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EFFECTS OF THE PIPE-JOINTS ON ACOUSTIC EMISSION WAVE PROPAGATION VELOCITY

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Abstract

In jointed-pipes, a variety of different acoustic emission (AE) waves can be generated by way of mode conversion, wave reflection and wave transmission from a joint. This can lead to interference waves as resulting complicated signals propagate along the pipe structure. To find out how the joint affects AE wave propagation in the jointed-pipes, experiments were conducted on a thin-walled copper pipes connected with two types of joint, compression and soldered. By using wavelet packet decomposition (WPD) analysis and the time-of-flight method, the apparent velocity of AE waves near the joints could be estimated as a narrow frequency band individually. Results confirmed that the wave velocities determined near a joint were influenced by not only the wave reflection but also the wave transmission. The measured wave velocity was least affected by those for the wave in the low frequency band (<125 kHz). It was also observed that a compression or soldered joint behaved like a low-pass filter to the transmitted AE signal.

Keywords: Acoustic emission, wave velocity, copper pipe, jointed-pipes, wavelet packet decomposition.

1.0 Introduction

Acoustic emission (AE) is the mechanical waves generated by rapid release of energy from a source within a material. They propagate through the material of the structure. One major application of the acoustic emission method is source location of defects in a structure using the arrival times of the signals at one or more sensors and this includes locating leaks in pipeline. Due to the fact that more than one AE wave mode is often produced at a source and that the different modes propagate at a different velocity, if the pipes connected with joints are now considered, complication occurs. When one of these modes interacts with the joint, reflected and transmitted waves of a variety of modes may be generated. This is because when a wave impinges an interface or boundary between two media, the wave energy is partly reflected and partly transmitted. The reflected waves might interfere with the original incident waves leading to more complex waves. Jin et al. [1] studied the wave reflection, conversion and transmission of Lamb wave mode propagating in a boundary plate. Hamstead et al. [2] studied the edge reflection using a small sample block superimposed on a large sample block with the lateral dimension sufficiently large to avoid the reflections from the sample edges. They reported that edge reflections, caused by the side edges of the small sample and also from the ends of the large sample, could superimpose on the direct signals when the source was an in-plane dipole located at a depth of 0.47 mm below the top surface. Rose [3] used the ultrasonic through-transmission approach for lap splice joint inspection to study the effects of the joint on wave propagation.

In this paper, the effects of joints on the wave propagation velocity were studied. Experiments were conducted on thin-walled copper pipes connected together with compression or soldered joints. The joints caused the pipe discontinuity in geometry due to the different thicknesses of the pipe wall and of the joints. Wave propagation was studied for this case where at the discontinuity, part of the incident wave energy is reflected and the rest is transmitted. If the AE sensor is positioned upstream of and close to the joint, the combined incident and reflected waves can make the accurate determination of the time of arrival of the signal at the sensor very difficult. This is because the cross-correlation method, which is used to obtain the time delay in the arrival of the signals at the two sensors, relies on the integrity of the wave shape of the signal.

If a signal from a given source position is detected at some other position after a time delay, Δt, and if the received signal comprises a swept sine wave plus extraneous noise, a cross-correlation between the two signals provides a signal which peaks at a time delay corresponding to the transmission delay. Given the wave propagating velocity, V, in the medium, the cross-correlation function thus allows an estimation of the distance, L, between the source and the receiver by the simple equation:

$$L = V \cdot \Delta t \quad (1)$$

2.0 Wavelet Packet Decomposition

It was reported that wavelet transform (WT) could improve the accuracy of AE source location on thin plates where the source was a transient AE signal [4]-[8]. However, for sources that produce a continuous AE signal, the accuracy seems to be less satisfactory. In the work by Shehadehand et al [9], they used wavelet packet decomposition combined with cross-correlation for determining the wave velocity in a long steel pipeline and they reported good estimates.

The work of Wichaidit and Au [10] shows that the idea of decomposing a dispersive wave component down to a single frequency or at least a narrow band of frequencies is a sensible alternative so that the wave velocity can be determined with greater accuracy. Wavelet packet decomposition (WPD) can offer that advantage because it separates a signal into narrow frequency bands. The number of bands depends on the level order of the WPD.

