Study & Modeling of 'Acoustic Matching Layers' for Ultrasound Imaging probes through pulse-echo FEM Simulation

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Introduction: Ultrasound Imaging probes are specific devices that require a very detailed design (1,3) of acoustic impedance match for the stack of layers that form the probe head. This calls for a translation of acoustic properties of each material into elastic ones, that are not easily measurable but are needed for the development of the best FEM. A Pulse-echo complete FEM for the probe is proposed here, along with its optimization through comparison with measurements. The result is a probe design procedure that allows to use acoustic measurement results for matching layers into an Acoustic-Piezoelectric interaction FEM, with intermediate conversion of material data from acoustic to elastic.

Figure 1. Acoustic impedance ('Z') matching

Design & Computational Methods: The acoustic impedance, measured in Rayls, have to be matched similarly to an electric circuit (2), from a high impedance power source (pzt piezomaterial) to a low impedance load (biological medium). Thus the materials in between need to be designed and characterized in terms of their acoustic properties, that are sound speed, density and acoustic impedance. On the other hand, when developing the Acoustic / Structure (piezoelectric) FEM, the stack of matarials should be part of the Elastic domain to get the best results from the model. The equations that relate sound speeds and elastic properties are (4) :

$$\sigma = \frac{1-2(v_s/v_l)^2}{2-2(v_s/v_l)^2} \quad ; \quad E = \frac{\rho v_l^2(1+\sigma)(1-2\sigma)}{1-\sigma}$$

with: σ = Poisson ratio , E = Young modulus

v_s = Shear velocity , v_l = Long. velocity , ρ = density

Both Longitudinal and Shear velocities were measured for all matching layer materials and their elastic properties were calculated with the equations above. Finally, a Pulse-echo equivalent FEM was developed, in order to simulate the probe performances

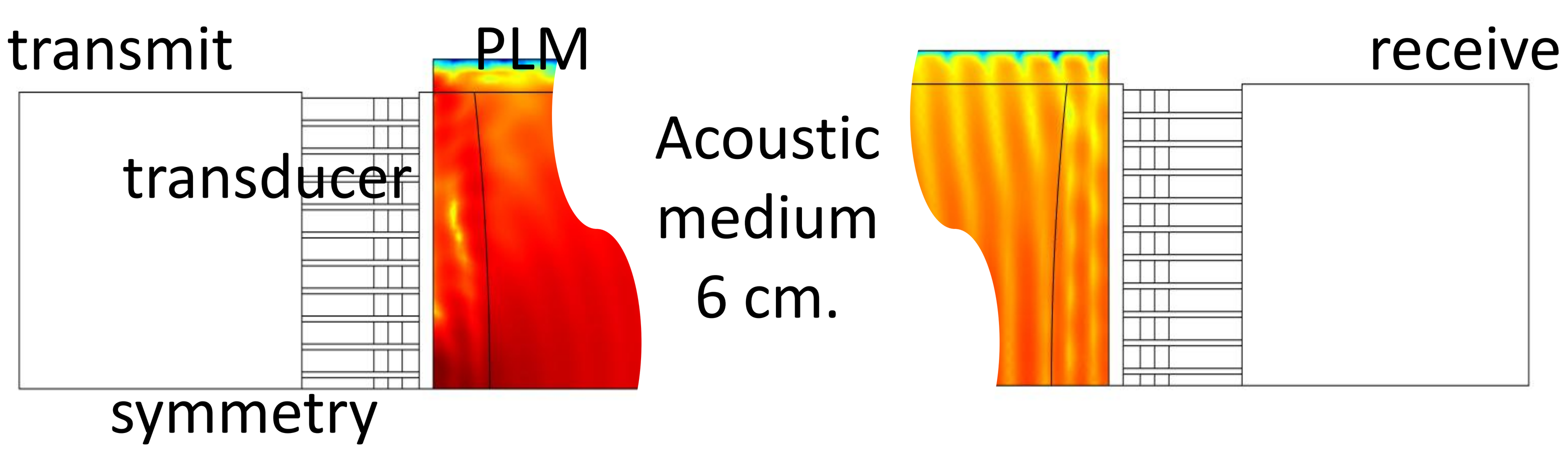

Figure 2. Pulse-echo equivalent FEM : pressure field

Results: The results of calculations for the material parameters are :

	Density	Long.vel.	Shear vel.	Acoust.Imp.	Poisson ratio	Young mod.
	kg/m3	m/s	m/s	Mega Rayls		Pa
1st Match.Layer	8500	1700	850	14	0.33	1.6E+10
2nd Match.Layer	4460	1750	875	8	0.33	9.1E+09
3rd Match.Layer	1130	2650	1325	3	0.33	5.3E+09
4th Match.Layer	1150	1820	364	2	0.48	4.5E+08

Table 1. Matching layers properties

And the comparison of FEM simulation results with measurements of probe pulse-echo performances shows a very good agreement :

