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Propagation Behaviors of Higher Order Modes Cluster Guided Waves in Geometrically Discontinuous Structures

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Abstract

This study explores advanced non-destructive testing techniques using higher-order guided wave modes. Unlike conventional ultrasonic methods limited to low frequencies and single modes, this research utilizes higher-frequency mode combinations to investigate wave propagation behaviors. Finite element analysis, along with Higher Order Modes Cluster (HOMC) technology, simulates guided wave packet propagation in structures. The study examines mode changes across different interfaces and tests geometrically varied specimens. Laser ultrasonic visualization confirms findings, showing that varying thickness and different welds influence mode composition and scanning outcomes of higher-order guided wave groups. Overall, welds play a significant role in shaping these wave modes and affecting inspection results.

Keywords：Higher Order Modes Cluster, Geometrically Discontinuous Structures, Quantitative Laser Ultrasound Visualization System.

1. Introduction

Traditional non-destructive testing (NDT) employs A0 and S0 modes within a frequency range (as shown in Fig. 1) controlled by time or angle. Frequency-thickness limitations affect mode selection and spatial resolution. Frequencies below 2 MHz enable single modes [1)]. In the 3-10 MHz range, complex group and phase velocities challenge mode acquisition. The 15-40 MHz range allows propagation for short-to-medium distances in structures, especially aiding circular plate inspections.

Beyond 20 MHz-mm, guided wave modes converge near 3200-3400 m/s, forming a minimal dispersion Higher Order Modes Cluster (HOMC) (Fig. 1). Multiple modes interfere, generating diverse modes based on excitation frequency and angle (Fig. 2). For frequencies above A1, incident angles of 50° to 60° are required [2,3)].

In summary, traditional NDT uses A0 and S0 modes within specific frequency ranges. Utilizing ultrasonic guided wave modes at higher frequencies benefits inspections of varying complexities [4,5)].

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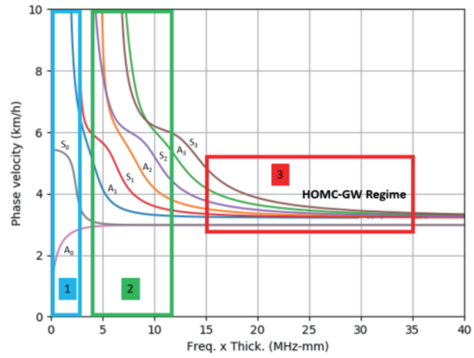

Fig. 1 Dispersion Relationship of Lamb Waves

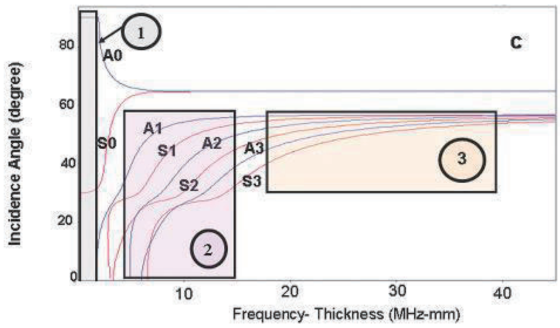

Fig. 2 Frequency-Thickness Relationship and Excitation Angle Chart

2. Material and Sample

The internal structures of oil storage tanks often encounter scenarios such as hierarchical arrangements with varying thicknesses. Different welding methods are employed at distinct positions, such as between the bottom plate and the annular sidewall, contributing to the assembly. Therefore, when selecting structural specimens for analysis, practical and common scenarios are considered. These scenarios include different thickness plates, butt welding, lap welding, and T-joint welding, as depicted in Fig. 3.

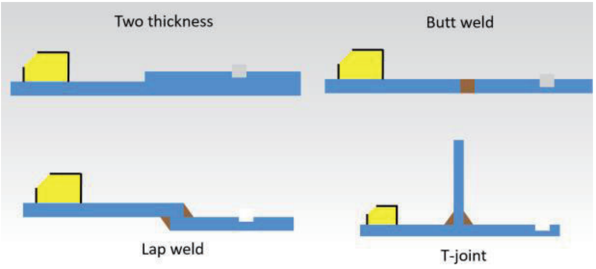

Fig. 3 Discontinuous structures

3. Experimental setup

The QLUVS employed in this study consists of three primary modules: a laser excitation system, an ultrasound reception system, and a scanning mechanism. The laser excitation system non-contactly delivers laser pulses to the target sample, inducing laser-generated ultrasound signals. Ultrasonic transducers capture these signals. A mirror-based scanning mechanism directs laser beams at diverse angles onto the sample, enabling comprehensive scanning. Subsequent signal processing techniques are employed for defect imaging. The schematic in Fig. 4 illustrates the setup, featuring a computer with a data acquisition card at the top-left, a pulser/receiver at the top-right, a two-dimensional scanning mechanism in the middle, and a pulsed laser source at the bottom-right. Through software integration, these components collectively constitute the laser ultrasound visualization system (LUVS).

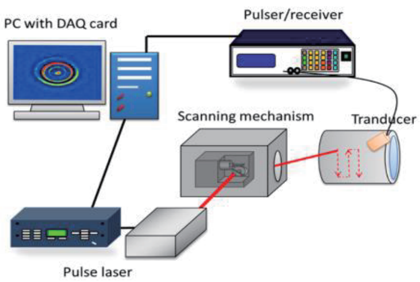

Fig. 4 Schematic diagram of the setup of the Quantitative Laser Ultrasound Visualization

4. Results and Discussions

This study investigates how discontinuities in a structure might affect the composition of higher-order guided modes. It uses both simulation and experimental data, utilizing Abaqus for simulations and a developed laser ultrasound system (QLUVS) for experiments. The focus is on observing wave behavior and mode changes. Two connection methods are analyzed: one using only weld seams for transmission and the other considering overlap between steel plates. Results reveal differences in higher-order guided mode propagation due to these methods.

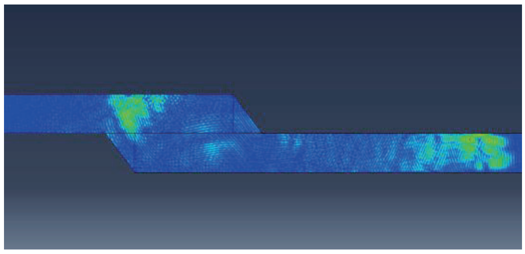

Fig. 5 Simulating the propagation of HOMC

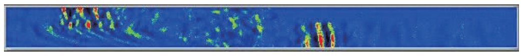

Fig.6 Weak HOMC generated through experimental lap welding

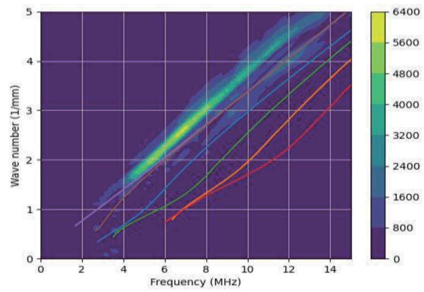

Fig. 7 2D FFT of lap welding

5. Conclusions

This study employs the Higher Order Modes Cluster (HOMC) theory to investigate ultrasonic propagation behavior within geometrically discontinuous structures. Through finite element simulations, it successfully models the transmission of HOMC guided waves under changing conditions in such structures. The research further validates the observed wave behavior through practical scanning on specimens using the developed Quantitative Laser Ultrasound Visualization System (QLUVS).

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