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MODELING THE INTERACTION OF GUIDED WAVE WITH THE WELDED SUPPORT IN PIPES

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Abstract

The guided wave technique plays an important role for the inspection of long-range pipes and large plates in recent years. In pipes, the axis-symmetric guided waves are able to propagate for a long distance with little attenuation, especially the T(0,1) mode. However, the superiority of the guided waves decreases when some complex features on pipe, such as welded supports and bends, etc., interfere with the guided waves. In this paper, a finite element model is applied to study the mode conversion in the welded support when the T(0,1) mode impinges onto it in pipes. From the visualization of FEM, the wave propagates in the support with circular waveform initially and becomes almost a straight waveform later. In addition, the time-frequency analysis recognizes the converted Lamb waves in the support. The finite element model used in this study shows the mode-conversion-phenomenon when waves propagate from the pipe-like structure to the plate-like structure.

1. INTRODUCTION

Corrosion in pipes is a major problem in industrial plants and can lead to a serious thinning of wall thickness. Leaks or sudden failures of pipes can cause injuries, fatalities and environmental damage. Recently, ultrasonic guided wave inspection technique in pipelines draws attention to in the refinery, gas, chemical and petro-chemical industries. This technique, employing a pulse-echo system applied to the pipe at a single location, generates Lamb waves propagating along the pipe wall. Low cost, long inspection range and time efficiency are the main advantages of guided wave inspection. Many researches used guided wave for defect inspection in pipes [1-3]. To improve the inspection, the ability of defect detection and the interaction of guided waves with the complex geometries, such as bends and supports, found in pipes are the major issues to study. Hayashi *et al.* [4] achieved visualization of guided wave propagation along a pipe with a bend. The semi-analytical finite element method was used to study the complex wave mechanics, such as the propagation of complicated guided wave beyond the bend. The reflection and transmission characteristics of the bend were studied by Demma *et al.* [5]. Not only the dispersion curves for toroidal structures were calculated to understand the modes in the bend, but also the frequency dependent transmission behaviour was obtained in the straight-curved-straight pipe. The longitudinal welded support is one of the common examples of the complex geometry in pipes. The pipe supports are used to line the pipelines and integrate the manufacturing process for refinery, chemical and petro-chemical industrials. In 2006, the authors [6] had studied the effect of the longitudinal welded support for T(0,1) mode propagation. The reflection of T(0,1) obtained from both the experiment and the simulation was behind the actual position of the support about tens of centimetres.

In this study, first, numerical simulation and visualization of guided wave, propagating along a pipe through a longitudinal welded support, have been investigated by finite element method (FEM). Then the mode conversion caused by the longitudinal welded support is discussed by dispersion curves, Snell's law, and short time Fourier transform (STFT).

2. FINITE ELEMENT SIMULATION

The results of numerical simulation are shown in this section. A commercial FEM program ANSYS is adopted to simulate the propagation of axis-symmetric torsional modes in a 6" steel pipe with a longitudinal support.

2.1 Finite Element Model

The FE models produced to investigate the propagation of T(0,1) mode through the welded support were excited at the end A of the pipe shown in Figure 1. The excitation signal and reflected signal from the support are monitored at line C. The distance between the end A and line C is 1.85-m. The total length of the pipe is 4.6-m and SHELL 63 element with 5-mm axial length is adopted for membrane modeling. In addition, there are 72 elements chosen around the circumferential section of the pipe. One welded support (with 25-cm in length, 10-cm in high, and 7-mm in width) located 3-m away from the end A and been modeled by SOLID 45 elements with 5-mm axial length. A six-cycle 32 kHz tone burst in Hanning window was chosen to be the input signal. The tone burst was applied as a sequence of prescribed displacements in the circumferential direction of the pipe. The excitation of T(0,1) mode was achieved by applied the same sequence at all of the nodes around the circumference of the end A. The received signals at line C are separated into single-mode waveforms with a mode extraction technique.

