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Design and Construction of a Bolt-Clamped Langevin Transducer

E. Moreno[1], P. Acevedo[2], M. Fuentes[2], A. Sotomayor[2], L. Borroto[1], M. E. Villafuerte[3], L. Leija[4],
[1]Institute of Cybernetics, Mathematics and Physics, CITMA, Havana, Cuba
[2]Department of Computational Systems Engineering and Automation, IIMAS-UNAM, Mexico D.F., Mexico
[3]Institute of Research in Materials, UNAM, Mexico D.F., Mexico
[4]Department of Bioelectronics Electrical Engineering, CINVESTAV-IPN, Mexico D.F., Mexico
Phone (537) 8320771 Fax (537) 833 3373 E-mail: moreno@icmf.inf.cu
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Abstract — **The design and construction of a bolt-clamped Langevin type transducer is presented in conjunction with its 3D analysis using Finite Element Analysis (FEA). Results show a good agreement between simulation using FEA and the mechanical adjustment of the transducer to tuned it at the desired operation frequency.**

Keywords — **Finite element analysis, Langevin transducer, PZT-4 ceramic**

I. INTRODUCTION

Langevin type transducers are used to generate high power ultrasonic radiation [1], reaching up to kilowatts, these type of transducers are used as industrial cleaners, underwater sonar and cell blasters to mention some examples. The structure of this kind of transducer is shown in Fig. 1, in which two PZT-4 piezoceramics sandwiched between two metallic pieces (one made from steel and the other from aluminum). The aluminum piece has a conic shape since this is the transducer's output. PZT-4 considered as a hard ceramic it was used in the design and construction of this transducer due to its low mechanical and dielectric losses (Qm = 400 and $tan\delta$=0.001). These losses are much less than for PZT-5 which is used for echo-pulse applications.

The whole structure of the transducer is clamped by a bolt which gives a mechanical bias, given by the clamp strength. Therefore the system will resonate as a response of the whole structure and it will depend on the bias given by the bolt. In this way it is possible to get high power since the piezoelectric elements are in the middle of the piece very close to the vibrating node of the working mode. This implies that the transducer will not have long displacements which could produce its braking. Then the long displacements will be supported by the steel and aluminum, these have a greater Qm than piezoceramics.

In the design of these kind of transducers it is advisable to know a priori the position of the nodes of the thickness mode as well as the electrical impedance. For many years simulation programs based on equivalent circuits such as Mason, Redwood and KLM [3,4] have been used , these assume an one-dimensional model that takes into account a laterally clamped piezoelement, this assumption does not apply to power transducers with larger height than diameter like in the Langevin type transducers. Then it is the objective of this work to carry out an analysis using finite element analysis that allows us to work in a three-dimensional way. Additionally, experimental results obtained using the constructed transducer are given.

II. METHODOLOGY

1) *Design and construction*: A power Langevin type transducer was designed and constructed using a PZT-4 ceramic and two metallic elements one of steel and one of aluminum. Using the ANSYS software tool the basic characteristics such as dielectric, mechanical and piezoelectric constants were introduced, also the mechanical constants for the metal pieces were introduced. Losses values were introduced according to the mechanical quality factor (Qm) reported [1,5]. Geometric dimensions shown in Fig. 1 were introduced to the analysis program. Fig. 2 shows this simulation. Fig. 3 shows another simulation, this time the electrodes and the mesh process were included, having all this information the calculus of solutions for the vibrating mode and the electrical impedance were achieved.

Once the results of the diverse simulations were obtained the transducer was constructed and tested. Electrical data was obtained using an impedance bridge (Agilent 4194). Radiation performance tests were carried out using a commercial signal generator and a power amplifier, these devices were tuned at the minimal impedance point in the fundamental thickness mode.

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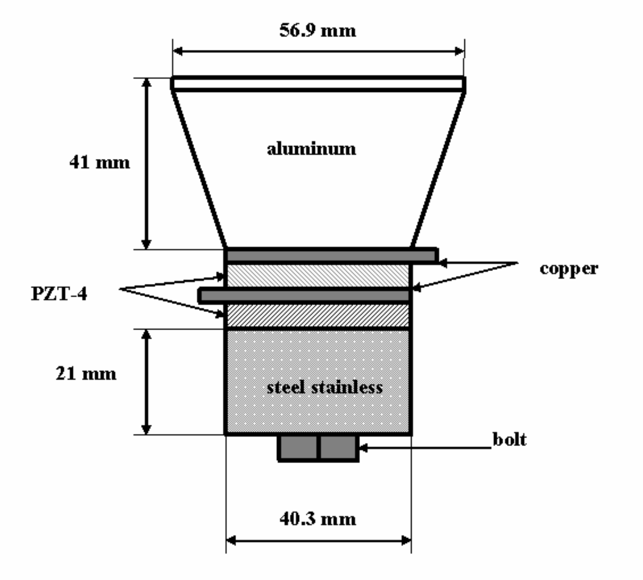

Fig. 1. Diagram of the Langevin type transducer.

