Lamb Waves in Fluid-Loaded Plates

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Abstract

Lamb waves are elastic waves propagating in free solid plates, showing complex properties as the existence of two infinite sets of waves modes and a dispersive nature of their velocities. While the equations describing these waves are known since the work by Lamb in 1917, their solution involves numerical methods. In the case of plates loaded with a fluid, these equations have to be modified to include the effects of the fluid. Also the modified equations can only be solved numerically and the understanding of such systems remains non-trivial.

In our work we have tackled this problem using COMSOL Multiphysics®. We have used the two-dimensional plane strain model of the solid mechanics interface to calculate the eigenmodes of the coupled system plate-water in a periodic representation of the system. The treatment of the fluid has been implemented using the PDE interface with different description for fluids following suggestions in the literature as incompressible potential (curl-free) flow (as suggested e.g. in Landau & Lifschitz 1959) or inviscid potential flow (as has been used in Wu & Zhu 1992). With a parameterized eigenfrequency study we have then calculated the phase and group velocities of the A0, S0, A1 and S1 modes versus frequency (for a typical example see Figure 1). Furthermore, the shape of the eigenmodes of the plate are readily accessible in COMSOL Multiphysics® (see Figure 2 for an example), which cannot be achieved by solving the dispersion equations directly.

Experimental validation of the calculated velocities revealed the breakdown of the incompressible flow model for high frequencies. Velocities derived from the inviscid flow model were consistent with the experimental data also at those high frequencies. The solution derived with COMSOL Multiphysics® led to a deeper understanding of the fluid-plate-system and COMSOL's flexibility did not only enable us to easily implement different fluid descriptions but will also allow to include a piezoelectric element to generate the forces closely modeled after the experiment. Eventually, the understanding of such complex systems will facilitate the development of new ultrasonic sensing technologies.

Reference

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L.D. Landau & E.M. Lifshitz, Theory of Elasticity, Pergamon Press, 1959
J. Wu & Z. Zhu, J. Acoust. Soc. Am., Vol 91, 861-867, 1992

Figures used in the abstract

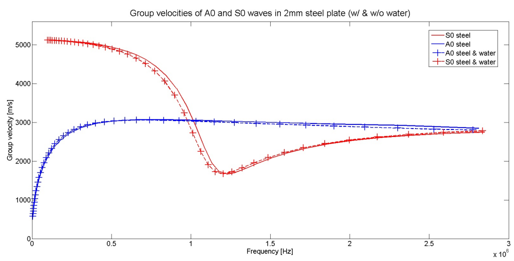

Figure 1: Group velocity of the A0 and S0 Lamb modes as a function of frequency for a free 2mm thick steel plate and the same plate loaded with water. The effects of the fluid were calculated using the incompressible flow model. The influence of the fluid is only significant in the S0 mode for frequencies around 1 MHz.

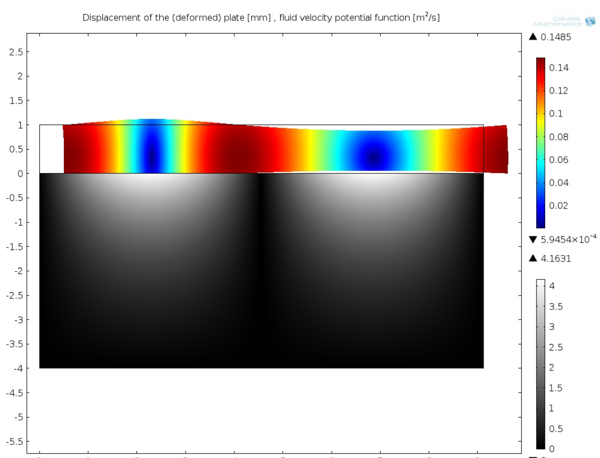

Figure 2: The S0 eigenmode of an aluminum plate [thickness 1 mm] at 0.6 MHz is shown. The plate is loaded with water (lower part of the plot) where the velocity potential function is shown. The effects of the fluid were calculated with the incompressible flow model.