Figure 2 shows the visualization results of T(0,1) mode propagation in a pipe through the longitudinal welded support at time equal to 1 , 1.08 , and 1.276 ms, respectively. It can be observed from Figure 2(a) that the T(0,1) mode impinges onto the support it will leak energy into the support. In Figure 2(b), the leakage causes an out-of plane disturbance; therefore, some converted modes of Lamb waves, initially propagate with a semicircular wavefront, are then becoming nearly a straight one in the support. In Figure 2(c), the modes within the region can reflect as well as transmit at the ends of the support, so that they reverberate over the length of the support. After the plate modes reflected from the boundaries, some energy leak into the pipe and become the T(0,1) and flexural modes in pipes again.

2.2 The Time History of Guided Waves in a Pipe with the Support

Figure 3 is the time history l of modes T(0,1), F(1,2), and F(1,3), respectively, simulated by FEM mode. In Figure 3, the reflection signals of axis-symmetric wave mode from the support are received at line C. In front of the support, the biggest wave packet W1 represents the incident T(0,1) mode. As shown in Figure 3(a), the welded support is the only feature between the ends of A and B. Therefore, the wave packets W2 and W3 are the reflection signals of the longitudinal welded support. The packet W2 is the direct reflection signal and the packet W3 is the leakage from the support. By calculating the time of flight of the signal and knowing the group velocity of T(0,1) mode, the calculated distance between the support and the end A can be obtained. It should be noted that the distance set in the FEM model is 3-m, but the calculated distance of the reflection signal from the support is 3.363-m when the excitation frequency is 32 kHz. Not only the peak of the signal lagged behind the actual position of the support but also the signal persisted for 1.1-m. The detection of the defect beyond the support is then more difficult.

The mode-conversion-phenomenon caused by the welded support is the asymmetric feature in pipes as was expected. In Figure 3(b), the flexural modes of converted order 1, such as F(1,2) and F(1,3) modes, were extracted by adding signals of each node with phase delay around the circumference.

To sum up, the time histories of the T(0,1) waves in the longitudinal welded support are related to signal delay, drag and mode conversion. All the drag signals are leakages from the support and larger than the direct reflection. To reduce the leakages, the understanding of the mode conversion and reverberation in the support is necessary.

3. DISPERSION CURVE AND WAVE STRUCTURE

The complex mode-conversion-phenomena occurred when axis-symmetric guided wave modes, such as T(0,1) mode, propagate in the pipe and impinge onto a longitudinal welded support. The geometry of the pipe is a hollow cylinder and the support is a plate-like structure. The modes on the two waveguides are different and the software DISPERSE 2.0 [7] can be used to trace the dispersion curves.

Since the exciting signal, a 6 cycles, 32 kHz toneburst in a Hanning window, is rather narrow-band, dispersion curve could reasonably traced below 50 kHz. At the frequency range from zero to 50 kHz, some possible wave modes of order 0, 1, and 2 are shown in the group velocity dispersion curves in Figure 4(a) for a 6 inch steel pipe and in Figure 4(b) for a steel plate with 7-mm thickness. The mode shape of T(0,1) mode is the profile of the tangential displacement through the thickness as shown in Figure 5. However, T(0,1) mode can convert to the S0, A0, and SV modes of a plate when it impinges onto the support. The efficiency of the conversion is dependent on the similarity in particle motion between the incident mode and the converted modes. Figures 6(a) and 6(b) are the mode shapes of the A0 and S0 modes, respectively, at 32 kHz. The A0 mode and the SV mode have dominant out-of-plane displacement so the conversions to those modes from T(0,1) mode are strong. However, the S0 mode has subordinate out-of-plane displacement so that the converted S0 mode is weak. Because of the match for the tangential disturbance in pipes and the wave structure of the support plate, the T(0,1) mode was incident on the support and converted to the A0 and SV modes in the support.

