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Material parameters in design of a thickness and radial mode vibrating piezoelectric transducer. Measurements and finite element modelling

Patricia Ordóñez Cebrián[1]*, Víctor Espinosa Roselló[1], Per Lunde[2], Vicente Puig-Pons[1], Isabel Pérez Arjona[1], Manuel Bou Cabo[1]

[1]Instituto de Investigación para la Gestión integrada de zonas Costeras (IGIC). Universitat Politècnica de València-Campus de Gandía, C/Paranimf nº1, 46730 Grao de Gandía, Valencia, España.

[2] Department of Physics and Technology. University of Bergen. 7800, 5020 Bergen, Norway.

*E-mail: patorceb@epsg.upv.es

Abstract

In this communication are presented several studies, related to material parameters that take a relevant role in the design and development of underwater piezoelectric transducers. The materials considered can be splitted in two groups, porous and linear elastic materials in one hand, and on the other hand active piezoelectric element. Considering the first group, compressional sound speed and density have been estimated at the system resonant frequency. Transversal sound speed and attenuation estimation have been obtained by comparing experimental measurements with finite element simulations. Referring to the second group material, piezoelectric ceramic material data have been fitted applying finite element method simulations, with the aim to obtain improved agreement with measurements. Two finite element models have been used, compared, and validated against measurements. These are the COMSOL Multiphysics software ®, and the FEMP software. FEMP is free software developed by Jan Kocbach, as part of his PhD thesis at the University of Bergen in 2000.

Keywords: Materials parameters, piezoelectric transducers, FEM, simulation.

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1 Introduction

In relation with transducer design various components are involved each one providing a particular functionality to the final transducer behavior: Active Element, matching layer, backing layer and housing [1] are consider. In order to decide which kind of material is the best choice for each part and also to simulate in a proper way their acoustic behavior, measurements have been performed for the compressional sound speed at the resonant frequency of the system.

The process set up in terms of modelling have been developed at the University of Bergen (UiB) since September to December.

The main goals of these studies can be summarized as follows:

- Characterization of acoustic properties of different materials

- Calculation of different properties of materials like transversal speed and attenuation of sound comparing numerical models and electrical measurements

2 Materials and methods

2.1 Materials Description

Four materials, have been electrically and acoustically characterized. Tables 1, and 2 give an overview of them, differentiating by materials for matching and backing, and ceramics [2, 3].

Material	Supplier	Type
Matching material (EL217C) 	ROBNORRESINS	Polyurethane resin
backing (CORK TD1120) 	Amorim T&D	Cork composites

Table 1 – Matching and Backing materials investigated.

Manufacturer	Description	Dimensions (mm)	Resonant Frequency (kHz)
Meggit 	PZ37	38X12.25	120kHz
PI ceramics 	PIC255	38X15.06	125kHz

Table 2 – The piezoelectric ceramics investigated.

2.2 Contact Method

Contact method [1] is used to measure compressional sound speed in the different test samples. In Figure 1 the experimental setup and the equipment used are shown.

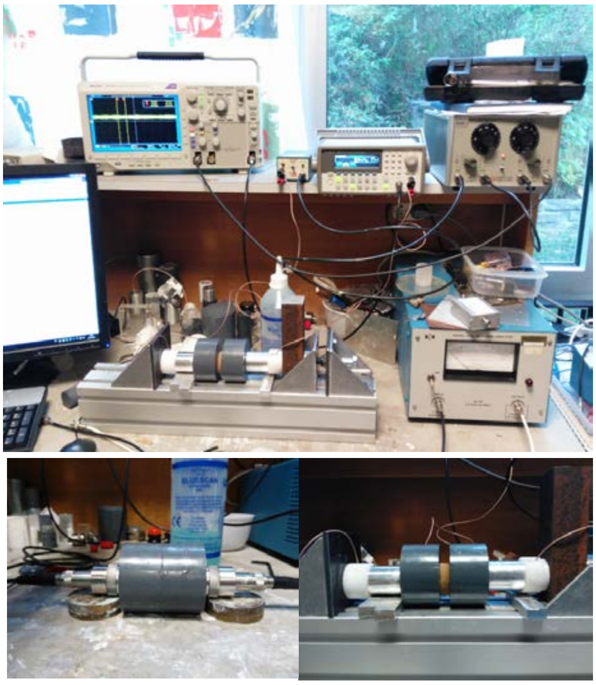


Figure 1- Contact method experimental set-up

- Transducers : Panametrics V304 0.5MHz/1" 654055
- Oscilloscope: Tecktronic DPO3012
- Function generator: HP 33120A
- PVC buffer
- Samples
- Ultrasonic pre-amplifier

