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Full Length Research Paper

Simulation of the crosstalk effect of a piezoelectric matrix array oscillating in the lateral mode

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The simulation of the crosstalk phenomenon which originated from the lateral vibration mode of a piezoelectric ceramic PZT (Lead Zirconate Titanate) in a matrix array is presented. This simulation was made using the Finite Element Method (FEM) in a 9 elements (3 × 3) piezoelectric matrix array, at a frequency of 8 MHz. Simulations showed the presence of crosstalk due to the lateral vibration mode. To validate the simulated results, an experimental 3 × 3 matrix array was constructed. This study presents some of the problems which came up in the construction of the matrix array transducers where crosstalk is an inherent problem. The lateral vibration mode has been little or not analyzed so far. Simulated and experimental results presented in this study showed that this vibration mode is one of the main factors in the generation of the crosstalk phenomenon.

Key words: Crosstalk, matrix array transducers, Lead Zirconate Titanate (PZT), Finite Element Method (FEM).

INTRODUCTION

The use of ultrasound and the associated ultrasonic transducers are an important diagnostic tool mainly in medical applications (Whittingham, 1997; Guess 1995). Nowadays, there are breakthroughs where miniaturization plays an important role in the performance of transducers used in diagnosis, since this process together with other factors (for example, the proximity between the elements or the geometry of the transducer) cause the phenomenon known as crosstalk.

In order to solve this problem, it is important to have measurements and models that are able to determine if this phenomenon affects the performance of the transducer which subsequently will affect the diagnosis or the measurements. In this study, simulated and experimental results are presented. Simulations were made using the Finite Element Method (FEM) (Frederick 1990). Simulated results showed the interaction between the elements of the array when they vibrate in the lateral mode generating the crosstalk effect.

Crosstalk

The crosstalk effect is an important factor in the performance of a transducer; this phenomenon is able to distort the radiation pattern, affect the directivity of the pattern, and also reduce the amplitude of the signal radiated from the transducer.

Crosstalk can be defined in a simple manner as an unwanted signal that interferes with the main signal or as disturbances in a transmission caused by interference from inductive signals or capacitive coupling of the elements which are part of the matrix array. Figure 1 shows the inductive mode and the capacitive coupling generated by the elements of a matrix array.

The crosstalk effect arises particularly in matrix arrays,

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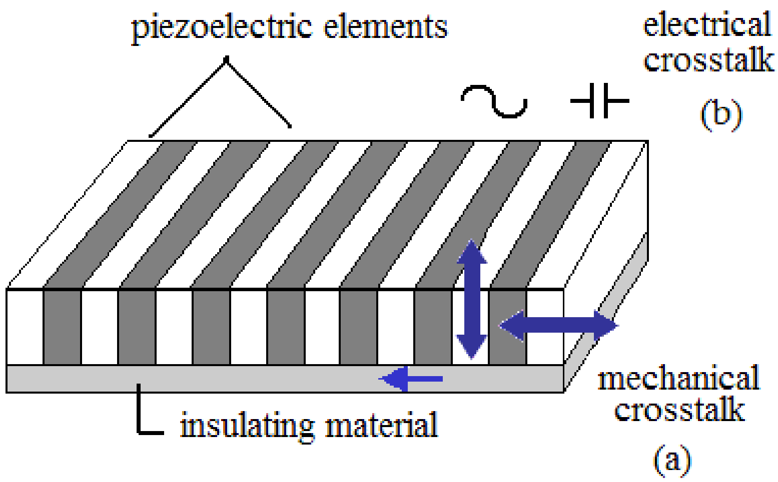


Figure 1. Forms of interaction between the elements of an array that contribute to the phenomenon of crosstalk.