4. TIME-FREQUENCY ANALYSIS

When the T(0,1) mode impinges onto the support, the incident angle of the T(0,1) mode is 90°. By considering the Snell’s law in Equation (1), the refracted angle of the converted A0 mode is 25.1° and of the converted SV mode is 90°.

$$\sin\theta = \frac{\sin(90^\circ)}{C_{T(0,1)}} \times C \tag{1}$$

As shown in Figure 7, there are three points keep the same 65-mm distance away from the corner of the support. The time history of the three points D, E, and F are received as “Trace D”, “Trace E”, and “Trace F”, respectively. There is only a pure 6 cycles toneburst signal in Trace D, but a group of wave packet both in Trace E and Trace F. T(0,1) mode and SV mode are completely non-dispersive at all frequencies, but A0 mode is dispersive within the frequency range as shown in Figure 4. Compare with the three traces, the SV mode propagates faster through the point D and the dispersive A0 mode propagates slower through both the point E and F.

For the STFT analysis, we select the window type, window size and the step size appropriately. Figure 8 shows the results of the STFT analysis using a barthannwin window and time-frequency amplitude spectrum of each trace presented as spectrogram. The results of STFT spectrogram show that it is hard to provide the frequency analysis for narrow band signal in this case.

5. CONCLUSIONS

When the T(0,1) mode propagates from the cylindrical structure to the plate-like structure, the mode conversion is observed and studied in this paper. The mode shapes, dispersion curves, the time history and STFT analysis are used to understand the mode-conversion-phenomena. First, because of the match for the tangential disturbance in pipes and the wave structure of the support plate, the T(0,1) mode converts to A0 and SV modes in the support. Secondly, the refracted angle of the converted A0 mode is 25.1° and of the converted SV mode is 90°. Finally, guided waves are initially launched with a semicircular wavefront that become nearly a straight one as propagation proceeds. The forward A0 mode can reflect at the ends of the support, and reverberate over the length of the support.

To improve the corrosion inspection next to the longitudinal welded support, further work is needed to reduce the reflection from the support by considering the reverberation phenomenon in the support.

