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 specific 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.

Transducer high Z Z-matching layers stack Human body Low Z

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 materials 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):

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

with: \( \sigma \) = Poisson ratio, \( E \) = Young modulus, \( v_s \) = Shear velocity, \( v_l \) = Long. velocity, \( \rho \) = 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.

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

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<tr>
<td>1st Match Layer</td>
<td>8500 kg/m³</td>
<td>1700 m/s</td>
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<td>0.48</td>
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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:
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

Figure 2. Pulse-echo equivalent FEM : pressure field

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