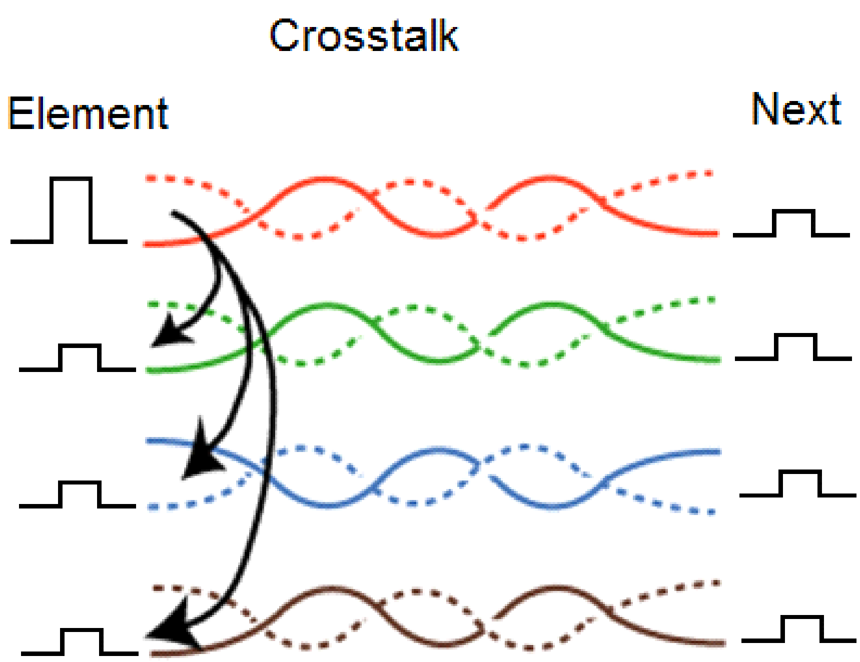


Figure 2. Interaction between the elements of a matrix array.

which main characteristic is the close proximity between the elements within the array. Crosstalk can be of electrical or mechanical nature (Kino and Désilets, 1979; Smith et al., 1979; Turnbull and Foster, 1992; Wojcik et al., 1996; Certon et al., 2001), or caused by other factors such as those mentioned by Kino and Baer (1983) and Lamberti et al. (1999).

The problem of crosstalk is obvious according to Berg and Ronnkliev (2006) and Wilm et al. (2004) particularly when the elements of the array are excited at a different phase. In this case, the lateral vibration mode generates the crosstalk phenomenon. This can be seen in Figure 2, where the elements of an array are excited at a different phase.

According to Bayram et al. (2006), the main mechanism of crosstalk are the modes of propagation in the interface, where the coupling energy between the elements of an ultrasonic array degrades the performance of the transducer in applications such as medical imaging, therapy or non-destructive testing

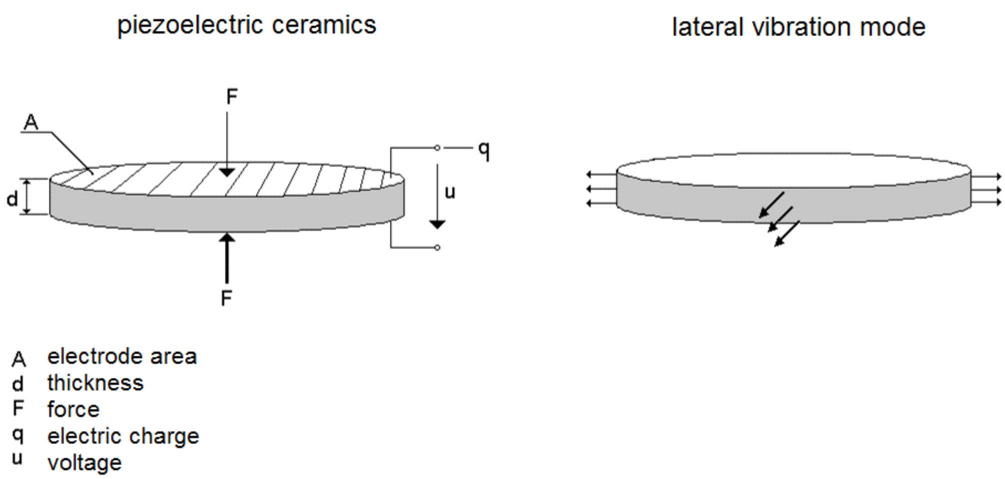


Figure 3. Physical characteristics of the piezoelectric ceramic, and lateral vibration mode of the ceramic.

Table 1. PIC255 piezoelectric properties.

Physical and dielectric properties		
Density	P (g/cm^3)	7.80
Curie temperature	Tc (°C)	250
Permittivity direction of polarization	ε_{33} (T/ε_0)	2400
Permittivity perpendicular to the polarity	ε_{11} (T/ε_0)	1980
Dielectric loss factor	Tan δ(10^{-3})	20
Electromechanical properties		
	κ_p	0.62
	κ_t	0.53
Coupling factor	K_{31}	0.38
	K_{33}	0.69
	K_{15}	-
	d_{31} (10^{-12} C/N)	-210
Piezoelectric constant load	d_{33} (10^{-12} C/N)	500
	d_{15} (10^{-12} C/N)	-
Piezoelectric constant voltage	g_{31} (10^{-3} V_m/N)	-11.5
	g_{33} (10^{-3} V_m/N)	22

(NDT). Figure 3 shows the lateral vibration mode of a piezoelectric ceramic.

