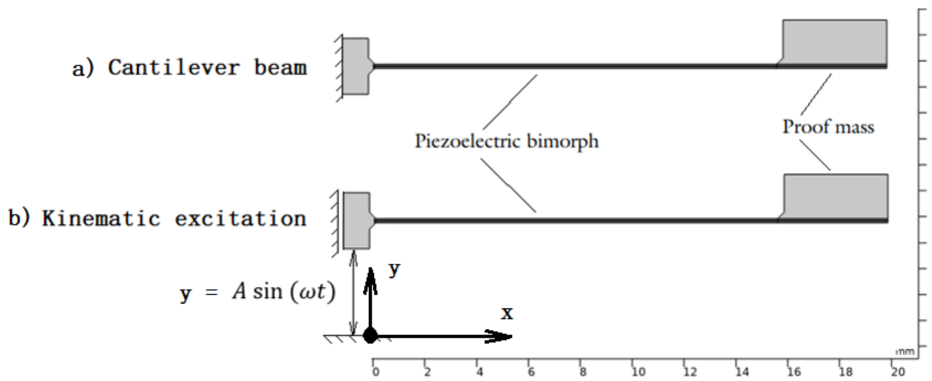


Fig. 3. The supporting schemes used

Static study and free vibration study

The cantilever beam case from Fig. 3a is used for these studies. The proof mass is released and the beam deforms – Fig. 4(left). After this, the beam starts a free damped vibration – Fig. 4(right).

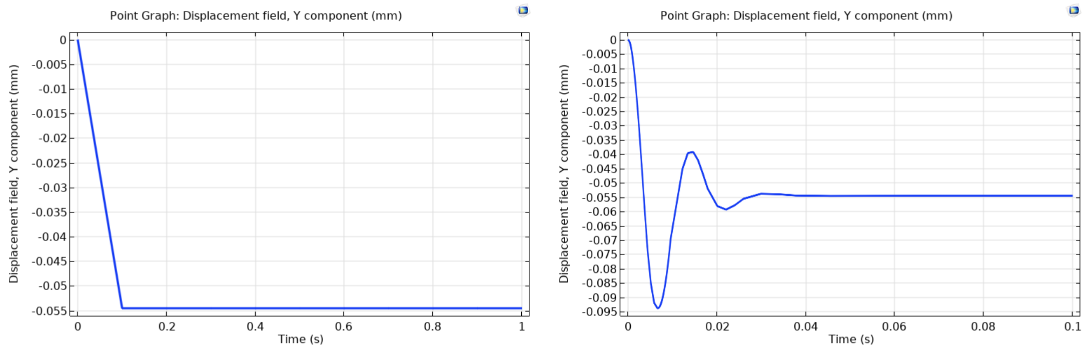
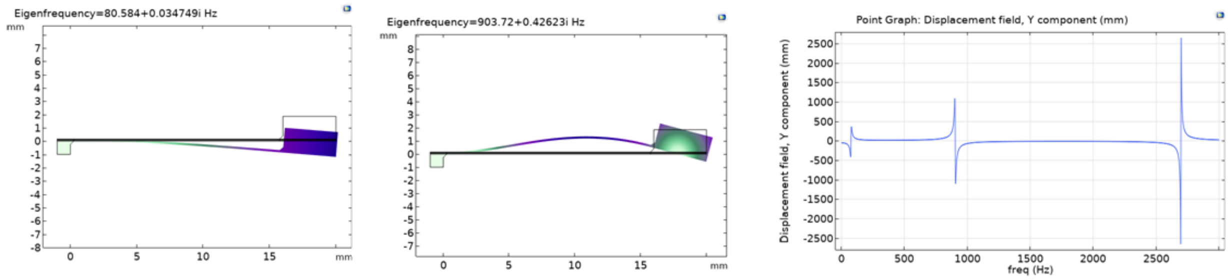


Fig. 4. Static (left) and dynamic (right) behaviours

Eigenvalue study and frequency response

An eigenvalue study is performed and the natural frequencies and shapes are obtained – Fig. 5. One can see that the first natural frequency has a value of 80.6 Hz, and the corresponding natural shape has one node. The second natural frequency is 903.8 Hz, and their natural shape has two nodes. Also, a frequency response study is conducted. The spectrogram is shown on Fig. 5c.



