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Simulation of an Ultrasonic Transducer for Medical Applications Using the Finite Element Method

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Abstract: This paper presents the simulation of a PIC255 commercial piezoelectric ceramic which was used in the design of an 8 MHz ultrasonic transducer, as a novelty a biocompatible material known as rexolite was incorporated as acoustic matching. The FEM (Finite element method) was used in the simulation. This work shows that it is feasible to predict the response of the ceramic in each one of the stages generating with this a significant saving in time and human resources. Frequency responses are presented in addition to the stress and strain responses of the ceramic.

Key words: Piezoelectric ceramics, PZT, Rexolite, FEM (Finite element method), transducer, COMSOL.

1. Introduction

The main components of an ultrasonic transducer are: the active element (piezoelectric ceramic), the rear part (backing) and an acoustic coupling material (matching), in addition to the respective electrical connections. Commonly used materials are polarized ceramics, the backing material is usually a strong attenuator or a high density material used to control the transducer vibration and to absorb the energy radiated by the rear side of the active element.

An acoustic coupling material is used to protect the active element of the transducer from the environment. For contact transducers, the acoustic coupling material should be durable and resistant to corrosion and be able to couple the impedance between the transducer and the propagation medium. In the simulation it was used a material whose impedance is similar to that of water. Fig. 1 shows a diagram of the different components of an ultrasonic transducer.

The active element used in the simulation was the PIC255 (PZT Lead Zirconate Titanate) commercial piezoelectric disc which central frequency is 8 MHz, as backing material a general porpoise low viscosity epoxy material Insulcast 501 was used, and as matching material Rexolite which is a plastic polymer with similar acoustic characteristics to that of water produce by C-Lec Plastics, Inc. [1-4] was used in this work. Commercial COMSOL software was used for the simulation.

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2. Material Properties

Simulations were performed using the finite element method and the properties and dimensions of each of the elements were used as parameters. The PIC255 ceramic has 7.5 mm diameter a 750 µm thickness, its properties are shown in Table 1.

INSULCAST 501 was used as backing material being its thickness the double of that of the PIC255 ceramic disc and its properties are shown in Table 2 [5].

Rexolite is a unique cross linked polystyrene microwave plastic, biocompatible, it maintains a Dielectric Constant of 2.53 through 500 GHz with extremely low dissipation factors, some other properties

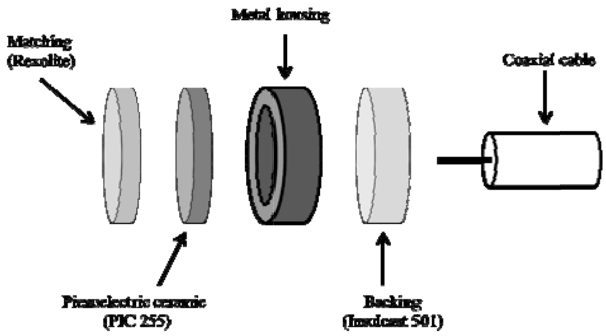


Fig. 1 Diagram of the different parts of an ultrasonic transducer.

Table 1 PIC255 properties.

Density [Kg/m^3]	7,800
Young's model [N/m^2]	1×10^{11}
Thermal expansion coefficient [1/K]	-5×10^{-6}
Poisson Radio	0.34

Table 2 INSULCAST 501 properties.

Density [Kg/m^3]	3,860
Young's model [N/m^2]	0.19×10^{11}
Termal expansion coefficient [1/K]	75×10^{-6}
Poisson Radio	0.30

Table 3 1422 Rexolite properties.

Density [Kg/m^3]	1,050
Young's model [N/m^2]	31.02×10^{11}
Thermal expansion coefficient [1/K]	70×10^{-6}
Poisson radio	0.37

are shown in Table 3.

3. Simulation

Data from Tables 1-3 was used in the simulation; the boundary conditions and the subdomain of each of the elements were set to finally select the meshing procedure in the simulation. The modeling for the different parts of the transducer is described in this section [6, 7].

3.1 Ceramic Modeling.

The geometry and physical properties of the ceramic discs are set in this part of the simulation; it is possible to analyzed the oscillation frequency, the interaction between elements and its possible deformation.

3.2 Backing Modeling

It is necessary to decide the dimensions of the backing (accordingly to experimental experience) and include its physical properties. A good backing material must be capable of absorbing the radiation from the rear side of the ceramic.