Schema of measurements: A 10 cycles burst of 125 kHz is transmitted. The voltage used in the transmission is different depending on test sample attenuation. This varied from 100mVpp to 2Vpp. A first measurement is performed transmitting the signal through the PVC buffer. The signal, at the receiving transducer is recorded on the oscilloscope. Then, a second measurement is made, repeating the process but this time introducing the sample under test between PVC buffers. Delay time differences between the two received signals and the thicknesses of the samples gave the compressional sound speed values.

3 Results

The values obtained for each material are shown in table 3. Density measurements is also added.

Material	EL217C	CORK TD1120	PZ37	PIC255
Densidad (kg/m3)	1100	850	6470	7800
c_L(m/s)	1470	580	3460	4485
Z(Mrayls)	1.61	0.489	22	35

Table 3: Materials acoustic properties

3.1 Materials validation

Once compressional sound speed is obtained, values for all test samples are introduced in two Finite Element programs (FEMP and COMSOL MULTIPHYSICS). Comparison between FE simulations and electrical measurements have been done to fit the data and to obtain transversal sound speed and attenuation [4, 5, 6]. Results are shown in the Fig.2, 3, 4 y 5.

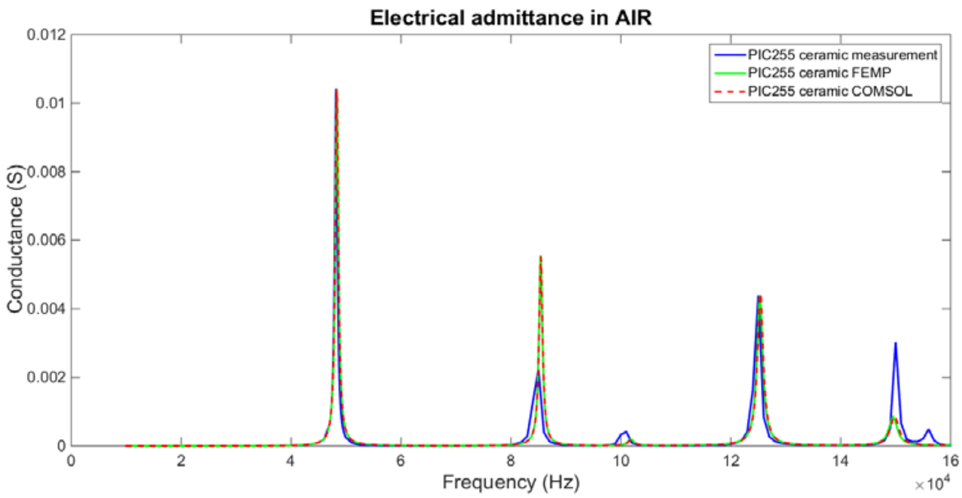


Figure 2– Admittance comparison between simulation and measurement. PIC255 piezoelectric ceramic