MATERIALS AND METHODS

The physical properties of the piezoelectric ceramics used in the simulation are those of the PIC255 8 MHz commercial ceramics from PIceramics (PIceramicas Co, UK). This type of ceramics was used in the construction of the experimental matrix array since their central oscillation frequency value and geometry are typically used in the construction of ultrasonic matrix arrays for medical applications.

In the simulation process, COMSOL software was used with the aid of the Finite Element Method (FEM), the geometry and the physical properties of each element of the array were integrated to the model and finally the grid of the model was selected (at this point, the final accuracy of the simulation was selected). Finally, the design solution was obtained using the matrix arrays that were generated with the FEM. Table 1 shows the physical properties of the PIC255 ceramics used in the simulation (PIceramicas Co, UK).

The particularity in these simulations is that only the

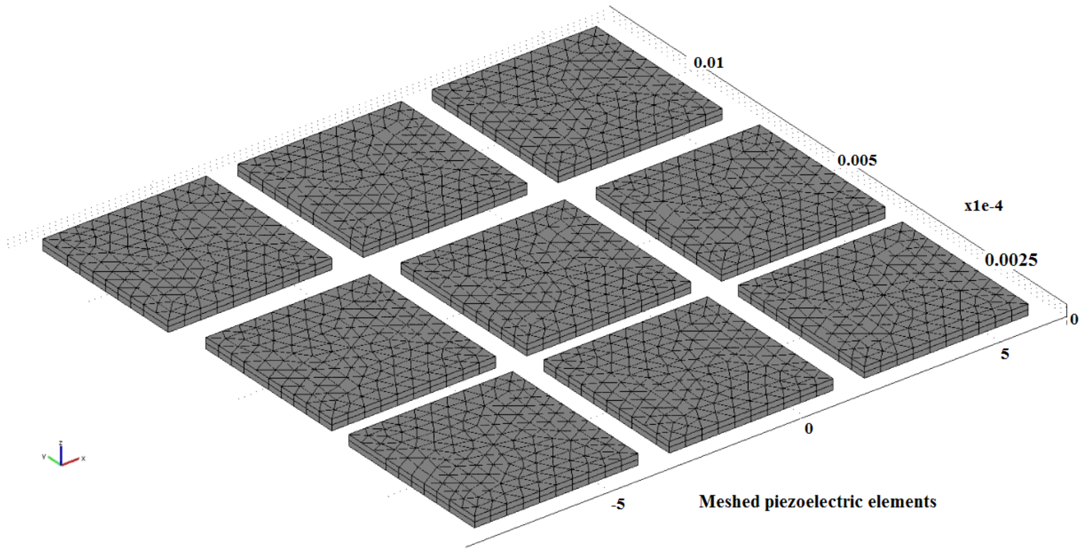


Figure 4. Meshing used in the simulation process. Each square represents a ceramic of the array.

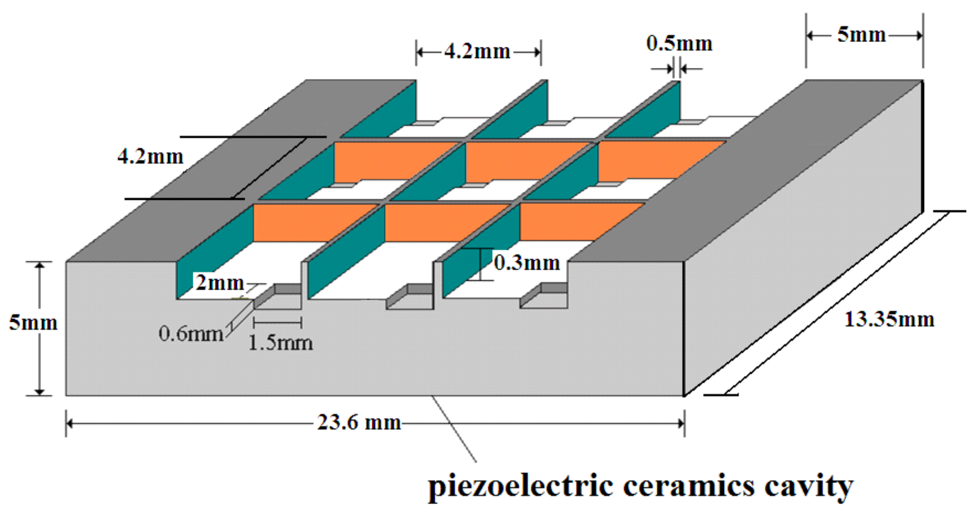


Figure 5. Diagram of the experimental setup.

lateral vibration mode of the piezoelectric elements in the array was obtained, it is worth mentioning that this vibration mode is one of the main factors in the generation of crosstalk and it has been little studied.

