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EXCITATION OF PURE SH1 MODE AND EVALUATION OF ITS SENSITIVITY TO VERY SHALLOW CRACK-LIKE DEFECTS

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ABSTRACT

Inspection of plate-like structures in the petrochemical industry is vital. Ultrasonic guided waves have been used extensively to detect various types of defect by monitoring reflected and transmitted signals; however, testing becomes difficult for sharp, shallow defects as current inspection techniques suffer from a lack of sensitivity to such features. Previous studies, obtained by comparing various inspection techniques, suggest that the SH1 mode in particular, at around 3 MHz-mm, would be suitable when testing for shallow defects; however, it is clear that both the SH0 and SH1 mode can exist at this frequency-thickness product which can complicate the inspection process and therefore limit defect detectability. This paper investigates the possibility of single mode excitation of the SH1 mode at around 3 MHz-mm. the ability of this method towards detecting very shallow defects (<10% cross-sectional thickness loss) has also been studied. Using finite element analysis simulations and verification experiments it is shown that a signal dominated by the SH1 mode can be generated using PPM EMATs. Furthermore, it is shown that, by studying the reflection coefficient of the SH1 mode, the pure SH1 mode can be used to detect vary shallow defects (< 10% thickness loss) that will be missed by standard, lower frequency guided wave testing.

Keywords: ultrasonic guided wave, shear-horizontal wave, defect detectability

1. INTRODUCTION

Inspection of plate-like structures in the petrochemical industry is vital. Ultrasonic guided waves have been used extensively to detect various types of defect by monitoring reflected and transmitted signals [1-3]; however, testing becomes difficult for sharp, shallow defects (< 10% cross-sectional thickness loss) as current inspection techniques suffer from a lack of sensitivity to such features.

There have been a number of studies which point towards the use of the Shear Horizontal (SH) guided waves [4-5] when inspecting for defects such as cracks and corrosion patches as well as recent applications of such methods for pipeline tomography. There are various industrial application examples [6-7] which employ electro-magnetic acoustic transducers (EMATs) in an automatic inspection system to scan for defects in the axial and circumferential directions. Previous studies [8], obtained by comparing various inspection techniques, suggest that the SH1 mode in particular, at around 3 MHz-mm, would be suitable when testing for shallow defects; however, it is clear from Figure 1 that both the SH0 and SH1 mode can exist at the desired 3 MHz-mm frequency-thickness product which can complicate the inspection process and therefore limit defect detectability.

This paper investigates the possibility of single mode excitation of the SH1 mode at around 3 MHz-mm. the ability of this method towards detecting very shallow defects (<10% cross-sectional thickness loss) has also been studied.

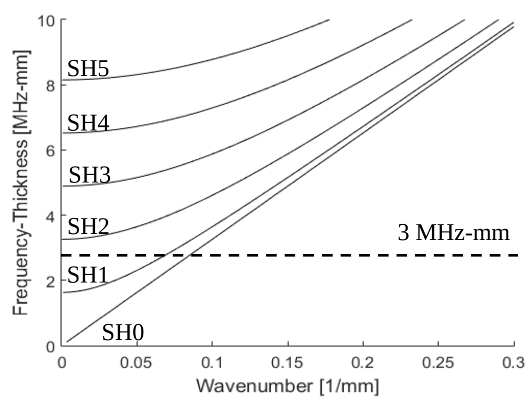

FIGURE 1: SHEAR HORIZONTAL (SH) WAVE WAVENUMBER DISPERSION CURVES IN STEEL; GENERATED USING DISPERSE SOFTWARE [9].

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2. MATERIALS AND METHODS

Here a simple 2-D analytical model, implemented in the MATLAB software, was employed as it can produce the essential physics while enabling the study of a large number of probe configurations practically [10]. In order to predict the wavenumber and frequency bandwidths of the excitation force, the surface force generated by the PPM EMAT was simulated by a spatial distribution of in-plane surface point forces followed by the use of a Fourier transform in space and time (2-D FFT).

The force pattern for the PPM EMAT was simulated by in-plane surface forces with opposite polarity depending on the direction of the acting Lorentz force; this pattern is repeated according to the wavelength (λ) and the number of cycles of the magnets in space.

Finite Element (FE) analysis was employed in order to verify the validity of the analytical predictions, where excitation equivalent to that obtained from the analytical model was applied and the in-plane surface displacement was output along a line; a 2-D FFT was performed to identify the modes excited within the waveguide.

2D models were considered in this study which allowed the investigation of the sound wave as it travels along the plate-like waveguide.

In order to verify the analytical and numerical predictions, experiments were carried out to establish the possibility of exciting a pure SH1 mode at 3 MHz-mm.