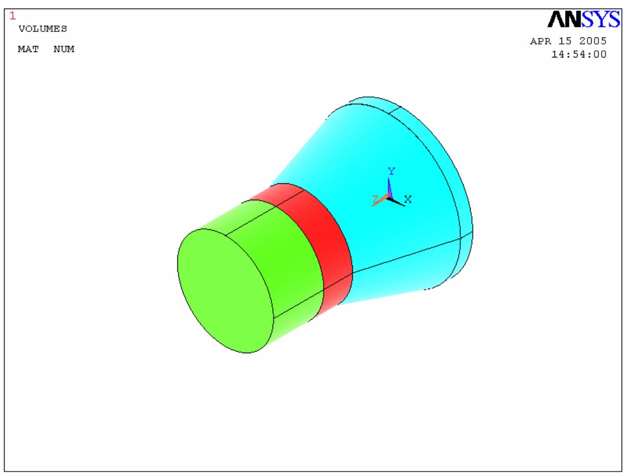

Fig. 2. Transducer simulation using FEA.

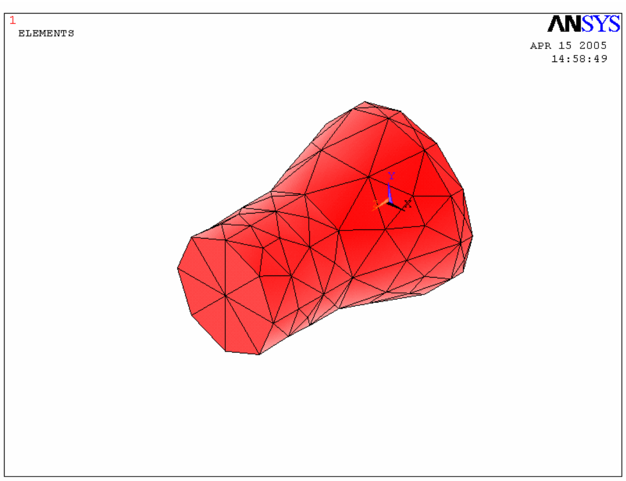

Fig. 3. Mesh representation applied to transducer simulation.

III. Results

Fig. 4 shows the simulated results, these results identify a thickness mode in a frequency value around 21 KHz. Fig. 5 shows the experimental results where the impedance module has been included in conjunction with the phase. It is observed a good agreement between simulated and experimental values with some discrepancies at high frequency around 50 KHz.

The small modes observed in the experiment (right side of Fig. 5) are probably due to fact that neither the bolt nor the copper plate which are part of the transducer were neglected. Also a frequency shift of the thickness mode (23 KHz) was observed, this was probably due to the mechanical bias which was not taken into account in the simulation. It is possible to say that the lowest frequency mode (23 KHz) corresponds to the thickness mode since this was corroborated using the FEA simulation which showed animated figures of the mode. In the simulated animation at 23 KHz it was observed the expansion and contraction of the whole system in a symmetrical way with a nodal area at the geometric center. The other modes correspond to other forms with diverse deformations. It is fundamental to find the thickness mode in power applications since the transducer works in a piston like form, giving as a result that the highest radiation output is obtained.