Figure 4 shows the mesh that was used in the simulations. This process is important because it allows the placing of nodes for a better resolution and a solution to the equation system; an optimal response of the simulated system is obtained. All simulations were performed using a Xeon Intel 2.2 GHz with 8-core (16 GB RAM and 400 GB hard disc) high performance computing cluster (Sánchez, 2014).

To carry out the experimental part, a 3 × 3 matrix array was constructed. The dimensions of this array are shown in Figure 5. The array has slots and these slots prevent the interference of the welding with the coupling of the piezoelectric ceramics. This procedure was implemented to avoid unwanted electrical contacts which might interfere in the measurement of the lateral vibration mode.

As mentioned previously, the array was constructed using PZT (PIC255) piezoelectric ceramics where each ceramic had two points of contact (electrodes), one on each side. Figure 6 shows a photograph of one of the ceramics used in the array.

Nine ceramics were used in the matrix array, only one

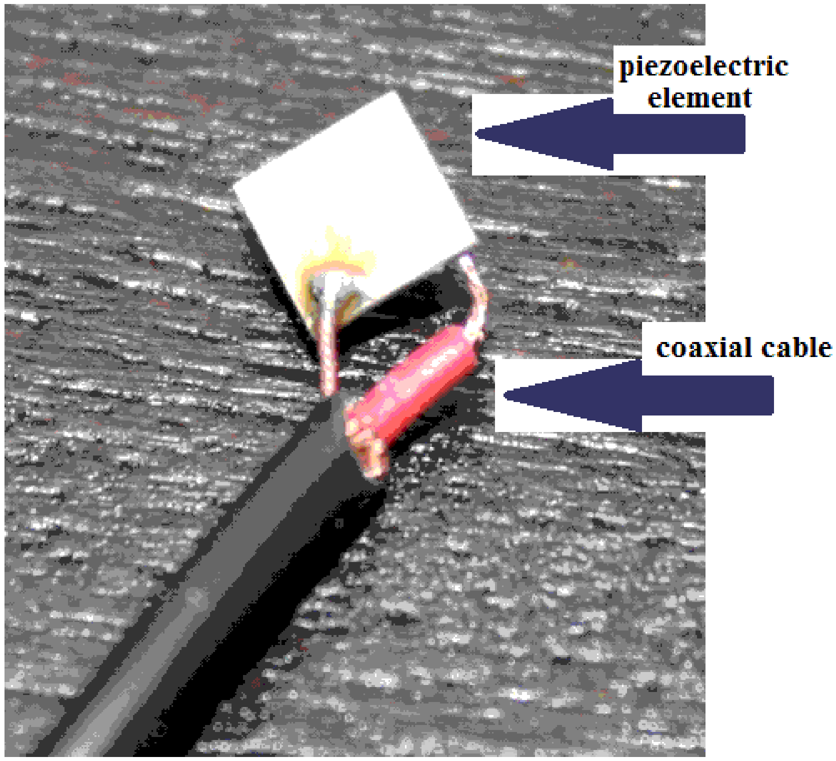


Figure 6. Piezoelectric ceramic used in the construction of the matrix array.

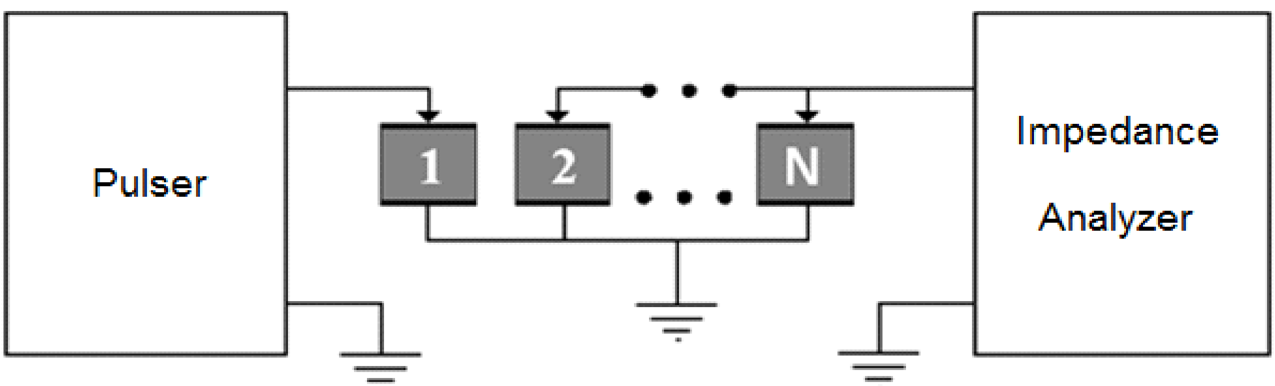


Figure 7. Diagram of the experimental setup.

