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PARAMETRIC ANALYSIS OF PIEZOELECTRIC TRANSDUCER USED FOR SIGNAL PROCESSING

M. BLASIAK*

Abstract: *A two dimensional model of interdigital transducer (IDT) used for processing particular physical quantities into electric signal was presented in this paper. The results of numerical calculations of the above mentioned model were presented as well as a parametric analysis was conducted in order to obtain information concerning stress distribution in the transducer.*

Keywords: Piezoelectric Crystals, Interdigital Transducer, Surface Acoustic Waves, Stress

1. Introduction

Piezoelectric transducers are basic elements of components which use surface acoustics waves in order to process particular physical quantities into electric signal. The physical quantities that are measured might include: displacements, velocities, accelerations and acoustic pressure. The principle of operation of piezoelectric transducers involves using direct and converse piezoelectric effect: as a result of mechanical stresses, piezoelectric materials produce electrical current (Blasiak & Kotowski, 2009). Such attributes are characteristic of some monocrystals: barium titanate, quartz, Seignette's salt. Currently natural crystals are substituted with polycrystals, i.e. artificially polarized ceramic products (e.g. piezoceramic PZT6). Transducers made of piezoelectric crystals are used for building various devices in different branches of industry. They are widely used for measuring the vibrations in non-contacting face seals (Blasiak, 2015a, 2015b), the vibrations in the cutting process (Miko & Nowakowski, 2012a, 2012b), vibrations and control in mechanical devices (Takosoglu et al., 2012) and building gyroscopes (Koruba et al., 2010). Piezoelectric materials are widely applied as well in aviation industry, e.g. to building flying objects (Krzysztofik & Koruba, 2012). The aim of this paper is to show the stress distribution in the interdigital transducer, used for signal processing.

2. Methods

The subject of the research was interdigital transducer (IDT), built of two electrodes in the form of combs combined with each other with the use of metal rails and placed on a piezoelectric surface. A two-dimensional model of the transducer consists of an interdigital transducer that is fixed on a piezoelectric layer, and a metal plate (Fig. 1).

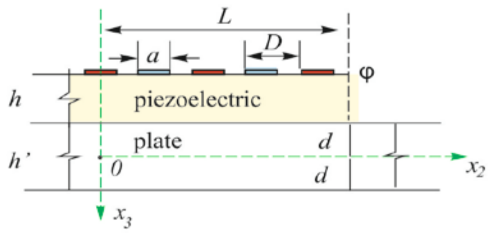


Fig. 1: A two-dimensional model of the interdigital transducer, where: $a-$ *width of the electrode,* $D-$ *gap between the electrodes,* $L-$ *length of the transducer,* $2d-$ *thickness of the plate,* $h-$ *thickness of the piezoelectric layer,* φ $-$ *potential.*

* Małgorzata Błasiak, PhD.: Department of Mechanics, Kielce University of Technology; Aleja Tysiąclecia Państwa Polskiego 7; 25-314 Kielce; PL, mdrab@tu.kielce.pl

Voltage put against electrodes of the transducer creates electric field and thus, generates mechanical waves that result from piezoelectric effect. Under the influence of electromechanical coupling, a cooperation between the transducer and the plate might be expected. The surface of the transducer was modelled in the form of a metal plate. Moreover, a strong electro-mechanical coupling as well as a finite number of electrodes in the transducer were assumed. It was assumed that the potential distribution on the surface of the transducer is continuous and it was described with a cosine potential distribution along x_2 axis (Blasiak & Kotowski, 2009, Jin et al., 2003).

For consideration piezoelectric crystal dynamic equation of motion and electric displacement satisfying Maxwell equation have the form:

$$\sum_{j=1}^{3} \sigma_{ij,j} = \rho \ddot{u}_i, \quad \sum_{i=1}^{3} D_{i,i} = 0 \tag{1}$$

where $i = 1,2,3$; σ_{ij} – stress tensor, u_i – displacement, ρ – mass density, D_i – electric displacement. Hooke's law and the electric displacement written in the form of constitutive equations:

$$\sigma_{ij} = c_{ijkl} u_{k,l} - e_{kij} E_k \tag{2}$$

$$D_i = e_{ikl} u_{k,l} - \varepsilon_{ij} E_j \tag{3}$$

where c_{ijkl}, c'_{ijkl} – tensor of the elastic modul, e_{ikl}, e'_{ikl} - piezoelectric constants, ε_{ij}, ε'_{ij} - dielectric constants for the piezoelectric crystal and the plate, respectively (Moulin et al., 2000).