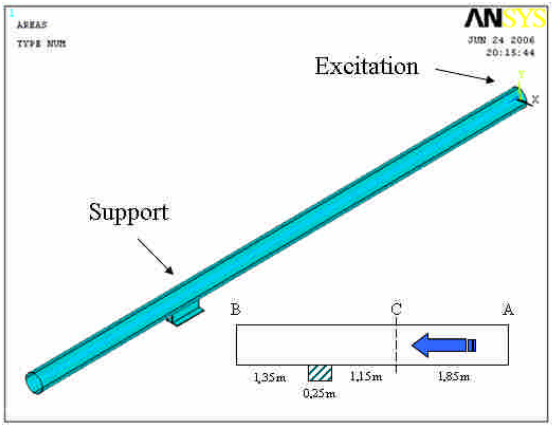
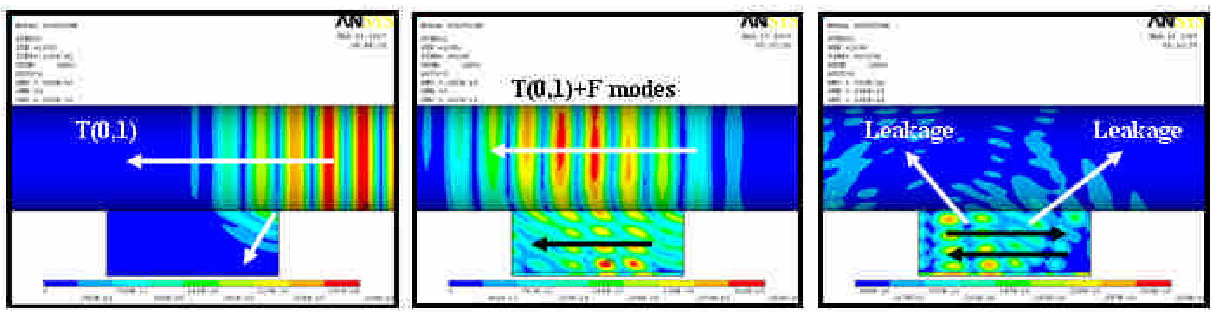
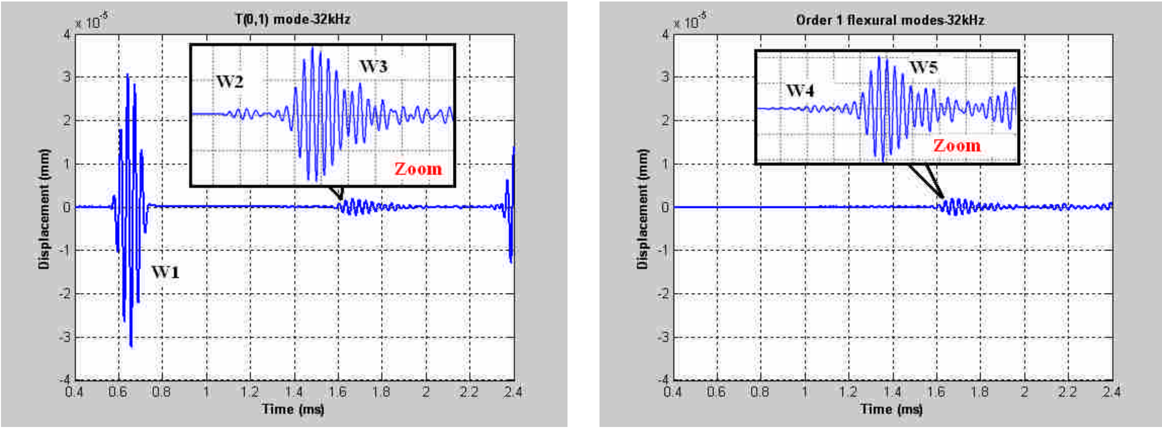


Figure 1. FEM model of a pipe with a longitudinal welded support.



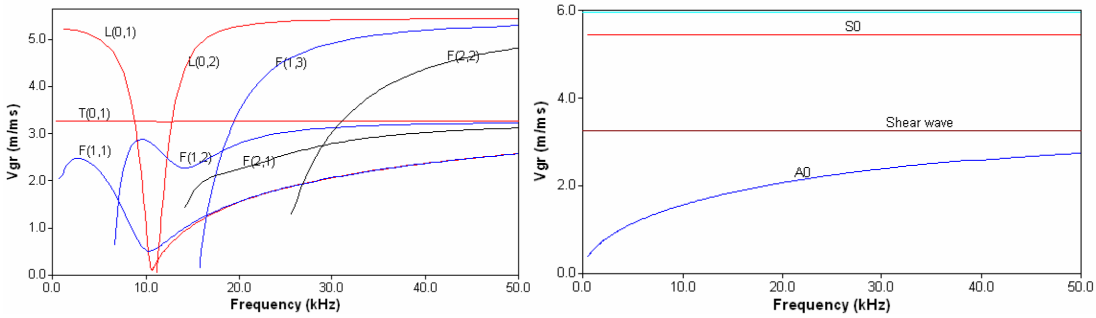
(a) 1 ms (b) 1.08 ms (c) 1.276 ms

Figure 2. Snapshots of T(0,1) mode propagation in a pipe with welded support.



(a) (b)

Figure 3. The time history of (a) T(0,1), (b) F(1,2) and F(1,3) mode at monitor line C.



(a) (b)

Figure 4. Group velocity dispersion curve of (a) a 6 inch pipe and (b) a 7 mm thick steel plate [7].