3.3 Matching Modeling

Matching modeling allow us to see if there is attenuation or displacement of the oscillation frequency of the transducer.

Finally, when we join these three sections we obtain a whole model of the transducer and we are able to analyzed the performance of the transducer.

4. Results

Results show the response of each one of the elements of the transducer. First results show the simulation of the PIC255 piezoelectric ceramic. Fig. 2 shows the deformation of the ceramics when are driven at 12 Volts [8] .

These graphics show the magnitude of the deformations in the disc. Fig. 3 shows the frequency response of the ceramic when is excited at 12 Volts, it resonates at 8 MHz, which is the central resonance frequency (data from the manufacturer).

The next step in the simulation process was to add to the ceramic disc the backing material, a layer of twice the thickness of that of the ceramic disc. To determine if this material meets the condition of absorbing radiation in the backside of the piezoelectric ceramic and if there is a variation in the performance of the transducer it was necessary to analyze this part of the simulation. Fig. 4 shows the response of the ceramic disc with the INSULCAST 501 backing material.

Fig. 5 shows the frequency response of the piezoelectric ceramic with the INSULCAST 501 backing layer, where it is possible to see a frequency shift, this may be due to the thickness of the baking layer.

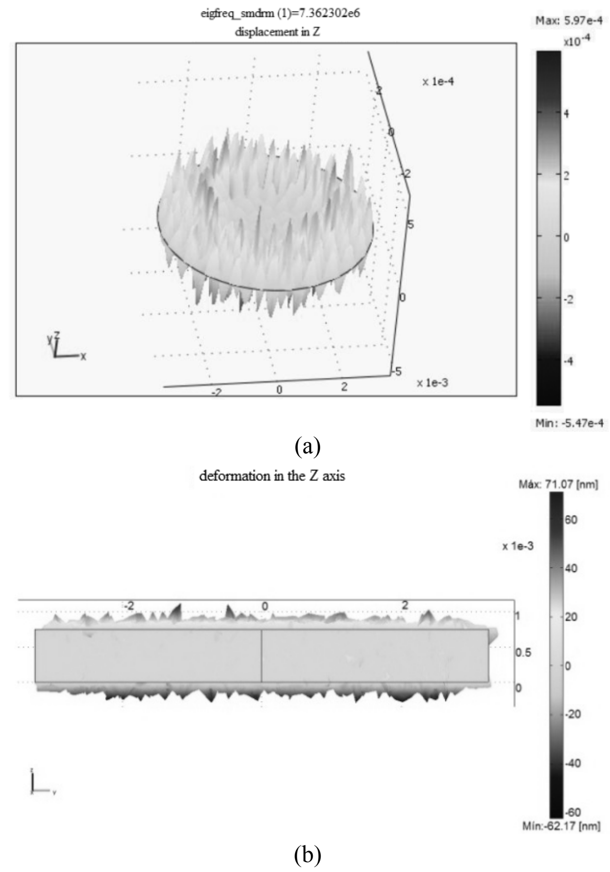


Fig. 2 (a) Simulation of PIC255 ceramic at 8 MHz. (b) Side view of the same ceramic.

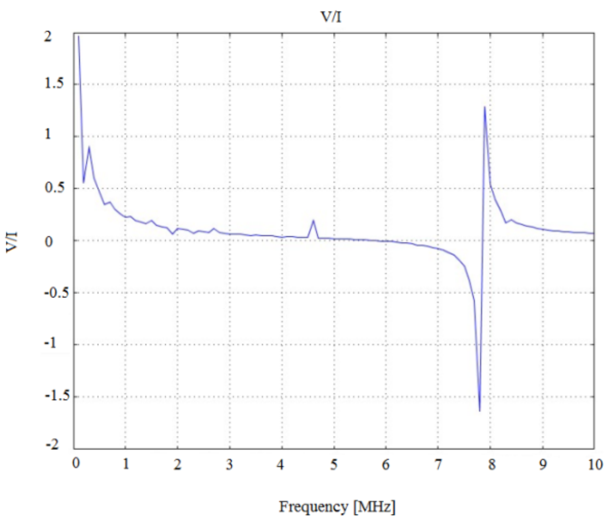


Fig. 3 PIC255 ceramic Impedance.

A layer of Rexolite was added to the ceramic disc, the thickness of this layer was 1/5 of that of the ceramic disc. Fig. 6 shows the simulation of the piezoelectric ceramic with the Rexolite layer.

