The Study of Wave Propagation through Plates Welded Joints Using Guided Waves SH₀ Mode

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Abstract

The objective of the research presented here is the investigation of SH₀-mode guided wave propagation through butt joint, lap joint and T-type joint welded plates. Magnetostrictive EMAT (Electromagnetic Acoustic Transducer) transducers are used to generate the fundamental SH₀-mode guided wave. The investigations have been performed using numerical simulation by finite element method (FEM) and tested by measurement of the reflection characteristics and transmission situation of the SH₀ guided waves transmit through different welded joints. The results show that the amplitude of each weld signal between numerical simulation and experimental measuring demonstrates different value but multiple correlations. The numerical result value was larger about three times than experimental result.

Keywords: Magnetostrictive EMAT, SH₀ guided wave, Plate, Weld, Finite element method, Wave propagation.

1 Introduction

The steel plate is known as the basic material of a petrochemical, ship, aerospace and much other industries, its quality directly affects the safety and operation of related equipment. Once the defects caused by leakage or explosion and other security incidents, so that the factory suffers casualties, environmental shocks, unplanned shutdown losses, maintenance costs and deterioration of the operating environment and other huge losses. Much industrial equipments is made of welded steel of various shapes, and many defects often occur in these welds and in the heat affected zone around the weld bead. Based on public security issues, a variety of non-destructive testing of assessment techniques born to reduce the opportunities for such incidents. Among them, the use of guided wave detection for petrochemical pipelines, railways and other industrial facilities and the use of other structures more and more. In this paper, the use of equipment for the use of magnetostrictive effect of the SH-mode generated by the high-frequency short-range guided wave, according to the relevant literature research results show that the SH wave by its particle vibration direction parallel to the characteristics of the surface of the test object, The effect of roughness is small, and it is not easy to produce wave-type conversion when the wave travels to the surface boundary, which has many advantages for non-
destructive detection techniques [1-4]. The purpose of this study is to present the wave propagation behavior of SH0 guided wave passing through different welded joints.

2 Theory

2.1 Dispersion Curves

The properties of Shear horizontal (SH) waves in a plate depend on frequency-thickness product $f/d$ and linear acoustic propagation is assumed. The dispersion relation of shear waves showing phase and group velocity for a 6 mm thick steel plate is shown in Figure 1. The horizontal axis is the frequency, the vertical axis is the phase velocity and the group wave velocity. They were calculated using the program Disperse [5]. This paper only uses simple central frequency, 128 kHz. So, by Figure 1 below, only SH0 mode appear. The properties of this mode are not frequency dependent: it is completely nondispersive at all frequencies and its phase velocity is the bulk shear velocity.

![Dispersion Curves](image)

Figure 1: SH guided wave phase and group velocities dispersion curves for 6 mm thick steel plate.

2.2 Magnetostriction Effect

Similar to the piezoelectric effect of the piezoelectric transducer, the magnetostrictive transducer is a magnetostrictive effect to produce or receive ultrasound, so in many kinds of literature also known
as the magnetic effect (Piezomagnetic Effect). The use of current pulses into the coil to produce alternating magnetic field, and by the magnet polarization of the static magnetic field superposition, in the two magnetic field under the combined effect of the ferromagnetic material volume changes, the formation of internal vibration of the material, and finally in the form of ultrasound. The vibration spread out.

Figure 2 [6] is to explain the magnetostrictive effect of the wave transmission mechanism, the left figure H from the ferromagnetic material by the polarization after the static magnetic field itself, δH for the stack coil (Meander Coil) through the AC power I after the alternating magnetic field, in the static magnetic field and the stack of two magnetic field under the action, and then as shown in the right to guide the ferromagnetic material to produce a specific direction of the deformation of the material, and then excite the SH wave transmission.

![Figure 2: Magnetostrictive effect generates SH wave.](image)

### 3 Numerical Simulation of the Guided Waves Propagation

To investigate how the welded butt, T-type and lap joint influenced the propagation of SH0 guided wave. The numerical modeling was carried out using the ANSYS 15.0 finite element software. In this paper, the theoretical simulation plate’s material was medium-carbon steel plate widely used in industrial as the object. The elastic properties of materials used in the numerical model were as follows: density $\rho = 7932 \text{ kg/m}^3$, Young’s modulus $E = 216.9 \text{ GPa}$, and Poisson’s ratio $\nu = 0.2865$. The plate model was established by using linear elastic hexahedral element Solid 45, which was a hexahedral structure with 8 nodes. Each node had the corresponding degrees of freedom in its $U_x$, $U_y$ and $U_z$ per coordinate system. Since the weld section was transversely isotropic, it was necessary to select the solid185 element having the same node and the hexahedron, in combination with the transverse isotropic material element and matching the element solid45 of the plate. The excitation was performed by applying horizontal force as two periods of 128 kHz sine-burst signal. The time interval used for the modeling of elastic wave propagation was $\Delta t = 0.1 \mu\text{s}$. The models were presented in Figure 2. They are all 6mm thick plate and respectively build butt, T-type and lap joints.
Figure 3: Model used for the investigation of the SH0 guided wave propagation.

