RESPONSE OF AN ULTRASONIC TRANSDUCER WHEN THE PIEZOELECTRIC CERAMICS EFFECTIVE AREA IS MODIFIED

I. Sánchez D.*, M. A. von Krüger**

* Universidad Nacional Autónoma de México, Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas, Mérida, Yucatán, México

** Universidade Federal do Rio de Janeiro, Programa de Engenharia Biomédica, Rio de Janeiro, Brasil

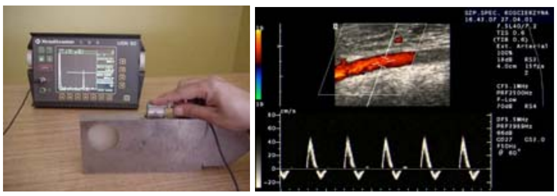
email: israel.sanchez@iimas.unam.mx

Abstract: When the effective area of a piezoelectric element of an ultrasonic transducer changes, its performance is impaired. Such changes occur mainly during the transducer construction particularly when the leads are soldered to the electrodes of the element and when the element is loads by the matching and backing layers. To study and analyse this process is proposed here a comparison between experimental data from an especially constructed transducer with a PZT piezoelectric ceramic of 8 MHz and its corresponding model using Finite Element Method (FEM). This study enabled the observation of shift on transducer resonance frequency, weakening of its acoustic field and side lobes formation.

Keywords: Piezoelectric element PZT, ultrasonic transducer, Element finite method, frequency.

Introduction

The uses of ultrasound applications ranges from the industrial to medical area, as illustration in Figure 1 are presented: a NDT (non destructive testing) application for flaw detection in metals and a medical application, Duplex Scan (where a Colour Doppler image of a vessel is combined with an anatomical image).



a) b)

Figure 1 Examples of application of ultrasonic transducers both in a) industry (NDT), and b) in medicine (Duplex scanner)

Ultrasonic transducers play the key role of coupling the mechanical reality under investigation with the electronics of signal conditioning and processing, because of that the quality of the measurement and diagnostic obtained with ultrasonic equipment is directly impacted by the transducer performance, and its construction is a fundamental activity both from the technical and industrial point of view. The core of an ultrasonic transducer is the piezoelectric element; it can be made of materials like crystals, polled ferroelectric ceramics or polymers. Piezoelectric materials exhibit a crystalline structure containing some sort of asymmetry. This results in the formation of electric dipoles with a certain degree of net orientation. Any distortion in this structure (strain S) caused by mechanical action (stress T) will lead to a redistribution of charges in the lattice (displacement current D) resulting in generation of a net proportional voltage (electric field E) across the material. Conversely, a redistribution of charges in the lattice (D) caused by an external electric field (E) will produce a proportional distortion (S) in the crystalline structure applying a proportional stress (T) in the surrounding medium. The piezoelectric effects are also dependent on the temperature. From the point of view of power transduction, the piezoelectric material is better characterised by the coupling factor k [1], [2] which represents the effective electromechanical energy conversion and can be expressed as:

$$k = \sqrt{\frac{U_{e-m}}{U_e}} = \sqrt{\frac{U_{m-e}}{U_m}} \qquad (1)$$

Where U_m is the total applied mechanical energy, U_e is the total applied electrical energy, $U_{e\text{-}m}$ is the electrical energy converted to mechanical energy, and $U_{m\text{-}e}$ is the mechanical energy converted to electrical energy.

Viewed from its electrical port any piezoelectric device may be represented as a pure electrical device where the mechanical parameters are translated into electrical parameters providing the basis for the electrical modelling of ceramics and transducers. The earliest model was proposed by Van Dyke (1948). The equivalent circuit is presented in Figure 2. It has two branches in parallel; branch 1 contains a capacitor C_0 and branch 2 a resistance R_1, an inductance L_1, and a capacitance C_1 in series. The resonance occurs at the frequency causing serial resonance in the $R_1L_1C_1$ circuit in branch 2 (at this frequency the impedance of the equivalent circuit is at a minimum). The antiresonance occurs at the frequency causing parallel resonance between branches 1 and 2 (at this frequency the impedance of the equivalent circuit is maximum).

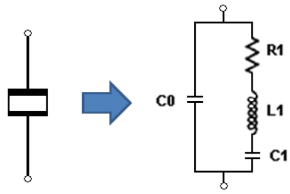


Figure 2: Electrical equivalent circuit of a piezoceramic.

The electrical impedance as a function of frequency Z(f) is measured with a network analyser by sweeping the frequency (f) of the input signal and recording simultaneously the impedance module |Z|(f) and the phase α(f). This reveals the resonance and anti-resonance frequencies of the material. The coupling coefficient, k, can also be approximately determined from the resonant f_r and antiresonant- f_a frequencies [1]

$$k \cong \frac{f_a^2 - f_r^2}{f_r^2} \quad (1)$$

Materials and methods

In the present work the piezoelectric element employed was made of PZT (Lead Zirconate Titanate) which is still the most widely used piezoceramic today. It was a square plate (4.2 mm X 4.2 mm) made of PZT (Lead Zirconate Titanate). The working frequency was 8 MHz.

