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DEFECT SIZE ESTIMATION IN PIPES BY MEASURING THE GROUP VELOCITY OF GUIDED WAVE

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Abstract

The guided wave measurement gives an estimation of the defects over a long distance in the pipe; therefore, the guided wave is usable for long pipe monitoring. In this paper, an angle beam transducer with a 46.49 degree incident angle excited by a tone burst signal of 2 MHz are used in our experiment to generate the L(0,2) mode of the guided wave in the steel-stainless test pipe. Experiments are carried out for estimating the defect size by measuring the group velocity and time delay of the echoes by an identical angle beam transducer. The relationship between the group velocity and pipe thickness is shown in the dispersion curve distinctly. The time delay and group velocity changes of L(0,2) mode are measured for the pipe without and with various defects. The results show that L(0,2) mode propagates in defects with different veloc ity when the depth of the defect is not the same. In addition, the wider defect causes a longer time delay of the signal. From the results obtained in this study, we can quantitatively determine the severity of the defects using guided wave along the pipe.

INTRODUCTION

The refinery, gas, chemical and petro-chemical industries operate widely the pipeline systems which usually carry high pressure, high temperature or even highly corrosive fluids. Therefore, it is necessary to develop methods to assess reliability of pipeline testing for public safety. Conventional ultrasonic testing of compression wave essentially measures the wall thickness of the pipe below the transducer; however, it is a time-consuming inspection.

In recent years, guided wave inspection having a lot of superiorities over conventional ultrasonic inspection has been paid attention to. Low cost, long inspection range and time efficiency are the main advantages of guided waves. Lots of researches have used guided wave for defect inspection in pipes [1-5]. There are several ways to introduce guided wave in pipes. Alleyne and Cawley reported the use of dry coupled piezoelectric transducer system in long range pipeline inspection for corrosion and other defects. Rose *et al.* used a circumferentially placed array composed of Plexiglas wedges for transmitter and receiver. By tuning phase velocity and frequency, they improved penetration energy on coated pipe and were able to detect difficult defect shape. For performing non-contact thickness measurement of stainless steel pipe, EMAT excitation was adopted by Luo and Rose. A possible solution for non-contact measurement is the combination of laser ultrasound with air-coupled transducer. Kim *et al.* successfully displayed the defects in 2D scanning image by this kind of setup. Another interesting transducer type of non-axisymmetric end loading was rotated around the pipe and then the directivity of the energy distribution of echo from notches can be detected. Based on the FEM results, Li applied the transducer to the inspection in a pipe.

As far as the quantitative detection of defects are concerned, the shape and axial location of detects and features in the pipe are also determined by reflected signals and the arrival times. Under the L(0,2) mode incidences, the notch reflection problems of the axisymmetric mode and of the mode-converted non-axisymmetric modes are investigated by experiments and FE analysis [6-7]. The reflection coefficient of the echoes increased with increasing circumferential extent and the relationship between the depth of the notch and the reflection coefficient presented with a parabolic curve. Furthermore, the effect of the axial length of the notch for quantitative detection was discussed. The merging effect of the two edge reflected signals enlarged the reflection amplitude for the notch with short axial extent [8]. The reflection coefficient was found by Sanderson *et al.* to change cyclically with the axial length of the notch [9]. More recently, Demma *et al.* [10] investigated the reflection coefficient at varying axial extent and maps of reflection coefficient as a function of the circumferential extent and depth of the notch when a torsional mode T(0,1) was excited. Instead of array of transducers, Siqueira *et al.* [11] used acrylic wedge transducer for generating guided wave in pipe and detecting the echo from the defects. Bandpass filters and wavelet transform were successful signal processing to improve the S/N ratio of the noisy signals. Hayashi *et al.* [12] performed a defect imaging technique by considering the reflections of the defect including only an axisymmetric mode but also non-axisymmetric modes.

In this paper, we investigate a group velocity measurement technique, and the axial length of defects is obtained after calculating the time delay. This technique standing on the defect-induced change in travel time is proposed by Zhu *et al.* [13]. The following applications of the technique are developed individually by Tuzzeo [14], Jenot [15], and Hayashi [16]. However, the above-mentioned measurements of Lamb wave group velocity to gauge the corrosion thickness are implemented not in pipes but in plates. The main object of the present study is to quantify the axial size of defects in a pipe by measuring the group velocity change and time of flight.

EXPERIMENTAL SETUP

The experiment setup for the guided wave measurement is shown in figure 1. Two steel-stainless pipes used in the experiment are 1 m long; O.D. 76 mm; I.D. 70 mm. As shown in figure 2, there are three circumferential notches with different axial lengths and 0.5 mm depth in one pipe; moreover, the depth of four notches in another pipe is 1 mm. The axial lengths of defects are 2 cm, 3 cm and 4 cm in turn and the circumferential lengths are all the same as 60 mm long. Guided waves propagate along the pipe walls and are excited and received by a pair of identical angled transducers. The transmitter is connected to a function generator for tune burst excitation and the propagating signal is displayed in the oscilloscope connected to the receiver. The angle of incidence α_w in the wedge transducers is 46.49°. The centre frequency of the transducers is 2 MHz and the frequency range is about 800 kHz. Figure 3 shows the phase and group velocity dispersion curves of the pipe generated by Disperse software [17]. The phase velocity V_{ph} of the corresponding incident angle is 3764.2 m/s and the modes L(0,2), F(1,4) and F(1,6) would be generated at the same incident angle.