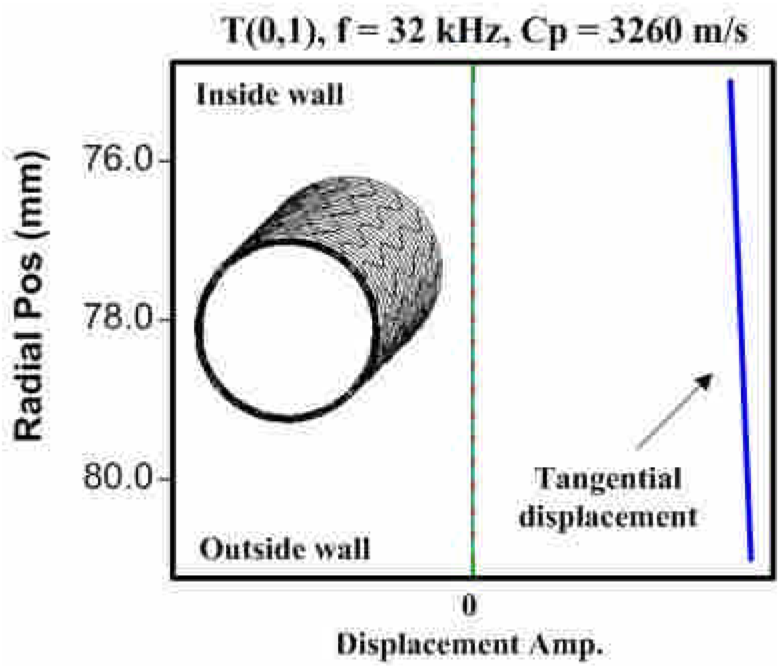
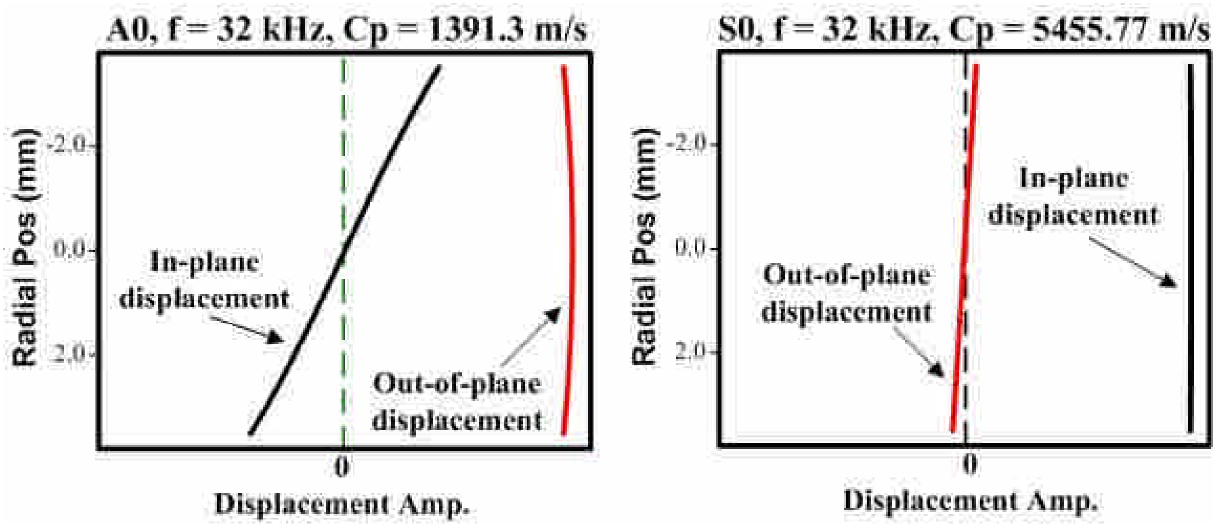


Figure 5. Mode shape of T(0,1) mode in pipe at 32 kHz [7].