The effect of soldering the leads to the piezo-element and the attachment of the matching and backing layer would require a quite complex simulation however in this work the modelling of the effect of the lead soldered to the electrodes was simply by reduction of the radiation area by 10% and by increasing the mass of the element to simulate the extra load represented by the leads and matching and backing layers. In Figure 3 the area reduction is shown [4].

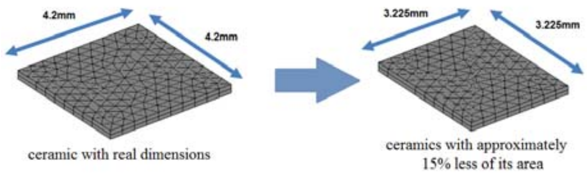


Figure 3: Piezoceramic with its dimensions modified as a consequence of soldering the leads to the electrodes representing the reduction in the effective area of oscillation.

A simulation with Finite Element Analysis was performed representing the piezoelement with the original dimensions and the element with the modified dimensions. Using the following physical properties of piezoelectric ceramics, the Table No.1 shows the properties [5].

An electrical equivalent Impedance of the piezoelement [6], [7], [8], was measured as a function of frequency by measuring the impedance of the piezo ceramic alone.

Table 1: physical properties of ceramics

Density (Kg/m^3)	7800
Young's modulus (N/m^2)	1x10^{11}
Poisson's ratio	0.34
Coefficient of thermal expansion (1/K)	-5x10^{-6}

Subsequently an electrical equivalent Impedance of a transducer constructed with this ceramic was measured to verify how the construction process affects the frequency response of the ceramic.

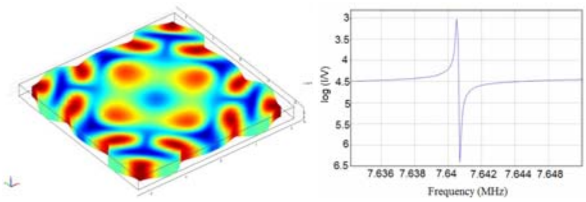
The sequence showing the construction of the transducer is shown in Figure 4. It basically consists of: soldering the leads, fixing the transducer on a supporting/backing placing this assembly in the case, placing the matching layer.

Figure 4: Steps in construction of an ultrasonic transducer.

The experimental measurements of the equivalent impedance were performed using an Impedance Metter Agilent 4294.

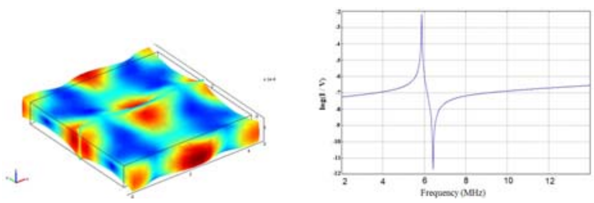
Results

The finite element analysis results are shown in Figure 5 for the Piezoceramic with the original dimension and in Figure 6 with the reduction in dimension. It was possible to observe the vibration mode and the shift in frequency as a function of geometry change and increase of mass.



(a) (b)

Figure 5: Piezoceramic alone- a) Finite Element Model (FEM), b) Frequency response curve.



(a) (b)

Figure 6: Piezoceramic altered- a) Finite element Model b) Frequency response curve. When the effective area has reduced, and therefore the frequency is different from the original.

In the case of the eletrical equivalent circuit Figure 7 represents the case of the piezo ceramic alone.

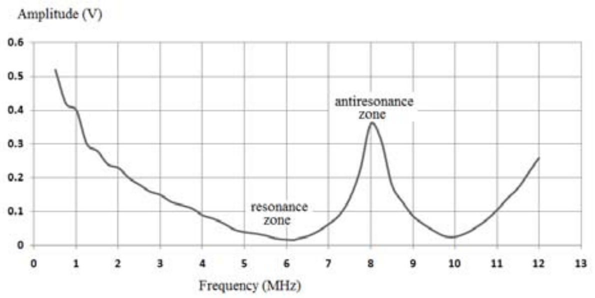


Figure 7: Response obtained from the equivalent circuit of a piezoceramic in the frequency range of 1 to 12 MHz. The resonant frequency is 8 MHz

The eletrical equivalent circuit of the ceramic with area reduction, loaded with of the soldered leads and maching and backing laiers presnts a freqeuency shift Figure 8 agreing with the finite element model.

