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Application of the finite element method (FEM) to analyze the mechanical behavior on piezoelectric materials when an electric field is applied to a piezoelectric structure (Inverse Piezoelectricity

Mehdi BOUDOUH , Brahim El Khalil HACHI, Mohamed HABOUSSI, Sadam Houcine Habib

Laboratory of Development in Mechanical and Materials (LDMM), Ziane Achour University, Djelfa 17000, Algeria

Laboratory of Process and Materials Sciences (LSPM), Sorbonne Paris Nord University, UPR 3407 CNRS, F-93430 Villetaneuse, France

INTRODUCTION & AIM

The phenomenon of piezoelectricity represents a link between two vast fields of physics which are electromagnetism and acoustics. The major interest of this phenomenon resides in the coupling between the electrical quantities and the mechanical quantities. It allows an action on the mechanical state of a structure by the application of an electric field or vice versa. For more than a century, the exploitation of piezoelectricity has led to applications in extremely varied fields, ranging from measurement techniques, such as ultrasonic sensors, to renewable energy such as energy harvesters. About sixty years ago, piezoelectricity was placed in a field of application rich in perspectives which is that of low power electronics. These are piezoelectric voltage transformers whose principle is based on the combined use of the inverse and direct effects of piezoelectricity, and whose main advantage is the possibility of miniaturizing the systems. Millimetric in size, allowing them to be integrated into mobile or embedded electronic devices (cameras, mobile phones, flat screens, etc.), piezoelectric transformers also enjoy a number of advantages, compared to their counterparts. electromagnetic: a light weight (a few grams in a volume of less than 1 cm3), operating in a wide range of frequencies (from 1 kHz to 2 MHz), a voltage gain of up to 1000 with a power density between 10 and 100W/cm3. In addition, they generate no magnetic noise, and have very good immunity to electromagnetic disturbances, whether radiated or conducted (primary-secondary coupling capacitances of the order of pF). Finally, they offer excellent galvanic isolation, with primary-secondary isolation voltages of around 5 kV.

METHOD

LINEAR THEORY OF PIEZOELECTRICITY

In linear piezoelectricity the equations of linear elasticity are associated with the equation of the electrostatic charge by the piezoelectric constants. However, electrical variables are not purely static, but only quasi-static, because of the association with the mechanical equations of dynamics. So to provide a proper theory for the material, the applied mechanics and electric field variables are briefly defined along with the electrical equations. [3]

A-MECHANICAL CONSIDÉRATIONS

Let us designate by o the Cartesian component of an infinitesimal mechanical displacement in a precise point of a material. The strain tensor is defined by:

$$\varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}) \quad \text{With} \quad u_{i,j} = \frac{\partial u_{j,i}}{\partial x_j}$$

Note that the antisymmetric part of the gradient of the mechanical displacements determines the local, infinitesimal rotation.[4]

The mechanical interaction between two portions of a solid, separated by an arbitrary surface S, is characterized by a vector of tensile forces t applied to this surface. The traction vector t is related to the stress tensor σ by the relation: $t_j = n_i t_{ij}$

Where n_i denotes the normal component external to the surface in question.

Finally, the dynamic equilibrium equations are given by the following expression (Einstein summation formalism): $\sigma_{ij,i} = \rho \ddot{u}_j$ where ρ is the density of the material.

ELECTRICAL CONSIDERATIONS:

The intensity vectors of the electric field E and of the electric displacement D are linked by the expression:

The intensity vectors of the electric field E and of the electric displacement D are linked by the expression: $D_i = \varepsilon_0 E_i + P_i$

With P the polarization vector and ε0 the vacuum permittivity: $\varepsilon_0 = 8.854 \times 10^{-12}\,\mathrm{F/m}$

The electric field vector E is derived from the electric potential ϕ by: $E_i = -\varphi, i$

Finally, the electric displacement vector D satisfies Gauss's theorem (no free electric charges) in an insulating material: $D_{i,i} = 0$

Linear piezoelectricity:

RESULTS & DISCUSSION

To determine the value of the displacement associated with the applied electric field, we carried out numerical simulations with the Comsol software.