ceramic was excited at the time and its interaction with the other ceramics was measured as indicated in the diagram of Figure 7 (Sánchez, 2003). Subsequently a different ceramic was excited until all experimental measurements were made in order to be compared with the simulated results.

RESULTS

The simulated results were compared with the experimental results obtained with an impedance analyzer (Impedance Analyzer HP 4194-A). The radiation fields emitted by the piezoelectric ceramics were measured using the peak to peak voltage values in parallel and perpendicular planes to the face of the ceramics, over a rectangular area and at an axial distance of 200 mm. Measurements were made using a calibrated hydrophone (1 mm in diameter) immersed in a water tank (SEA System CINVESTAV, México); a TR 1000 Matec board was used to excite the ceramics.

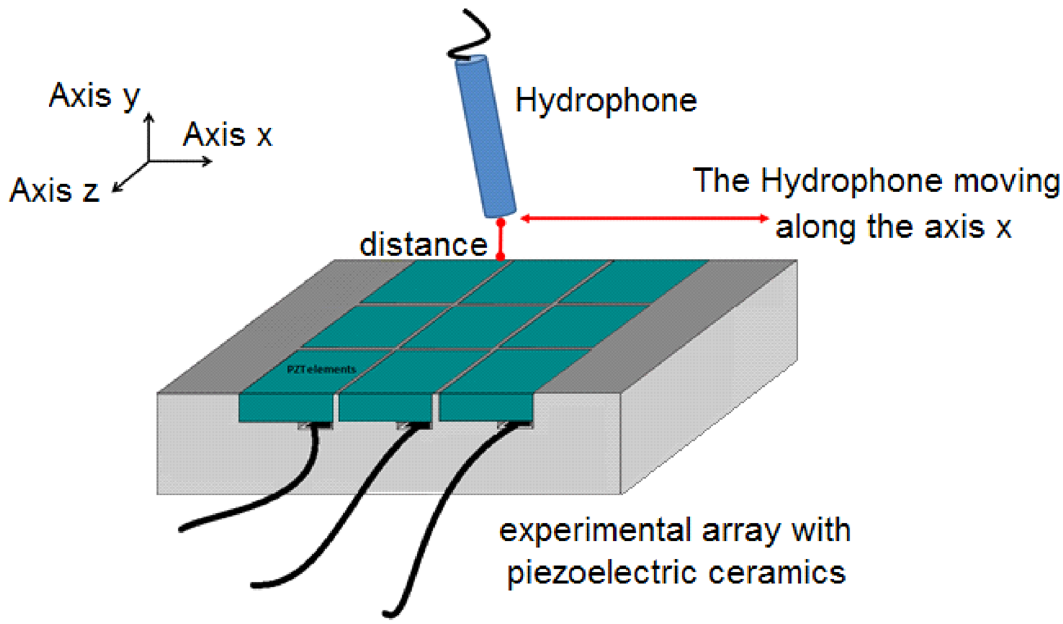


Figure 8. Experimental setup to measure the radiation field in the matrix array.