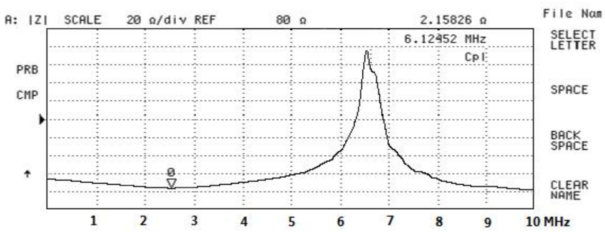


Figure 8: Response obtained in the impedance analyzer. The resonant frequency originally in 8 MHz is shifted. It is observed as the frequency has undergone a shift, due to fouling of the electrodes

During the simulation process using the finite element method, was observed that each ceramic to array presented a different frequency of oscillation, this caused because not ensure that the electrodes are welded in exactly the same position.

Generating that the response of the transducer will be modified so much in directivity, extent or width of the principal lobe.

We can this response can associate it with the phenomenon of the crosstalk, present in all the arrangements of elements piezoelectric, in the following figure (figure 9), there appears the response that is obtained in a matrix array where it is possible to observe that the boss of radiation meets modified thanks to the presence of these cables welded in all the ceramics that shape the array.

The simulation was realized using the software HPVee, where the variations were introduced in frequency that they present in every arrangement, as well as the variation of the effective area of the ceramics.

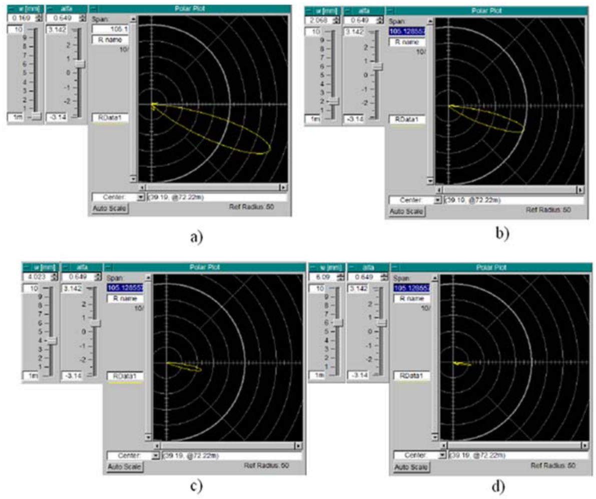


Figure 9: Graphics of the radiation pattern where the dimensions of the ceramics were modified by different factors, noting how affect the beam.

We presented here is just the beginning, where much experimental work has not yet been realized. When completed the experimental part, then it will be possible to carry out a full comparison of the phenomenon, and thus determine the effect on the generation of images through ultrasound.

Conclusions

The simulation presented here is easily implemented however simulations of physically induced modifications in the piezoceramic are useful in studying and designing ultrasonic transducers. The options of represent mechanical parameters in the electrical port and vice versa enable wide range of simulation possibilities. A realistic model should take into consideration a series of factors however is important to point that simple models capable of being refined can be a good starting point.

Modelling the physical behaviour of a transducer can provide efficient solutions and economy; this is why it is important to invest in modelling. The work presented here shows how easily implemented models can be useful in representing important construction features.

References

[1]Moulson A. and Herbert JM. Electroceramics, materials properties applications. Vol. 4, ed. Champman & Hall; London,1990.

[2] Berlincourt DA. Behavior of piezoelectric ceramics under various environmental and operation conditions of radiating sonar transducer.PN; 1964.

[3] PIceramics. PiezoMaterial Tutorial [internet]. 2014 Jan 31 [cited 2014 Sept 8] Available from:http://www.piceramic.com/piezo_effect.php.

[4] Sánchez DI, Acevedo CP, Moreno E, von Krüger MA. Crosstalk effects caused by the geometry of piezoelectric elements in matrix ultrasonic

transducers. Brazilian Journal of Biomedical Engineering. 2011; 27(2):90-97.
[5] Acevedo CP, Sánchez DI, Zamora VA. Improvement design and construction of na ultrasonic transducer applied to blood flow measurement. In:Proceedings of the 1st International Congress on Instrumentation and Applied Sciences ICIAS; México 2010 Oct. 26-29.
[6] Zamora VA. Diseño, construcción y caracterización de un transductor ultrasónico con ángulo para aplicaciones médicas. [Thesis]. Facultad de Ingeniería., Universidad Nacional Autónoma de México, México, 2011.
[7] Sánchez DI, Acevedo CP, Recuero LM, García-Nocetti DF. Simulation, construction and Characterization of a piezoelectric transducer using rexolite as acouostic matching. Journal of Materials Science and Engineering A&B. 2013; 3(4B):208-213.
[8] Sánchez DI. Efecto del crosstalk en la respuesta de un transductor ultrasónico tipo PZT. [Thesis]. Madrid: Universidad Politécnica de Madrid, España; 2014.