Because it considered the wave propagating in the direction (x_2, x_3), of developing the equations (1) and (2,3), an electro-mechanical coupled equation of motion for the piezoelectric layer was obtained which was expressed with a mechanical displacement and electrical potential.

$$\left.\begin{array}{c} c_{11}u_{2,22} + c_{44}u_{2,33} + (c_{13} + c_{44})u_{3,23} + (e_{31} + e_{15})\varphi_{,23} = \rho \ddot{u}_2 \\ (c_{13} + c_{44})u_{2,32} + c_{44}u_{3,22} + c_{33}u_{3,33} + e_{15}\varphi_{,22} + e_{33}\varphi_{,33} = \rho \ddot{u}_3 \\ (e_{15} + e_{31})u_{2,23} + e_{15}u_{3,22} + e_{33}u_{3,33} - \varepsilon_{11}\varphi_{,22} - \varepsilon_{33}\varphi_{,33} = 0 \end{array}\right\} \tag{4}$$

Equations of motions for the plate, without taking the piezoelectric and dielectric effects into consideration, take the following form:

$$\left.\begin{array}{c} c'_{11}u_{2,22} + c'_{44}u_{2,33} + (c'_{13} + c'_{44})u_{3,23} = \rho' \ddot{u}'_2 \\ (c'_{13} + c'_{44})u_{2,32} + c'_{44}u_{3,22} + c'_{33}u_{3,33} = \rho' \ddot{u}'_3 \end{array}\right\} \tag{5}$$

In the boundary conditions it was assumed that the upper surface of the piezoelectric layer and the lower surface of the plate are free from stresses: $\sigma_{33} = \sigma_{23} = 0$, $\sigma'_{33} = \sigma'_{23} = 0$. The electric condition is regulated with an input electric signal that is described with an equation (Jin et al., 2003)

$$\varphi(k)\Big|_{x_3=-h-d} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x_2) e^{ikx_2} dx_2 \tag{6}$$

On the border of two media, principles of continuity were presented in the following form $(\varphi = 0)$:

$$\left.\begin{array}{cc} u_2 = u'_2, & u_3 = u'_3 \\ \sigma_{33} = \sigma'_{33}, & \sigma_{23} = \sigma'_{23} \end{array}\right\} \tag{7}$$

In the model transducer it was assumed that the surface in the form of a metal plate has finite length. In case of introducing a finite number of points of computational grid, in order to avoid volatility of numerical calculations - absorbing layers on the plate edges connected with the direction x_2 were introduced. The physical sense of the layers that were applied is to simulate the exponentially disappearing vibration amplitude of the propagating waves. The equations of motion in the absorbing layer take the following form:

$$\rho \ddot{u}_2 = c_{11} u_{2,22} + c_{44} u_{2,33} + (c_{13} + c_{44}) u_{3,23} + \tau \dot{u}_2$$
$$\rho \ddot{u}_3 = (c_{13} + c_{44}) u_{2,32} + c_{44} u_{3,22} + c_{33} u_{3,33} + \tau \dot{u}_3 \qquad (8)$$

where τ – coefficient absorbing vibrations.

The mathematical model of the interdigital transducer was solved numerically with the use of the finite difference method and the elementary control volume method. It was assumed for this calculation that the piezoelectric layer has a hexagonal crystal structure of *6mm*, and an aluminium plate is the surface. Material constants PZT6 and aluminium were assumed in accordance with the paper (Blasiak & Kotowski, 2009). Dimensions of the transducer: $L = 0.02\,m$, $h = 0.001\,m$, $D = 0.002\,m$, dimensions of the aluminium plate: $L' = 0.02\,m$, $h' = 0.002\,m$.

3. Results

As a result of the numerical calculations, the distribution of displacement elements in the transducer (which were not presented here) as well as of stress elements σ_{23} (Fig.2) i σ_{33} (Fig.3) along the thickness direction x_3 were obtained. The frequency of the applied signal was $600\,kHz$, potential $\varphi = 5\,V$, thickness of the transducer $z = 0.001\,m$ (output parameters).