Finally, simple FE models were employed in order to establish the performance of the SH1 mode when used to inspect for very shallow cracks with <10% cross-sectional thickness loss.

3. RESULTS AND DISCUSSION

As stated above, the pure SH1 mode excitation at around 3 MHz-mm (300 kHz center frequency in a 10 mm steel plate) is of interest; the wavelength of the SH1 mode at this frequency-thickness value is around 13 mm which was calculated using the DISPERSE software [9].

While there are setups that maximize the absolute force amplitude on the SH1 mode, the ratio of the force amplitude of the SH1 mode to that of other modes is often more important in the practical signal-to-noise ratio (SNR) than the absolute amplitude [10]. In order to obtain the optimum setup towards pure SH1 mode excitation while minimizing the generation of the SH0 mode, different practical excitation setups were studied for PPM EMAT; for brevity, only the desired excitation configuration is presented in this paper.

It was found that due to the separation of the SH0 and SH1 dispersion curves, a PPM EMAT can be built so that it provides sufficiently narrow wavenumber and frequency bandwidths for pure SH1 mode excitation.

These analytical predictions were then verified via the use of a 2D FE model. Use of 2D analysis means that the attenuation values reported do not include the effects of beam spreading, also the effects of diffraction around small defects are not captured; these effects will be investigated later via analytical means which allows the 2D FE results to be extrapolated to obtain realistic results which would have been highly complex and computationally expensive to obtain from full 3D models.

Here, it was found that a signal dominated by the SH1 mode can be excited using a specific PPM EMAT at around 3 MHz-mm.

In order to verify the FE predictions, experimental measurements were carried out. For this section, the SH1 mode was chosen as it showed superior performance when used to inspect for shallow surface defects which are of interest to this study.

Initial experimental results were obtained in order to establish the ability of the optimized EMAT probe towards exciting pure a SH1 mode.

The measurement setup consisted of a computer, a data acquisition system (DAQ) containing two synchronised Handyscope-5 (TiePie Engineering Ltd., Town, The Netherlands) with arbitrary function generator (AWG) and oscilloscopes, an Amplification System (AS) developed in-house and an optimised PPM EMAT whose geometry was established by the analytical and numerical analysis that was described earlier; a generic PPM EMAT was used as a receiver. It is noteworthy that SH1 purity can be significantly improved if a similar optimised PPM EMAT is used in reception.

The computer, which controlled the experiment, executed a MATLAB (The Mathworks Inc., Town, USA) routine that used the HS5s to generate and transmit signals. Moreover, the HS5s were used to digitise the amplified received ultrasonic signals. In between the HS5s and the EMAT the AS was connected. The AS contains a buffer amplifier on the transmitting side, an isolation switch to interchange between transmitter and a 60 dB receiver amplifier.

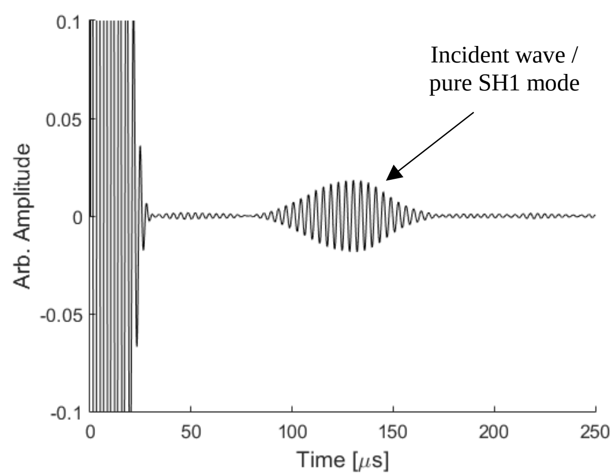

FIGURE 2: EXPERIMENTAL TIME-TRACE OBTAINED IN PITCH-CATCH CONFIGURATION ON A 10 MM THICK ALUMINIUM PLATE USING THE OPTIMISED PPM EMAT AS A TRANSMITTER AND A GENERIC PPM EMAT AS A RECEIVER OVER A PROPAGATION DISTANCE OF AROUND 300 MM.

Fig. 2 shows the incident wave time trace generated by the optimized PPM EMAT where the propagation of the pure SH1 mode is clearly evident; the results were obtain with 500 averages which resulted in a 23dB SNR value.

4. CONCLUSION

It has been shown via analytical, numerical and experimental means that PPM EMATs can be used to excite pure SH1 mode at around 3 MHz-mm region. The system will now be used to investigate responses to shallow defects. Initial simulation results are promising and both simulation and experimental results will be presented at the conference.

ACKNOWLEDGEMENTS

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