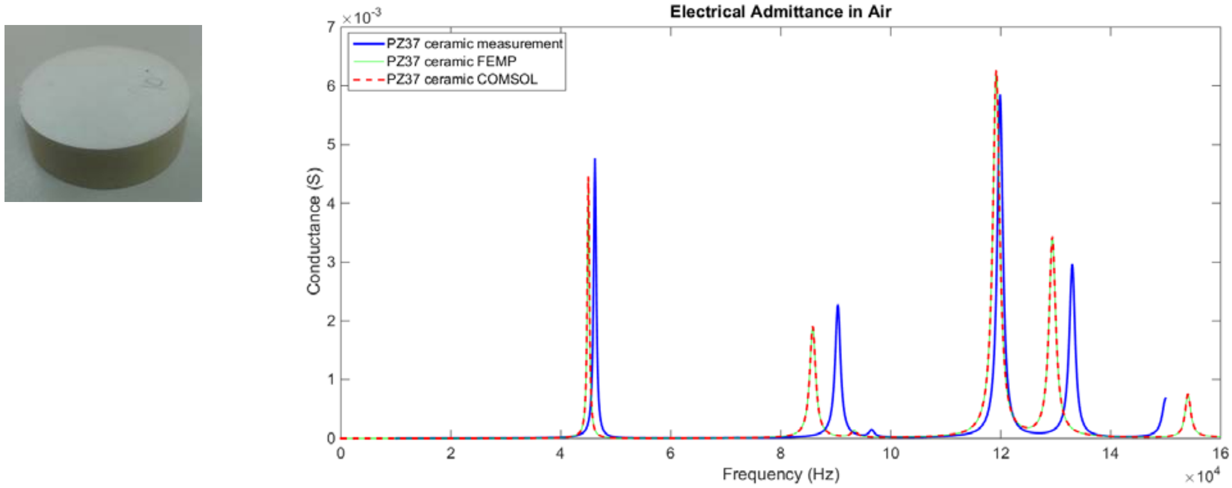


Figure 3– Admittance comparison between simulation and measurement. PZ37 piezoelectric ceramic

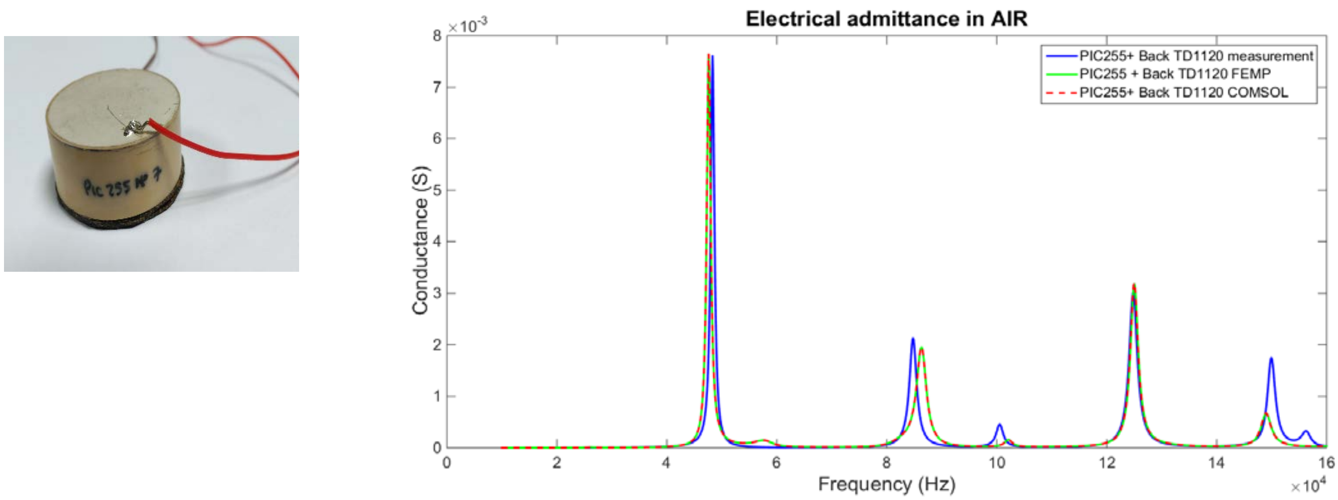
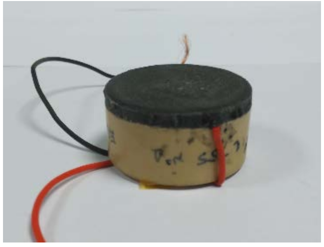


Figure 4– Admittance comparison between simulation and measurement. PIC255 piezoelectric ceramic + 2.5 mm of TD1220 backing material