In this paper, a third-level WPD with the fourth-order Daubechies wavelet was used. Consequently eight wavelet bands for each signal were created. The approximate frequency components for each band at each level are shown in Fig. 1

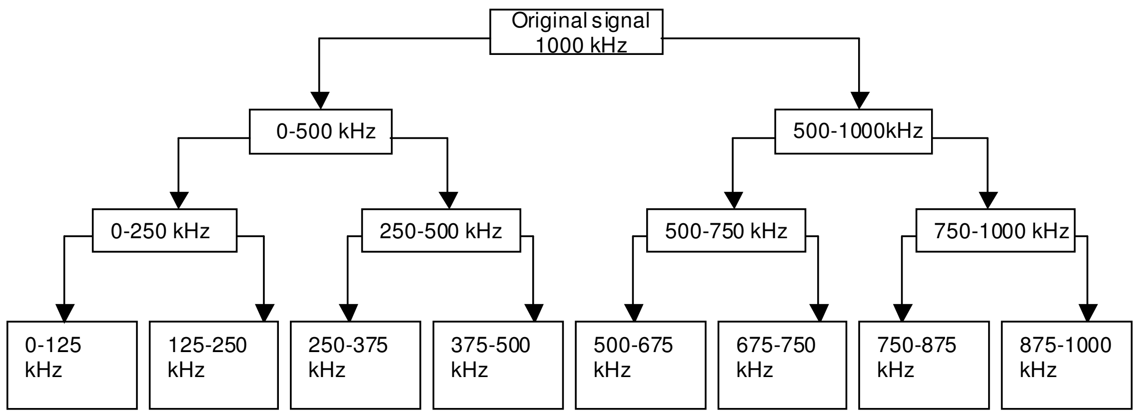

Fig. 1. The frequency bands for the different levels of the 3rd-order Daubechies (db4) wavelets for a signal sampled at 2 MHz.

3.0 Experiment

The objective of this experiment was to investigate how the proximity of the sensor to the joint affected the measured wave propagation velocity. Experimental setups involved two pipe test rigs. One was a 5-metre run of copper pipe (BS 2871:1972), formed from a 3-metre and a 2-metre pipe joined with a compression joint. The copper pipe had an outer diameter of 22 mm with a wall thickness of 0.9 mm. Another one was a 6-metre run of copper pipe with the same diameter and wall thickness, formed from two of 3-metre pipes jointed with a soldered joint. The AE source S generated by pencil lead break was picked up with two broadband PAC-WD type AE sensors, T1 and T2, as shown in Fig. 2. The output from the sensor was fed to a preamplifier (60 dB gain) with a built-in band-pass filter (20 kHz – 1 MHz). The voltage output from the preamplifier was sampled at 2 MHz into a PC driven by LabVIEW™. The record length for each signal was 0.050 s. The acquired waveforms were stored for subsequent signal processing in MATLAB™. Ten trials were recorded for each experiment. The experimental procedure is described below:

a) For both pipe test rigs (with compression joints and with soldered joints), sensors T1 and T2 were always placed 2-m apart and the pencil-lead source was always generated 0.2 m to the left of T1. The distance *y* measured from the middle joint to the sensor T2 was, however, variable, as shown Fig. 2. When T2 was to the left of the joint, *y* had a negative value and vice versa.

b) For the compression-joint pipeline, y = -0.525, -0.425, -0.325, -0.225, -0.125, -0.075, -0.025, 0.025, 0.075, 0.175, 0.275, 0.375 or 0.575 m.

c) For the soldered-joint pipeline, *y* = -0.507, -0.307, -0.107, -0.057, ±0.007, 0.207, 0.390 and 0.707 m.

d) At each of these positions of *y*, the pencil-lead source was generated and AE signals were recorded at the sampling rate of 2 MHz for the duration of 0.05 s.