a b c

Fig. 5. The first natural shape (a), the second natural shape (b), and a spectrogram of vibration of the end right point of the beam (c)

Time-dependent study

The time-dependent study is conducted with harmonic kinematic excitation (Fig. 3b)

$$y = A\,sin(\omega t) \tag{4}$$

where the amplitude A is 10 mm, and two values are selected for the circular frequency ω corresponding to 10 Hz and 40 Hz frequency. The results are shown on Fig. 6 and Fig. 7.

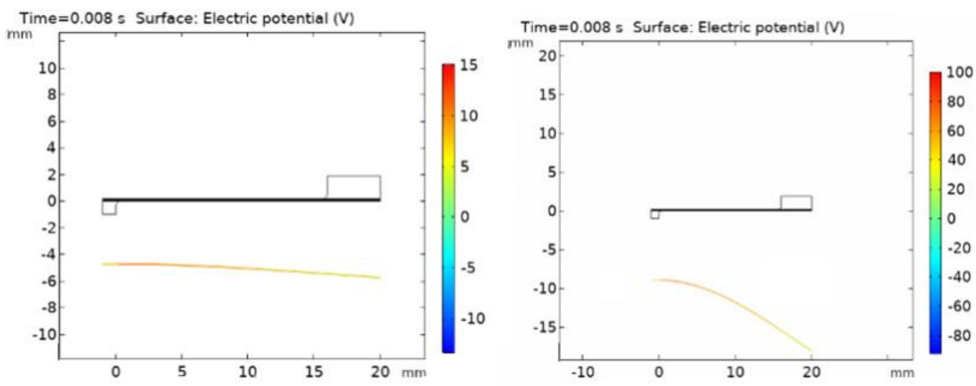


Fig. 6. Electric potential and deformed shape at a same time for frequency 10 Hz (left) and for frequency 40 Hz (right)

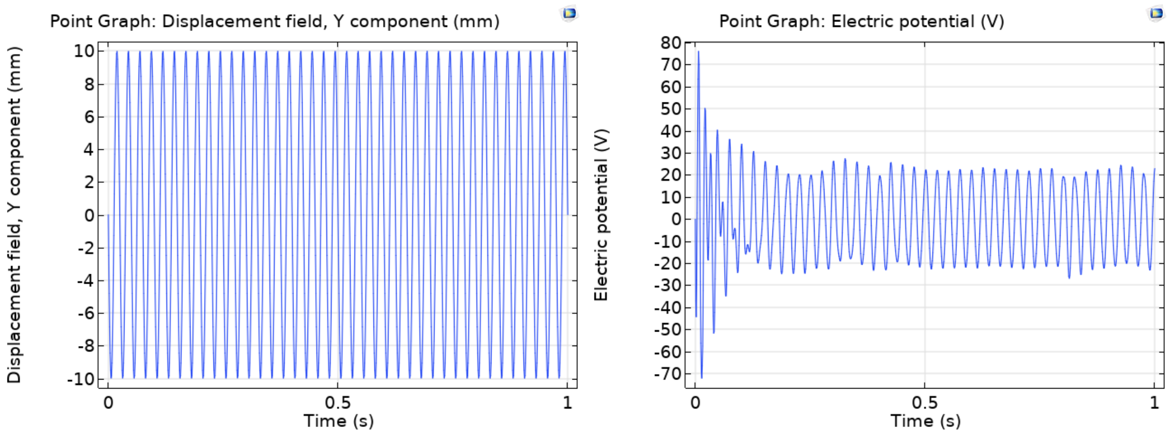


Fig. 7. Time-diagrams of the displacement (left) and the electric potential (right) of a point of the investigated beam

CONCLUSION

Various piezo beams models are studied in this investigation conducted. In the next step, it is reasonable the models to be observed deeply and the results to be concretised. After that, on the basis obtained, more complicated and efficient models can be developed and investigated.

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