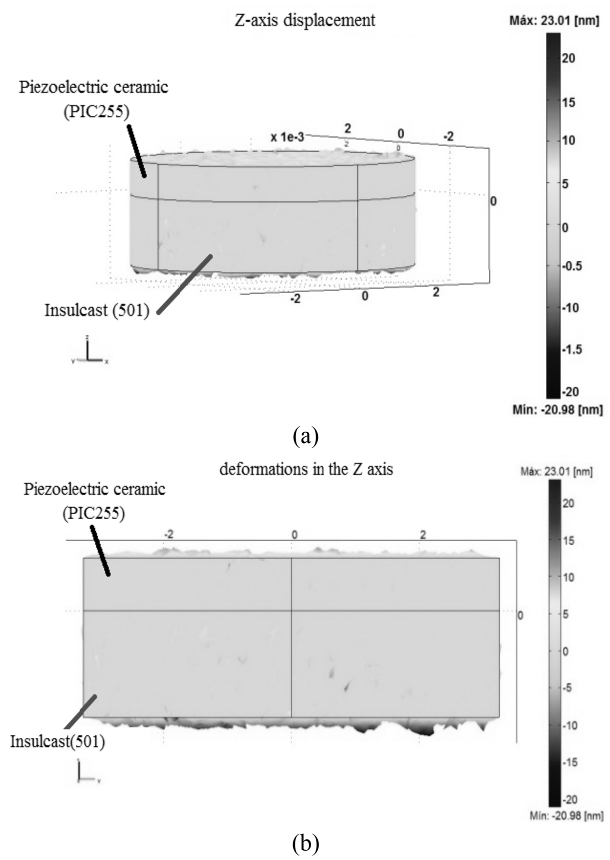


Fig. 4 (a) Shifts in the PIC255 piezoelectric ceramic with backing (INSULCAST 501) twice the thickness of that of the ceramic disc at 8 MHz. (b) Side view.

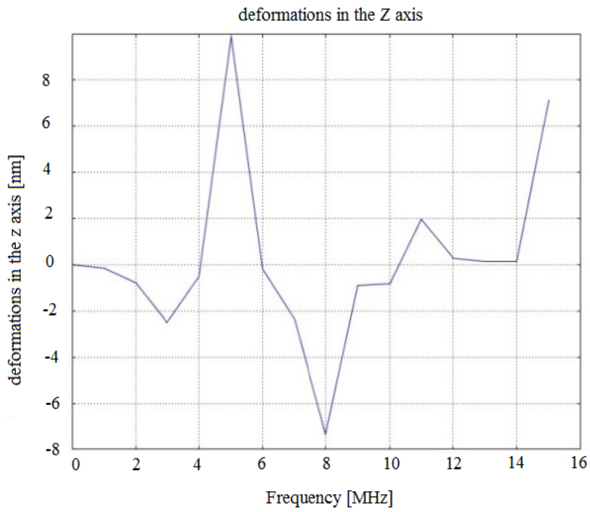
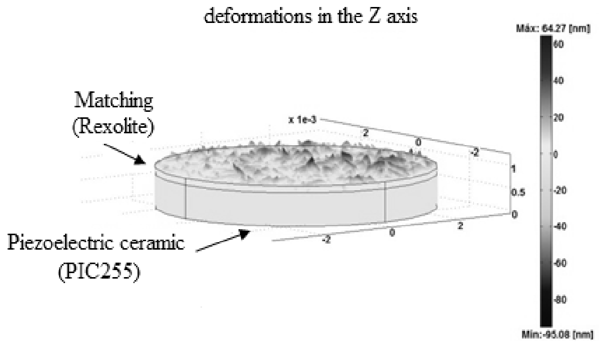
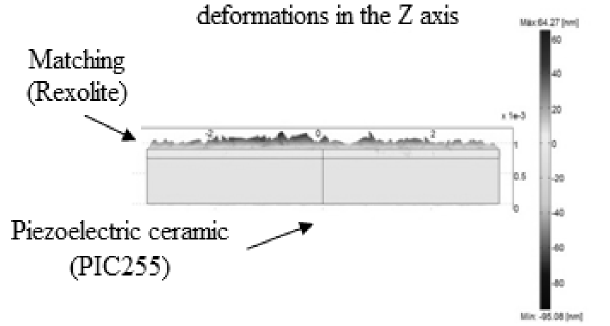


Fig. 5 Frequency response of PIC255 ceramic with backing layer (INSULCAST 501).