The received waveforms of the signals in the time domain of the ultrasonic SH0 guided wave were presented in Figure 4. The signal amplitude had been normalized by the maximum amplitude of the incident wave. Then the transmission situation when wave passes through weld was shown in Figure 5-7. When the wave propagated from the left side through the butt weld, it would focus on the top of the weld. It can be observed from the T-type weld case that the T weld includes the left and right weld. When the wave is incident from the left to the first weld, part of the wave passes through the first weld to the top plate. Most part of wave continue propagates in the original plate to the second weld and then divides into two parts once again. So, Figure 4(b) showed that the T-type weld signal includes two weld signal. And the right weld signal amplitude is larger than the left one. The transmission situation when wave passes through lap weld demonstrates that weld signal includes weld itself and the edge of the bottom plate. The amplitude of each weld signal was presented in Table 1, and would be divided by the metal reference blocks signal as a target to meet the experimental evaluation criteria. The target blocks used in this study were 13 mm long, 7 mm wide, 1.5 mm in thickness, and 19.5 mm in cross-sectional area. The amplitude of target signal was 5.8 %.
Figure 4: The waveforms of the signal measured: (a) butt joint; (b) T-type joint; (c) lap joint

Figure 5: The transmission situation when wave pass through butt weld
Figure 6: The transmission situation when wave pass through T weld

Figure 6: The transmission situation when wave pass through lap weld
Table 1: The numerically obtained signal amplitude of each weld.

<table>
<thead>
<tr>
<th>Weld type</th>
<th>Butt joint</th>
<th>T-type joint</th>
<th>Lap joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude (%)</td>
<td>23.5</td>
<td>23.11</td>
<td>43.89</td>
</tr>
<tr>
<td>Weld / target</td>
<td>4.05</td>
<td>3.98</td>
<td>7.57</td>
</tr>
</tbody>
</table>

4 Experimental Investigation of $SH_0$ Guided Wave Propagation Through Weld

The objective of this part was the experimental verification of the modeling results, obtained using a finite element model. For this purpose, the test sample was a 6 mm in thickness medium-carbon steel plates, then manufactured to generate weld. The width of the butt weld was 12 mm; the width of the T-type welds was total 18 mm and the width of the lap weld with the overlap zone was total 16 mm. Experimental investigation of the ultrasonic $SH_0$ guided wave propagation through the welded joints was performed using the experimental set-up presented in Figure 7.
In this paper, the use of $\text{SH}_0$ guided wave detection equipment mainly included the operation of the host and the transducer two parts. The transducer included transmitter and receiver together, so it worked by the pulse-echo method. The operating host was the non-destructive testing equipment produced by Innerspec, The Powerbox H. It could be selected to match the transducer, connected to the Lemo signal line, and could be applied to a variety of different types of detection. The excitation from the transducer was performed by using a two cycles tone-burst signal with a frequency of 128 kHz. The detection method was to paste a same size metal block on the experimental plate as a reference target. The signal of the target was used as the reference signal to compare with defect by the ratio of a defect to target, as an evaluation criteria to detect defects. The metal reference blocks used in this study were 13 mm long, 7 mm wide, 1.5 mm in thickness, and 19.5 mm in cross-sectional area. In each case of this study, weld and target had same propagation distance of wave to evaluate each weld reflection signal equally.

The measured signals in the form of an A&C-scan image was presented in Figure 8. In a C-scan image, dashed lines denote signals of welds and solid line denote signals of targets. Intersecting point is the largest amplitude of target and weld signal. Horizontal axis means scanning distance ($y$-direction); vertical axis means wave propagating distance ($x$-direction). A-scan image shows the waveform of weld signal. Each experimental case would carry out five times to show the consistency of the experiment. The measurement results were presented in Table 2, it presented a stable result.
Figure 7: An experimentally obtained A&C-scan image of the (a) butt joint; (b) T-type joint (c) lap joint weld.

<table>
<thead>
<tr>
<th>Weld type</th>
<th>Butt joint</th>
<th>T-type joint</th>
<th>Lap joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of weld to target</td>
<td>Measurement 1</td>
<td>2.32</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td>Measurement 2</td>
<td>2.35</td>
<td>2.32</td>
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<td></td>
<td>Measurement 3</td>
<td>2.33</td>
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<tr>
<td></td>
<td>Measurement 4</td>
<td>2.32</td>
<td>2.21</td>
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<tr>
<td></td>
<td>Measurement 5</td>
<td>2.35</td>
<td>2.31</td>
</tr>
<tr>
<td>Average</td>
<td>2.34</td>
<td>2.25</td>
<td>4.53</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.16</td>
<td>0.07</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Table 2: The measurement results of the experiment.
5 Conclusions

The SH\textsubscript{0} guided wave propagation through the butt, T-type and lap-joint welded plates used for almost all industrial equipment were investigated by numerical modeling and experimental measurement. Then the transmission situation when wave passes through weld were demonstrated. By comparing the ratio of weld to target between numerical simulation and experimental measuring, it demonstrated different value but multiple correlations. The numerical result value was larger about 1.7 times than experimental result.

References