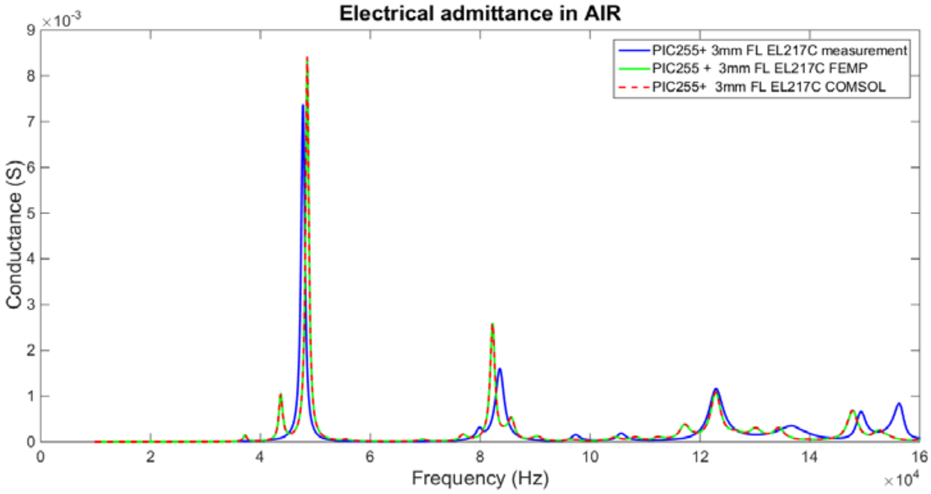


Figure 5– Admittance comparison between simulation and measurement. PIC255 piezoelectric ceramic + 3mm EL217C resin matching material

Final data for matching and backing material are collected in table 4. Piezoelectric coefficients for both ceramics under test are shown in table 5.

MATERIAL	EL217C	CORK TD1120
Densidad(kg/m3)	1100	850
c_L (m/s)	1460 (125K)	576
c_S (m/s)	485 (125K)	265
Z (Mrayls)	1.61	0.489
Q	45.61	14.5

Table 4: Acoustic material properties adjusted

PIC255	PI ceramics	Adjusted (FE simulation)
$c^E{}_{11}$ [10^{11}N/m^2]	1.23	1.229(1+i/58.6)
$c^E{}_{12}$ [10^{10}N/m^2]	2.226	7.66089(1+i/58.6)
$c^E{}_{13}$ [10^{10}N/m^2]	7.67	7.1178 (1+i/80)
$c^E{}_{33}$ [10^{10}N/m^2]	9.71	9.7056 (1+i/145)
$c^E{}_{44}$ [10^{10}N/m^2]	7.025	2.35 (1+i/120)
e_{31} [C/m^2]	-7.15	-7.8417
e_{33} [C/m^2]	13.70	13.5583
e_{15} [C/m^2]	11.90	11.244
ε_{11}[10^{-9}F/m]	930	930(1-i/50)
ε_{33}[10^{-9}F/m]	857	857(1-i/50)
ρ [kg/m^3]	7800	7800
Q_M	80	Not used
Tanδ	0.020	Not used

PZ37	Ferroperm	Adjusted (FE simulation)
$c^E{}_{11}$ [10^{10}N/m^2]	7.23	7.23(1+i/187)
$c^E{}_{12}$ [10^{10}N/m^2]	4.17	4.17(1+i/187)
$c^E{}_{13}$ [10^{10}N/m^2]	3.34	3.34(1+i/127)
$c^E{}_{33}$ [10^{10}N/m^2]	4.63	4.55(1+i/67)
$c^E{}_{44}$ [10^{10}N/m^2]	1.53	2.20(1+i/187)
e_{31} [C/m^2]	1.11	1.11
e_{33} [C/m^2]	11	11
e_{15} [C/m^2]		9
ε_{11}[10^{-9}F/m]		889(1-i/67)
ε_{33}[10^{-9}F/m]	689	689(1-i/67)
ρ [kg/m^3]	6470	6470
Q_M	127	Not used
Tanδ	0,015	Not used

Table 5: Material data for PIC255 and PZ37 respectively. Material data from the manufacturer and adjusted from FE simulations and electrical measurement

4 Conclusions

The studies presented in this communication reveal the possibility of using numerical simulations applying FEM method to obtain mechanical properties of materials attached to a piezoelectric ceramic. Direct measurements of longitudinal velocity and density of materials can be considered together with results of numerical simulations of a piezoelectric ceramic plus different attached materials, acting like a backing and matching layers, to obtain indirectly e.g the transversal velocity of materials by comparison between experimental and simulated data.

In addition FEMP code has been tested as a tool to simulate a complete ultrasonic transducer including matching layer and backing enabling the possibility to full design transducers in a proper way

5 Future work

Next step is to simulate full transducer and its behavior in water. Several models will be done to investigate the behaviour in different stages of the transducer design
A complete transducer simulation tool will be designed using a finite element method code developed at the University of Bergen and validated with COMSOL Multiphysics. Experimental measurements based in these materials will be compared with simulations and will set the basis for single or bi-frequency operation underwater piezoelectric transducers.

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