An electric field is applied to the piezoelectric elements of the beam generates a displacement magnitude well illustrated in Fig. 1.

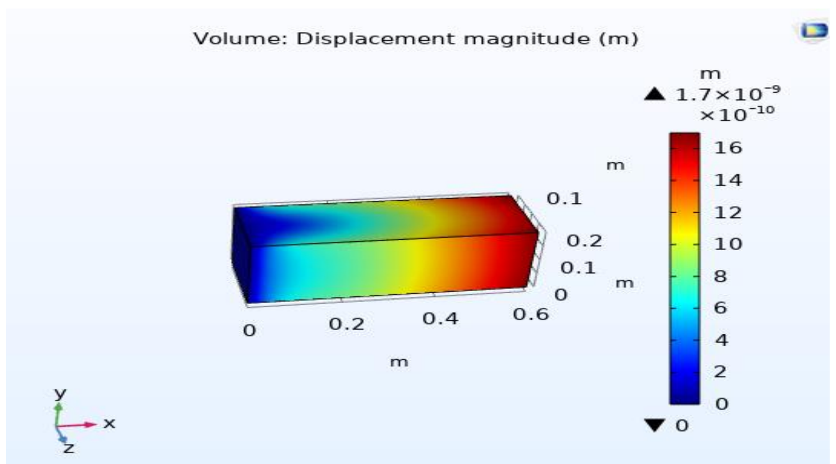


Fig 1.displacement magnitude

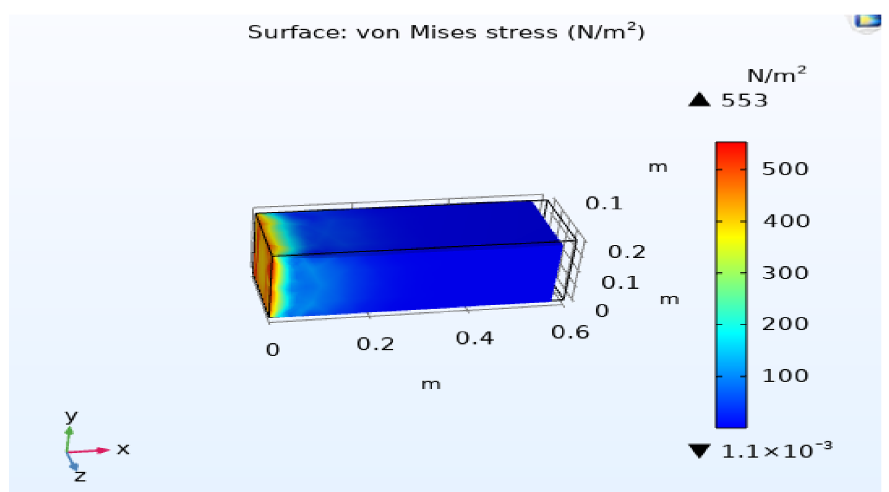
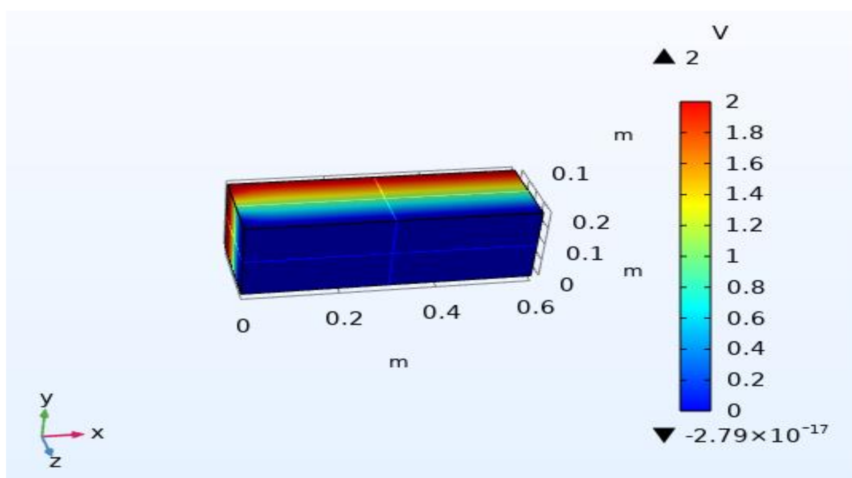
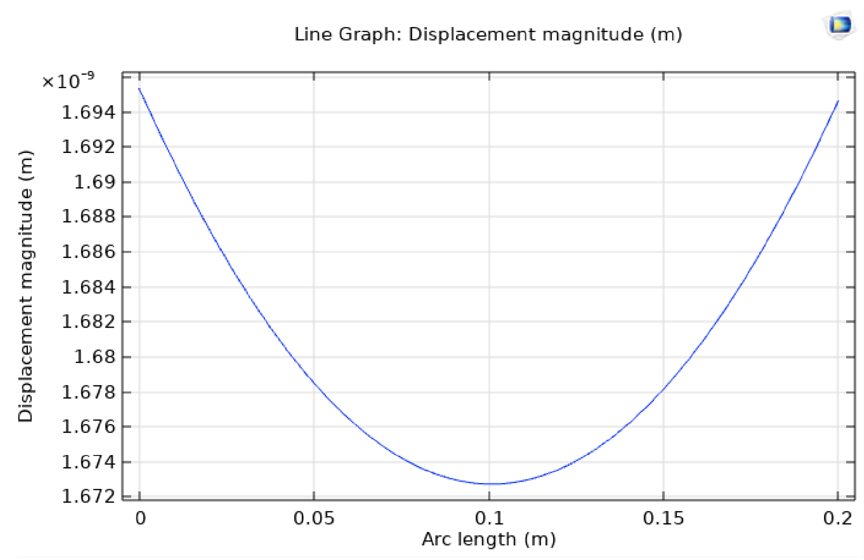