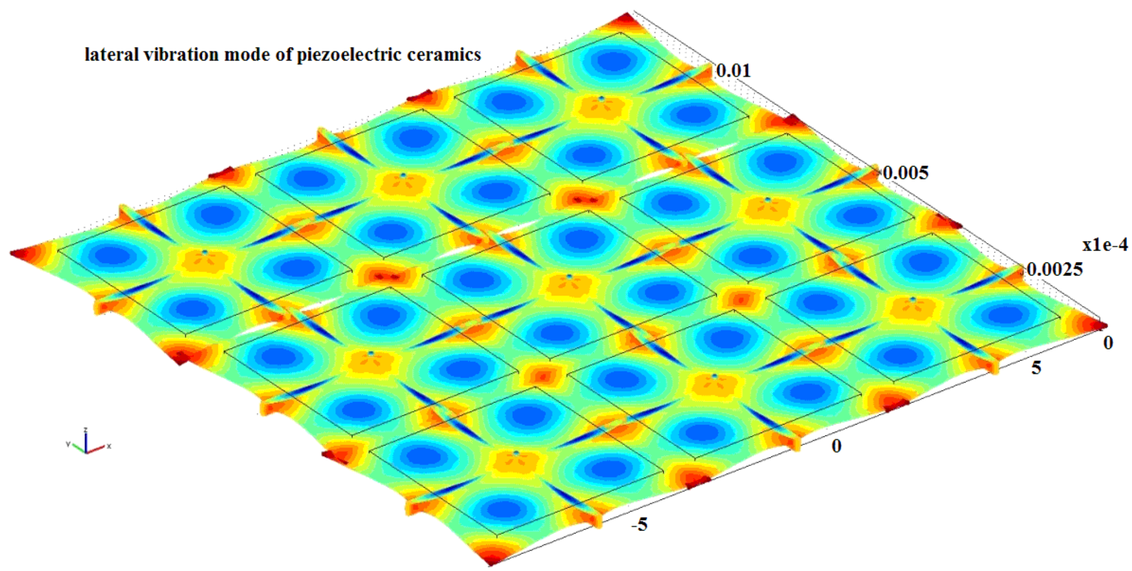


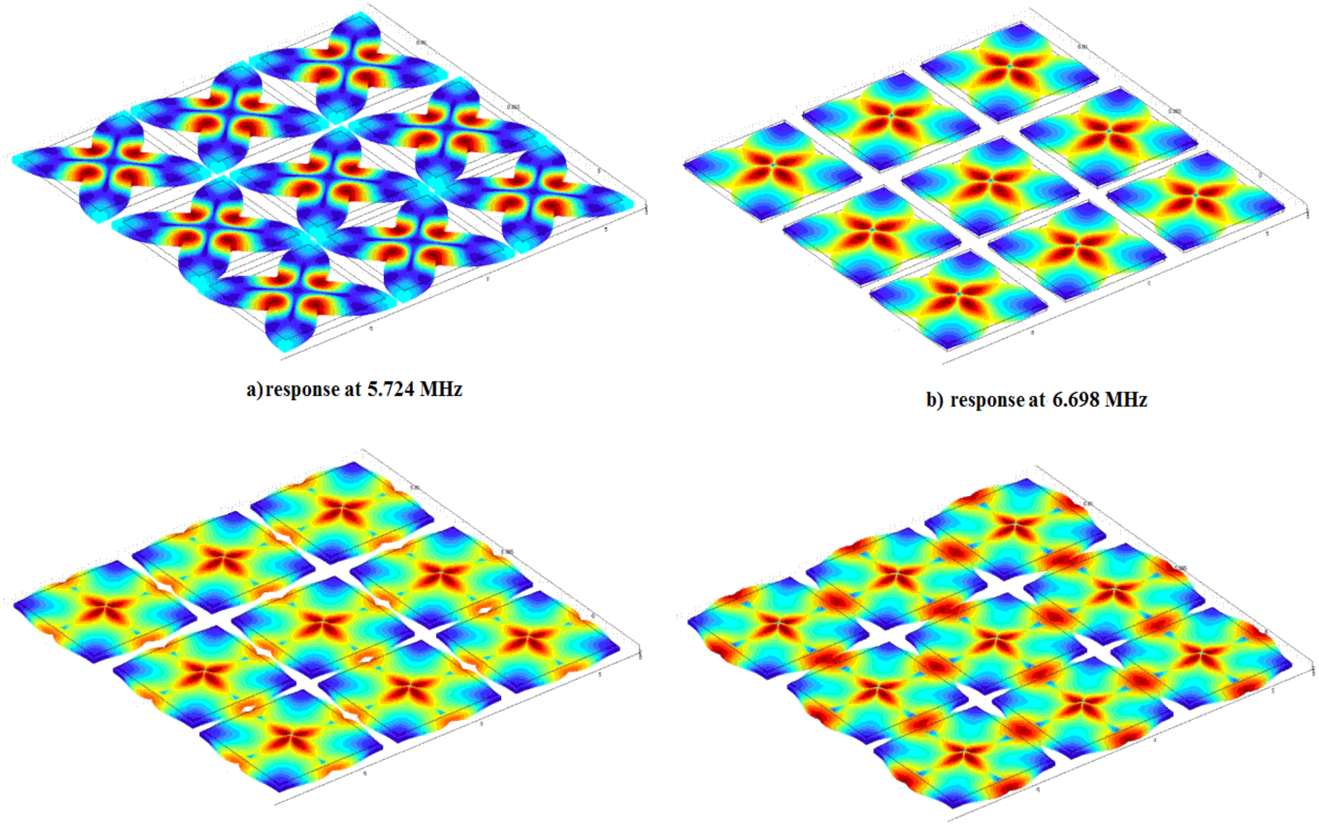
Figure 9. Response of the lateral vibration mode of piezoelectric ceramics in a 3 × 3 array.