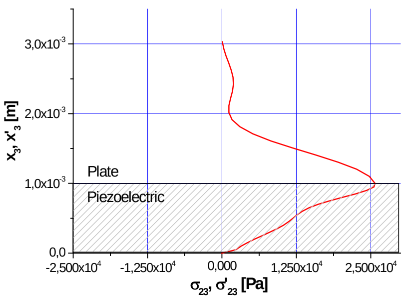


Fig. 2: Distribution of the stress element σ_{23} in the transducer.

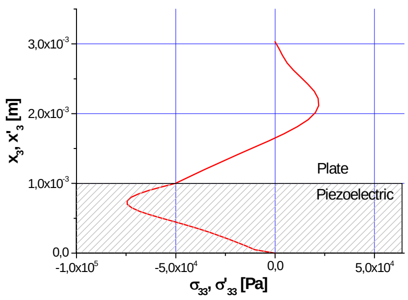


Fig. 3: Distribution of the stress element σ_{33} in the transducer.

The next was to conduct a parametric analysis of the transducer. The aim of the research was to verify, which quantities have the biggest impact on the distribution of stress elements in the interdigital transducer. All calculations were made for the same moment, namely $t = 1 \times 10^{-5}$. Potential, frequency and layer thickness were subsequently changed. Some results are presented below in the form of graphs. Fig. 4 presents the distribution of stress elements for various values of the potential φ (the remaining output parameters remain unchanged).

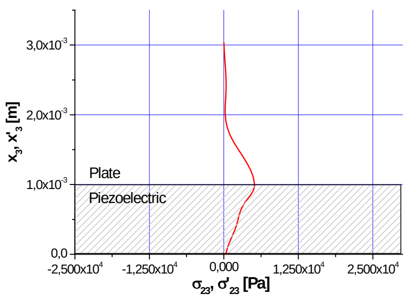


Fig. 4: Distribution of the stress element σ_{23} in the transducer for $\varphi = 1V$.

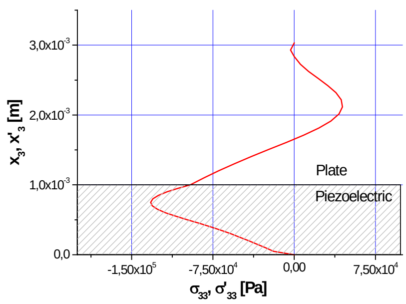
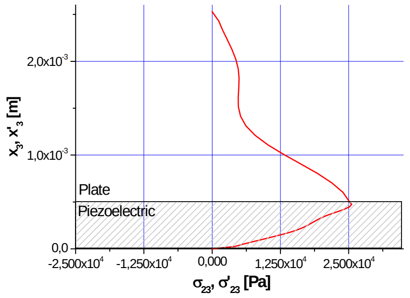


Fig. 5: Distribution of the stress element σ_{33} in the transducer $\varphi = 10V$.

Fig. 6 and 7 present the distribution of stress elements for various thicknesses of the piezoelectric layer (the remaining output parameters remain unchanged).



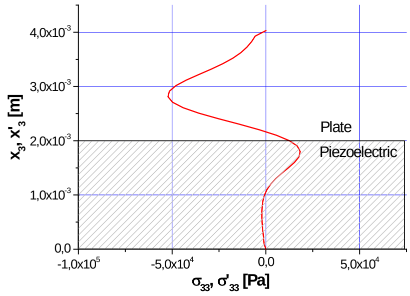


Fig. 6: Distribution of the stress element σ_{23} *in the transducer for* $z = 0.00005\ m$.

Fig. 7: Distribution of the stress element σ_{33} *in the transducer* $z = 0.0002\ m$.

Graphs (2-7) present the distribution of acoustic field in the coupled structure. Nil value on both ends connected with the thickness x_3 means that they are free from stresses. Moreover, the stress of the field is continuous along the piezoelectric layer and the aluminium plate which proves the fact that they cooperate with each other.

4. Conclusions

On the basis of the results of the parametric analysis of the transducer it was stated that with the potential increase, the stress value increases in a linear manner. It confirms the occurrence of the converse piezoelectric effect in the layer. The change in the thickness of the piezoelectric layer influences the stress distribution in the whole transducer the most. The impact of the stress distribution in piezoelectric crystals is crucial, because a lot of operating properties of piezoelectric devices depend on the stress state. Acquaintance of such stress states enables i.a. to determine the degree of the defects in the structure, limit the number of defects and modify the manner of production of the desired devices.

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