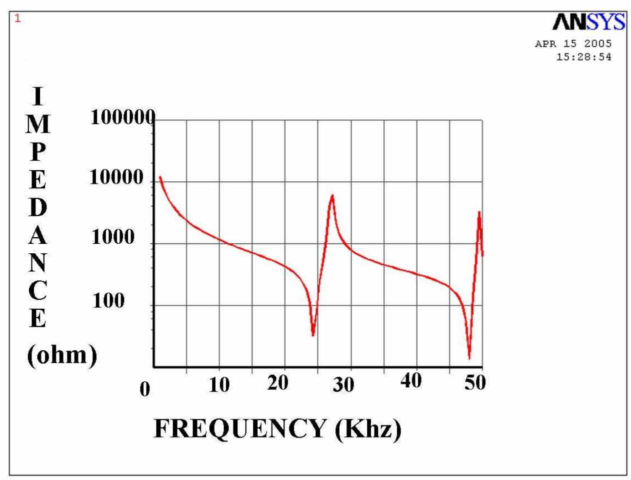

Fig. 4. Impedance plot obtained using FEA

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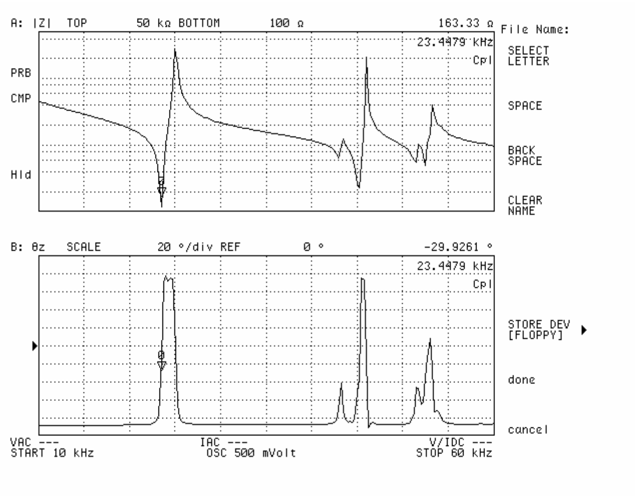

Fig. 5. Experimental impedance and phase plots

To analyse the influence of the mechanical bias a special experiment was carried out to compare this parameter to the electric response. Fig. 6 shows the values of the electrical impedance module for different mechanical bias, these mechanical bias values were not determined with accuracy at the moment of the experiment but it is well known that these values are directly proportional to the torque caused by the bolt in four steps. It was observed a strong dependence of the resonance values to the adjustment force which increased from bias 1 to bias 4 producing a shift to the right of the resonance values. Also the *Qm* of the transducer was increased, this increment produces a decrease of the impedance module when the resonance is minimal (and the anti-resonance is maximal) [1]. All this was corroborated with the increasing of radiation emission in a special container constructed specially for this experiment. The transducer was attached to this container, using a power amplifier with an output of 300 watts the transducer was excited with a sinusoidal waveform.

Comparing the simulated results with the experimental results it is possible to see that for the mechanical bias 1 these results are in good agreement and as the mechanical bias increases there is a shift between the simulated and experimental values, this is due to the fact that the mechanical bias value was not taken into account in the simulation, this value will be considered in future simulations, in order to achieve this, it will be necessary to adjust the mechanical loads. Although it is not graphically presented it was observed that the node of the sensor was in the border zone between the PZT-4 ceramic and the aluminium piece, this condition shows a good performance of the system. This condition is quite important since assures that the transducer will not be broken. It is important to mention that in the simulation only one PZT-4 ceramic

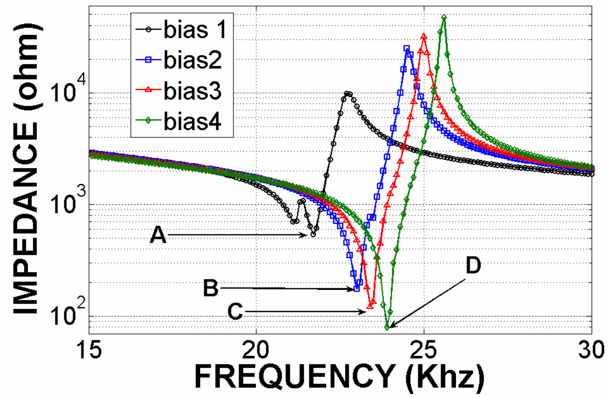

Fig. 6. Experimental adjustment, using the mechanical bias (from A to D), of the designed transducer optimal working frequency. A=Bias 1, B=Bias 2, C=Bias 3, D=Bias 4.

was introduced equivalent in thickness to the two ceramics which the actual transducer was constructed, in the construction of the transducer two ceramics were used instead of one since this was a simpler solution to the short circuit problem due to the bolt.

IV. Conclusion

A bolt-clamped Langevin type transducer was designed and constructed using a finite element analysis. The good agreement between the simulated and experimental results shows that the design procedure provides an optimal tool to construct a power transducer. Observing these results it is obvious that the mechanical bias value must be taken into account. It was also seen that losses due to heating and frequency shift must be taken into account for future designs. We think that all these aspects may be analyse at the simulation stage.

References

[1] J. A. Gallego, "New advances in the generation of directional sonic and ultrasonic radiation," Ultrasonic International Conf. Proc. pp 295-300, 1983.

[2] D. A Belincourt, D. R. Curran, H. Jaffe. "Piezoelectric and piezomagnetic materials and their function in transducer," in Physical Acoustics, Principles and Methods, Ed. W. P. Mason. Vol 1-Part A, Academic Press, 1964 ch3 , pp170-270

[3] G. S. Kino, *Acoustic waves: Devices, imaging and analog signal processing*. 1987, Prentice-Hall, INC.

[4] M. Castillo, P. Acevedo, E. Moreno, "KLM model for lossy piezoelectric transducer," Ultrasonics, vol. 41, pp. 671-679, 2003.

[5] W. P. Mason, *Physical acoustics and the properties of solids*. Nostrand Company, INC. 1958.