Fig. 7 shows the frequency response of the ceramic with a Rexolite layer, it is observed that there is a frequency shift, this may be due to the thickness of the



(a)



(b)

Fig. 6 (a) Simulation of PIC255 ceramic with a layer of Rexolite at 8MHz, (b) Side view.

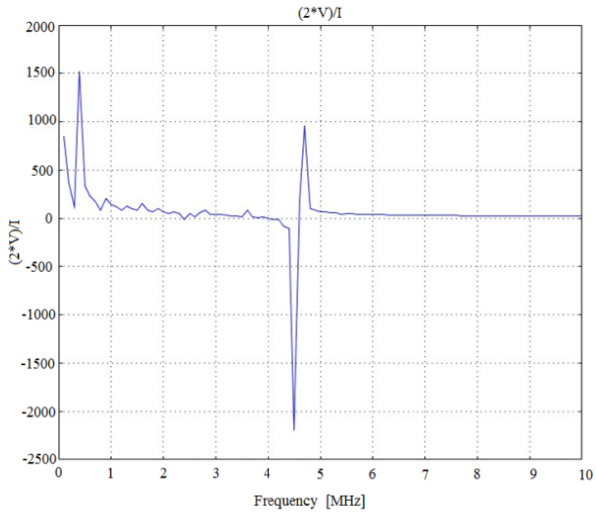


Fig. 7 Frequency response of the PIC255 ceramic with matching layer (Rexolite).

Rexolite layer, analyzing the performance of the transducer it would be convenient to use a thinner Rexolite layer in order to prevent this type of displacements [9].

One of the main objectives in the simulation process was to test the robustness of the transducer. Therefore, the three sections of the transducer were simulated

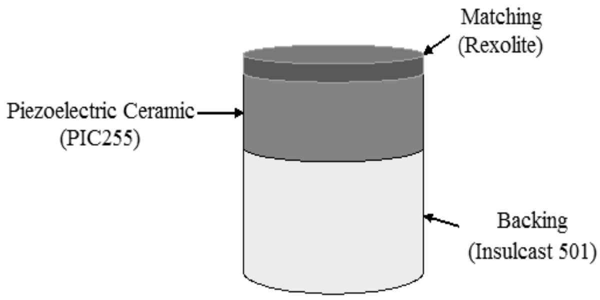


Fig. 8 Simulation of the three sections of the transducer.

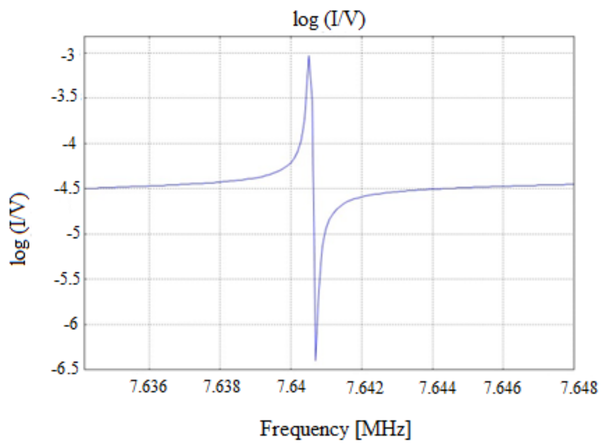


Fig. 9 Frequency response of the simulated ultrasonic transducer.

together as it is shown in Fig. 8.

Using the simulation of the three sections of the transducer the frequency response was obtained as shown in Fig. 9. The center oscillation frequency is around 7 MHz.

4. Conclusions

The simulation of an ultrasonic transducer for medical applications using the finite element method is presented. Each part of the transducer was simulated and analyzed separately.

The main features of each part of the transducer and the frequency response are shown. The experimental oscillation frequency of the transducer was 7.64 MHz, as shown in Fig. 9, where the presence of lateral lobes (harmonics) is minimal, this indicates that the simulation of each part of the transducer behaves as expected. However, the experimental frequency response is not the same as the ideal value which should be 8 MHz, this result shows that there is a shift in the frequency due probably to several factors such as the backing and matching layers and the electrodes of the ceramic. The results indicate that in order to obtain a transducer whose oscillation frequency is 8 MHz, it is necessary to use piezoelectric ceramics with higher oscillation frequencies. Backing and matching simulation shows that the materials used are reliable in the construction of this type of transducers.

Finally, results show that there is a tradeoff between the thickness ratios of each one the elements and the performance of the transducer.

Acknowledgments

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