(a) (b)

Figure 6. Mode shape of (a) A0 and (b) S0 mode in plate at 32 kHz [7].

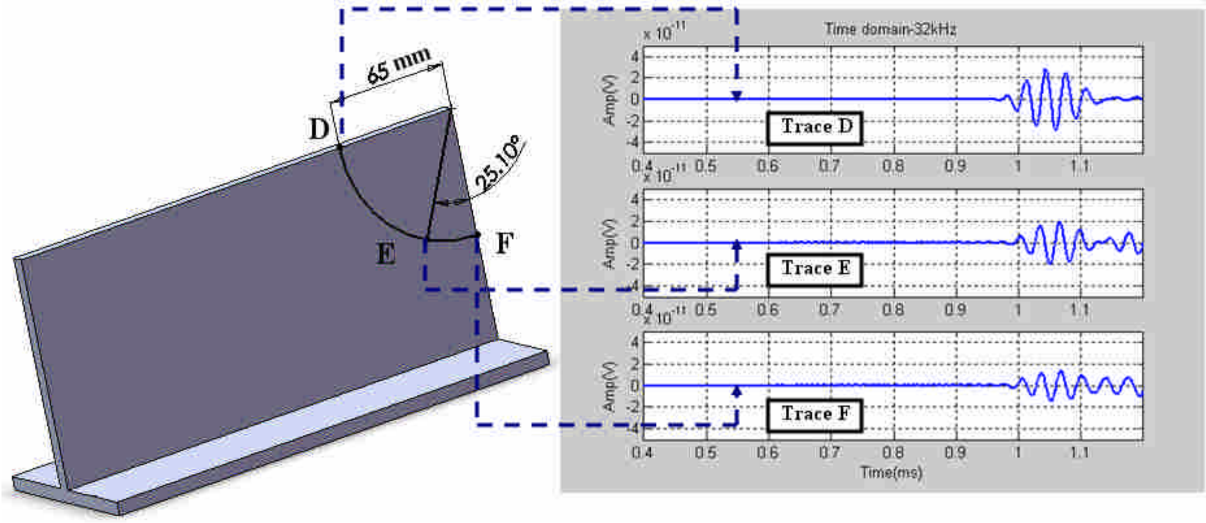


Figure 7. The time history of Traces D, E and F, respectively.

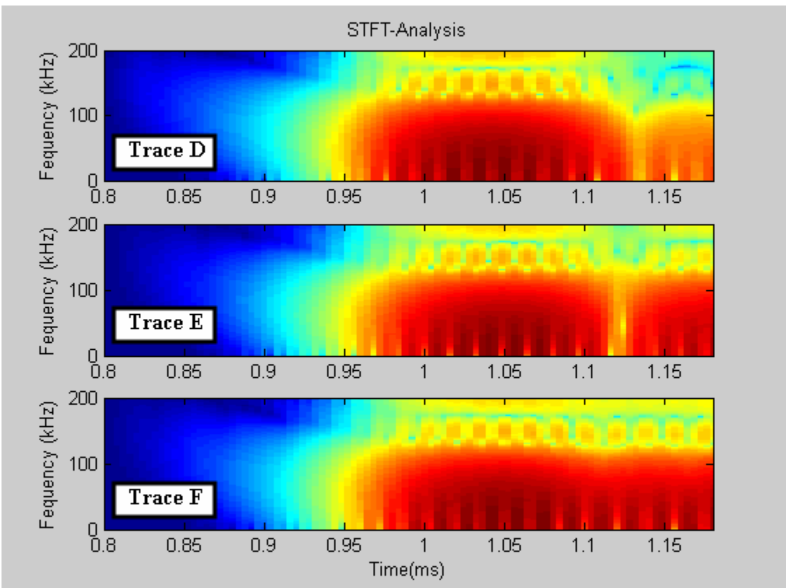


Figure 8. STFT spectrogram of Traces D, E and F, respectively.

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