Figure 8 shows the experimental set up to measure the radiation field in the matrix array.

Simulated results

Figure 9 shows the simulation of a 3 × 3 piezoelectric ultrasonic matrix array where the presence of the crosstalk phenomenon due to the lateral vibration mode of piezoelectric elements is clearly seen; it is also possible to appreciate the interaction between the elements of the array (Sánchez, 2014).

In this simulation, the main interest was to find out the presence of the crosstalk effect and the impact of the lateral vibration mode in the array; the literature available on this type of vibration mode is very little. Therefore, in the simulation, non acoustical or mechanical insulation is taken into account. This consideration is important since it shows the phenomenon in all its magnitude, making it



a) response at 5.724 MHz

b) response at 6.698 MHz

c) response at 7.462 MHz

d) response at 7.809 MHz

Figure 10. Response of the simulation of a 3 × 3 matrix array at different oscillation frequency.

clear that this form of vibration causes spurious signals which may be eliminated or minimized with the help of insulation materials or making adjustments in the electronics associated to the array.

Figure 9 shows that the interaction zones between the elements of the array are those where there is more proximity. This is important since previous works (Shiwei and Hossack, 2007; Vendrame et al., 2006; Saxena et al., 2011), have shown that the proximity between the elements of a matrix is an important factor in the generation of the crosstalk phenomenon. Once the presence of the crosstalk effect was detected in the simulation, a second step was to find out if at different oscillation frequencies, crosstalk was present or just at the natural oscillation frequency.

Figure 10 shows the crosstalk effect at different oscillation frequencies where the presence of the phenomenon is clearly seen along the side of the piezoelectric ceramics with higher intensities as we get closer to the natural oscillation frequency. Figure 10 also shows that at different oscillation frequencies, the crosstalk phenomenon is present with greater or lesser intensity; therefore, it is possible to conclude that the lateral vibration of the piezoelectric discs is affected since neither the distribution nor the characteristics of the other elements in the array are not modified.

Experimental results

Only one ceramic was excited at the time to observe its effect on the other ceramics of the array, as was already mentioned in the study's methodology. Figure 11 shows the experimental array.

Figure 12 shows the plot of the transducer impedance for both the constructed and simulated cases, a lower impedance value is observed in the experimental array, but nevertheless, the similarity in the behavior of signals indicates a reliable response in both cases. The natural oscillation frequency of the piezoelectric elements matches with the thickness.

Figure 13 shows the impedance phase values for both cases. In terms of phase, it is observed that there is a frequency shift, which may be caused by the crosstalk phenomenon, and however, it is necessary to carry out more detailed experiments in order to obtain more reliable results.

CONCLUSIONS

Simulations of a piezoelectric matrix array using the Finite Element Method (FEM) were presented. Such

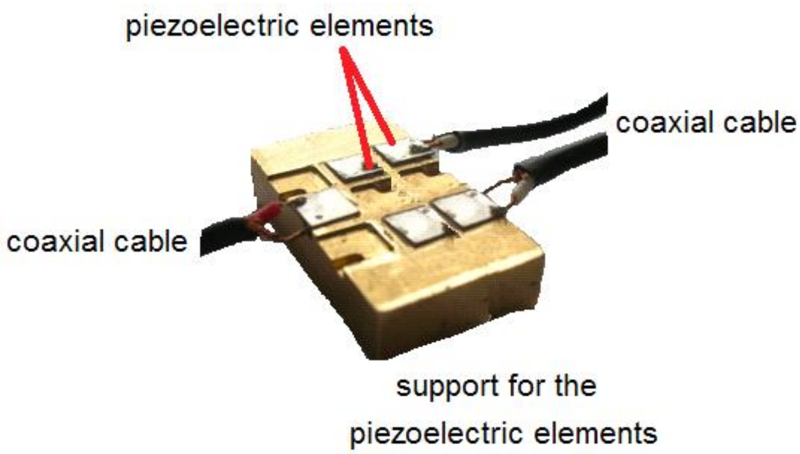


Figure 11. A 3 × 3 experimental matrix array.

