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Delay Law Calculations Based on Snell's Law for Multilayered Structure TFM Imaging

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Background, Motivation and Objective

The development of ultrasonic testing and imaging techniques for application to multilayered materials is of increasing importance due to the rapid uptake of composite and additively manufactured components by industry. In this paper, we develop a novel approach to delay law calculations for improved imaging in multilayered structures where the geometry is known a priori. First, Snell's law is used to calculate the travel times within a dual-layered medium. This is then extended to an arbitrary number of layers. The benefit of this approach is not limited to improved focussing of internal interfaces and defects, but the method also produces coverage maps, providing additional information on 'dead zones' in the component. This information could be used to optimize the ultrasonic phased array configuration for a given scenario.

Statement of Contribution/Methods

Full matrix capture (FMC) data from the ultrasonic phased array inspection of a three-layered component with planar interfaces was simulated using Onscale (CA, USA) software. It has previously been shown that to calculate the travel time to each point in a dual layered medium, the point of intersection of the interface with the ray between the source point at the top of the domain and the focal point in the second layer, can be used. From Snell's law, a double-quadratic equation can be derived of which the solution provides this intersection point. Thus, using the now known distances and velocities, the shortest travel time at each point in the second layer can be obtained. Unfortunately for an arbitrary number of layers, this system is ill-posed. To extend this work to a multi-layer scenario, we apply Snell's law to project rays from each point at the second interface to obtain a partially constructed travel-time field in the third layer (iterating this process for more layers). This has the benefit of allowing comment to be made on the coverage of the ultrasonic field.

Results/Discussion

Figure A shows a schematic of the 32 element phased array inspection of a four-layered structure where each layer is 20mm deep and has alternating velocities of 3359 m/s and 5900 m/s. Figure B shows a standard TFM image that assumes a constant wave velocity throughout the domain which results in significant offset of interface locations. Figure C was generated using our multi-layered method and shows the improved location of interfaces. Further refinement of the algorithm will be demonstrated to improve the quality of the TFM image, with the approach applied to representative industrial samples.