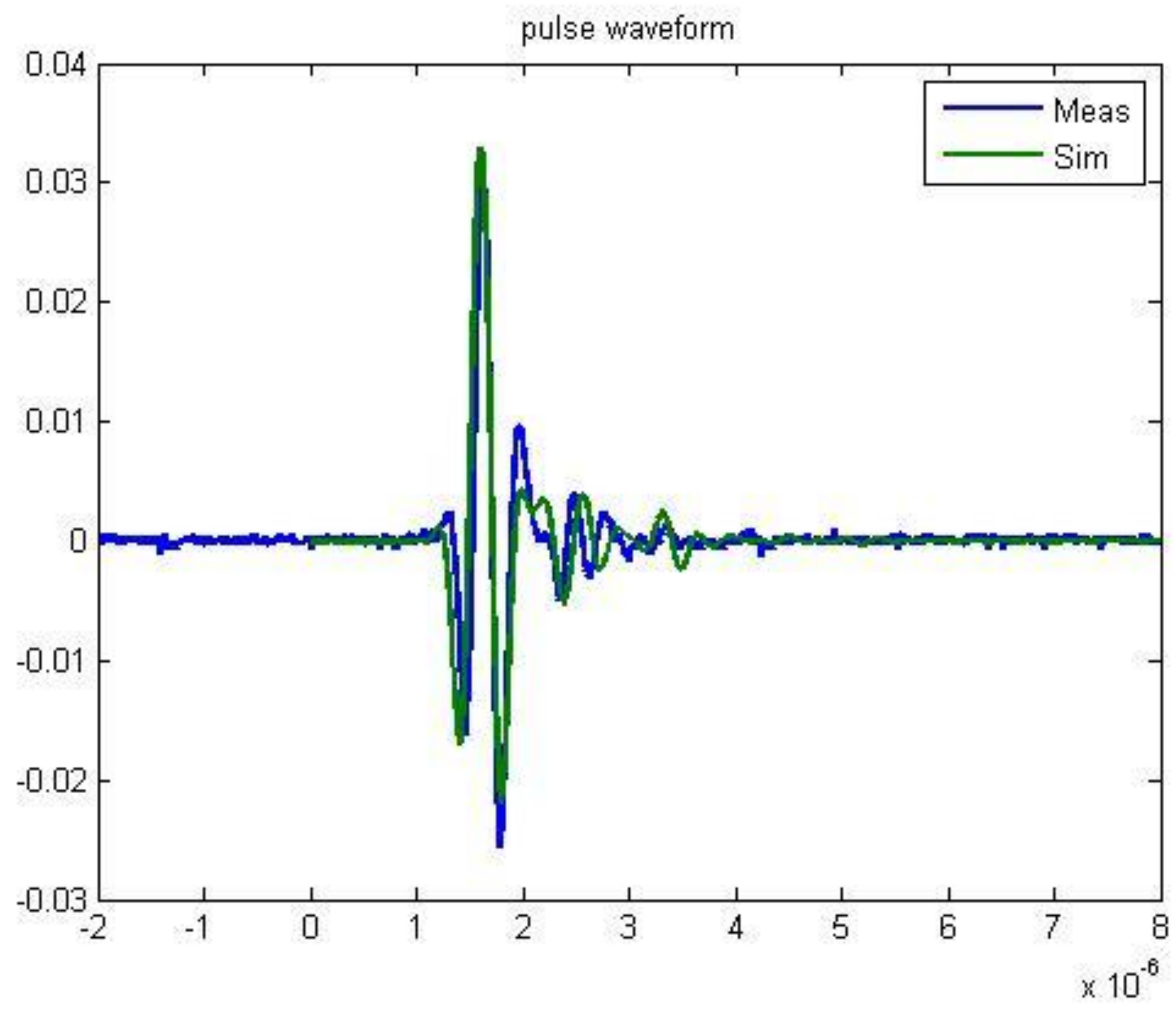

Figure 3. pulse waveform from single probe array piezo-element
(from Matlab IFFT of Comsol frequency response)

Conclusions: A method for the design of an Ultrasound Imaging probe was proposed and validated. The most important feature consists in how the probe materials were managed. Shear and Longitudinal wave velocities were measured, so that Young modulus and Poisson ratio could be calculated. Such operation allows to complete a FEM for the probe, in order to simulate its performances.

References:

1. *'Ultrasound Piezo-Disk Transducer Model for Material Parameter Optimization', Comsol Conference 2010 , Paris*
2. *'Design and Optimization of a High Performance Ultrasound Imaging Probe Through FEM and KLM Models' , Comsol Conference 2011 , Stuttgart*
3. *'FEM simulation for pulse-echo performances of an ultrasound imaging linear probe', Comsol Conference 2013 , Rotterdam*
4. *Olympus Ultrasonic Transducers Technical Notes, page 46, eq.15&16*

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