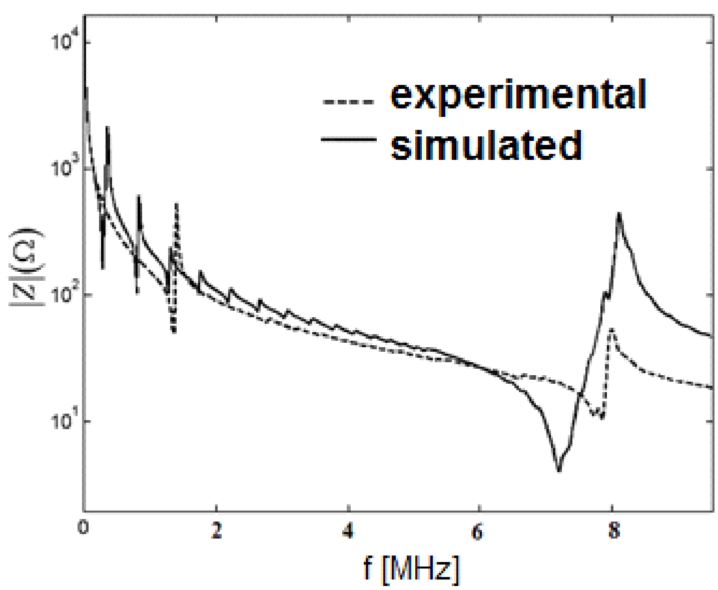


Figure 12. Module of the electrical impedance of both simulated and experimental arrays.

simulations showed the existence of the crosstalk phenomenon when the array vibrates in its lateral mode.

Simulations showed that crosstalk is magnified in the outer perimeter of the piezoelectric ceramics within the array where there is a greater interaction between the elements generating interference and modifying the performance of the array. This modification in the performance of the transducer may be due to distortions in the beam, attenuation or parasitic interference, including the formation of lamb waves.

Results showed that there is an adequate concordance between simulations and experimental measurements, and the variations found may be due to the crosstalk effect. It is necessary to carry out a deeper experimental work to verify and affirm this assertion. However, the simulated and experimental results obtained in this work are only a basis for establishing a better methodology to quantify the crosstalk effect which originated in a piezoelectric matrix array.

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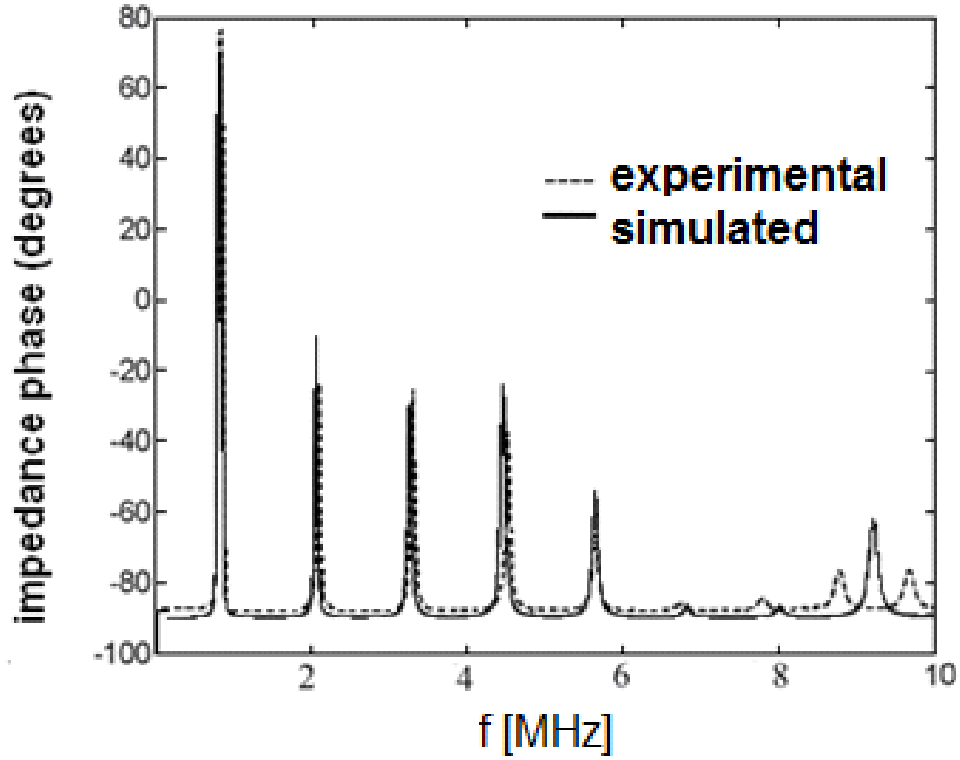

Figure 13. Simulated versus experimental impedance phase values.

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