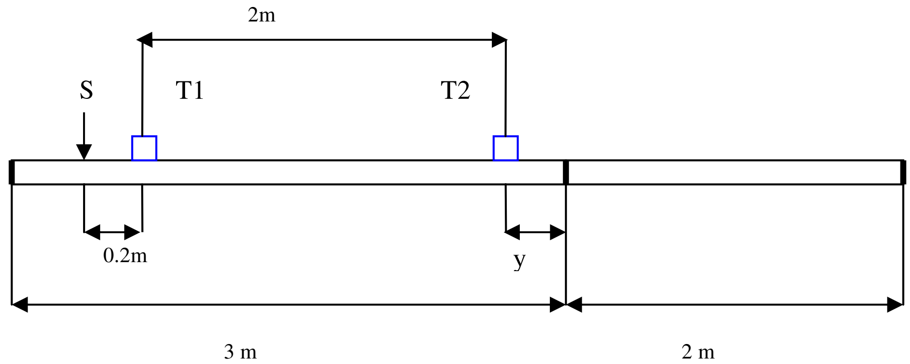

Fig. 2. Schematic diagram of the joint reflection measurement

4.0 Results and Discussion

The effect of the compression joint to the transmitted signal is clearly demonstrated in Fig. 3. The diagrams on the left are the AE time signals and those on the right are the corresponding frequency spectra. The top pair shows the signal detected at the sensor T2 (Fig. 2) which was at the distance of 0.525 m upstream of the middle compression joint, the middle pair for T2 being 0.225 m downstream and the bottom pair for T2 0.575 downstream of the middle joint. It is noted that as the signal propagated past the joint, the higher frequency components were much more severely attenuated than the lower frequency components.

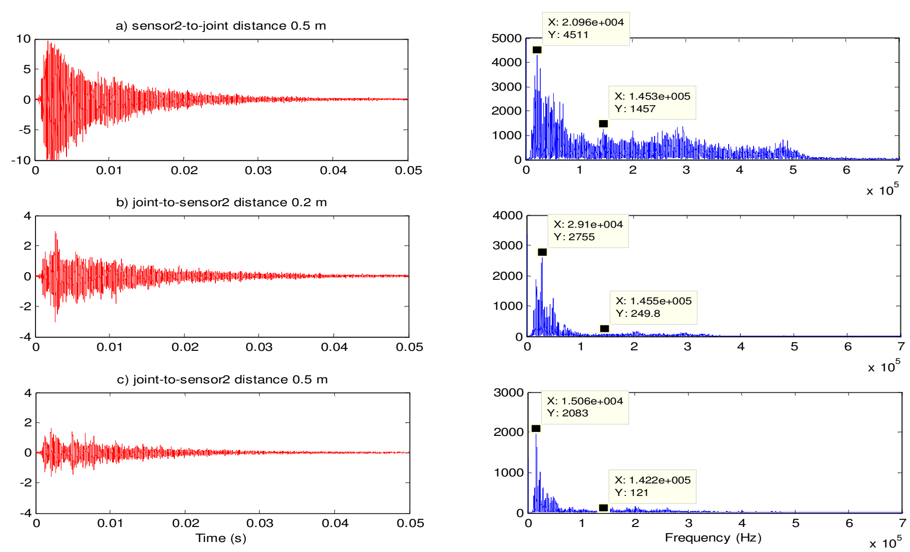

Fig. 3. The typical waveforms and their spectrum of the detected signal at sensor2 positions away from the compression joint a) 0.525-m T2-to-joint distant, b) 0.225-m joint-to-T2 distant and c) 0.575-m joint-to-T2 distant

The wave velocity at each position of *y* in Fig. 2 was determined. Due to the fact that when *y* was small, the value of the wave velocity obtained would be affected by the wave reflection from the joint, the wave velocity is therefore called the *apparent wave velocity*. This velocity can be calculated by the equation (1) where the distance, *L*, in this case was 2 m and the time difference, Δt, obtained using WPD analysis. The process was that the pair of detected signals was first subjected to a WPD three-level wavelet (db 4) decomposition leading to eight components as shonw in Fig. 1 and corresponding component pairs then cross-correlated.

Plotting these apparent wave velocities against the distance *y* of the sensor T2 from the middle joint, with *y* being negative if T2 is to the left of the joint and positive if T2 is to the right, Fig. 4 for the pipeline with compression joints and Fig. 5 for the pipeline with soldered joints were obtained.