Fig2.von Mises stress

The results extracted from these modelings in terms of displacement isovalues Ux and von mises stress are presented in Fig. 1 and Figs. 2. These simulations show that for an electric field value of 2V, the deformation obtained on the micro clamp is approximately 1.7.10^-9m. The maximum deformation zone coincides with the position of the object to be carried located on the end of the multilayer bar.



1. Fig 3.electric potential



1. Fig 4.the curve of displacement magnitude as a function of the length of the arc

The figure above Fig. 3 represents the electrical potential:

The figure above Fig. 4 represents the magnitude displacement curve as a function of the length of the arc

CONCLUSION

This study allowed us to clearly highlight the benefit of multidisciplinary research in the field of electro-active materials. However, it is important to emphasize that there is still work to be done on these intelligent devices and structures, in particular on their design, their choice of multifunctional materials to be used, their most suitable behavior law and their production, while based on a relatively simplified approach to the physics of the phenomena involved.Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit

FUTURE WORK / REFERENCES

[1] CHRISTOPHE VIGUIER, Contribution au développement d'actionneurs électroactifs pour l'assistance circulatoire - Application à la mise au point d'une fonction antithrombotique,Thèse de doctorat, l'institut national polytechnique de TOULOUSE, 2005.

[2] A. ENDO, N. SASAKI, Investigation of frictional material for ultrasonic motors, Jpn. J of Appl. Phys., Vol. 26, pp 197-199,1987.

[3] GOBIN P. F., ODORICO J. Matériaux Intelligent ; Lettre des programme interdisciplinaires de recherche du CNRS, PIRMA Novembre 1991.

[4] A. BAZ, S. POH, M. MUTA and J. GILHEANY 'Active control of Nitinol-reinforced beam', Intelligent structural systems, pp169-212, 1992.

[5] J. S. N. PAINE, C. A. ROGERS and R.SMITH 'Adaptative composite materials with shape memory alloy actuators for cylinders and pressure vessels', Journal of intelligent material systems and structures,Vol.6; pp210-219,1995.

[6] K.KURI BAYASHI 'A new actuator of a joint mechanism using TINI alloy wire', the international journal of Robotics research, vol.4, 99 47-58, 1986.

[7] Airmar Technology Corporation, www.airmar.com, Piezoflex polymer, 2004.

[8] Physik Instrumente (PI) GmbH & Co. KG, www.physikinstrumente. com, Tutprials : electrostrictive actuators, 2005.