Referring to Figs. 4 to 5, it is possible to make the following observations with respect to apparent wave velocity:

1. That the joints had a stronger effect on the velocity of the higher frequency components (>125 kHz) than on the low frequency component (<125 kHz).
2. That the compression joint caused velocity fluctuations up to the distance of 0.8 m both upstream and downstream.
3. That the soldered joint caused velocity fluctuations up to the distance of 0.8 m downstream but considerably much greater distance upstream, up to 2 m.

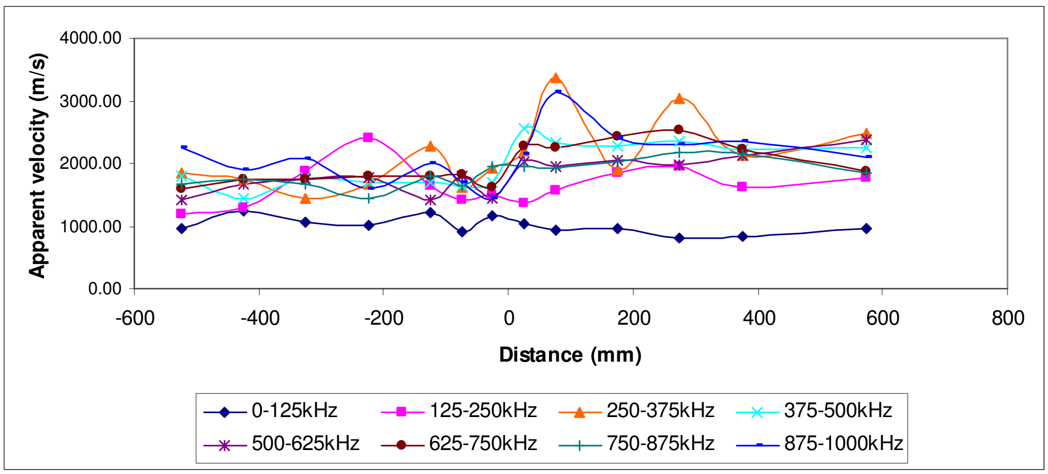

Fig. 4. Plots of the apparent velocities versus the distances of the sensor T2 from the compression joint distances ranging from -0.525 m to 0.575 m using WPD method

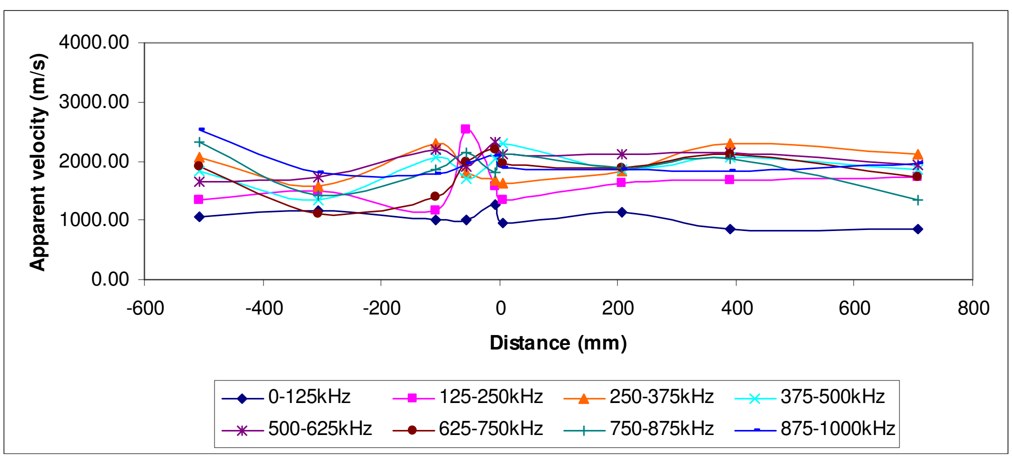

Fig. 5. Plots of the apparent velocities versus the distances of the sensor T2 from the soldered joint distances ranging from -0.507 m to 0.707 m using WPD method

5.0 Conclusion

The reflected and transmitted AE signals from the compression and soldered joints were studied. The wave velocity measured using the time-of-flight method showed considerable variation as the sensor was placed at various distances away from the joint up to a range. Beyond this range, the measured wave velocity remained constant. The measured wave velocity was least affected by this phenomenon for the wave in the frequency band of 0 to 125 kHz. It was also found that the joint behaved like a low-pass frequency filter for the transmitted signal.

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