Measurement of group velocity

We keep the right hand side of the test pipes defect-free for measuring the reference group velocity, V_{gm}. Two detection positions are acquired for the measurement. In the reference zone, the position of the transmitter is 20 cm away from the pipe end and the two distances L between the receiver and transmitter are 3 cm and 11 cm, respectively. The value of V_{gm} can be decided by the distance between two receivers and the time-of-flight measured from two received signals.
To determine the group velocity V_{gd1} and V_{gd2} of the defective zones with 0.5 mm depth and 1 mm depth respectively, the following relation is used

$$\frac{AL}{V_{gd}} + \frac{L - AL}{V_{gm}} = \Delta t \tag{1}$$

where Δt is the time of flight between the echo of the two receiving positions, AL is the axial length of the defect under testing, V_{gd} is the group velocity in the defect. As shown in figure 2, the defect with 2 cm axial length is used for measuring the group velocity V_{gd1} and V_{gd2} in the defects with 0.5 mm depth and 1 mm depth. For the value of AL is 20 mm and L is 80 mm, the group velocity V_{gd1} and V_{gd2} can then be determined when the value of V_{gm} and Δt is measured.

Defect axial length gauging

The process of the measurement of the axial length is the same as the measurement of the group velocity of the defective zone. Nevertheless, the difference is that we treat the AL as an unknown value and the value can be determined by measuring the time of flight. It should be noted that the value of V_{gm} and V_{gd} is known in this process. The axial length of the defect can be expressed as

$$AL = \left| V_{gd} (\Delta t - \frac{L - AL}{V_{gm}}) \right| \tag{2}$$

where V_{gd} depends on not the axial length of the defect but the depth of the defect [14].

RESULTS AND DISCUSSION

Guided waves are detected in the steel pipe in the experiment setup. The time domain of the measurement in reference zone is shown in figure 4. To measure the group velocity, we change the distance between the receiver and the transmitter from 3 cm to 11 cm and measure the delay time between the two centers of the received waveforms. After calculating the delay time, this group velocity V_{gm} is 2400.9 ms^{-1} for the experiment and 2507 ms^{-1} for the theoretical value V_{gc} obtained from the dispersion curve. The results of measuring the different defective zone are shown in figure 5 and 6. In defective zone 1, the depth of the defect is 0.5 mm and the measured group velocity V_{gd1} is 2166.8 ms^{-1}. In defective zone 2, the depth of the defect is 1 mm and the measured group velocity V_{gd2} is 2526.9 ms^{-1}. The relative theoretical group velocities V_{gdc} of the defects are 2204 $ms^{-1}$and 2576 ms^{-1}, respectively. With the known group velocities and the distance between the transmitter and receiver, and the time of flight of the test defects measured from figure 5 and 6, the AL can be obtained by equation (2). All the calculated results of the AL are listed in Table 1. The error of the calculated *AL*, compare to its actual length of the defective zone, is larger when the defect is deeper or the axial length of the defect is longer. That is to say, the shape of the defect will cause the waveform spread in the time domain and the corresponding error is then increased.

CONCLUSIONS

Quantitative measurement of the axial length of the defects using guided wave along the pipe is performed in this study. A pair of angle beam transducers is used to generate L(0,2) mode and receive the propagating modes in pipe respectively. According to the dispersive behavior of the L(0,2) mode in the frequency-thickness region we used, L(0,2) mode propagates in defects with different velocity when the depth of the defect is not the same. A change in group velocity can be observed in reference zone and in the defective zones. However, more signal processing methods are needed to improve the measurement of the time of flight and the errors caused by the dispersive waveforms.

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Table 1: Measured group velocity and the axial length of the defects for pipe1 (the defect depth is 0.5 mm) and pipe 2 (the defect depth is 1 mm)

	V_{gc} (m/s)	V_{gdc} (m/s)	V_{gm} (m/s)	V_{gd} (m/s)	AL_{3cm} (cm)	AL_{4cm} (cm)
Pipe 1	2507	2204	2400.9	2166.8	3.045	3.757
Pipe 2	2507	2576	2400.9	2526.9	2.635	4.295

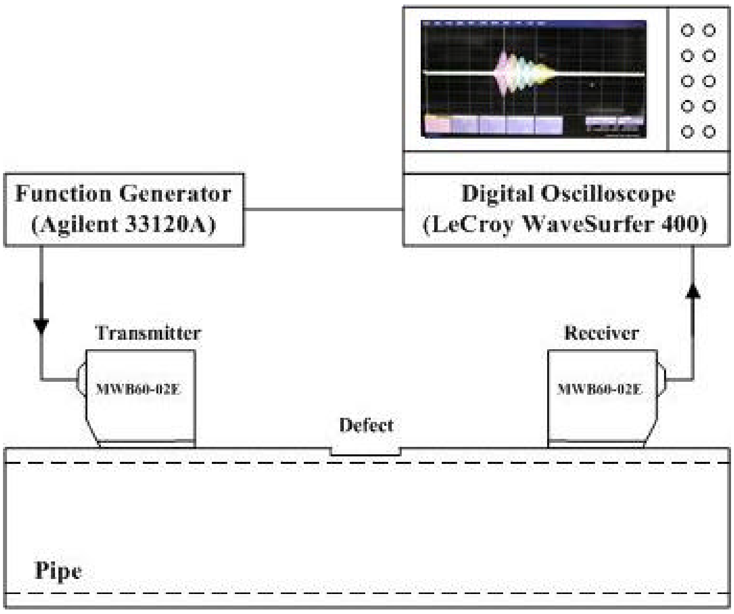
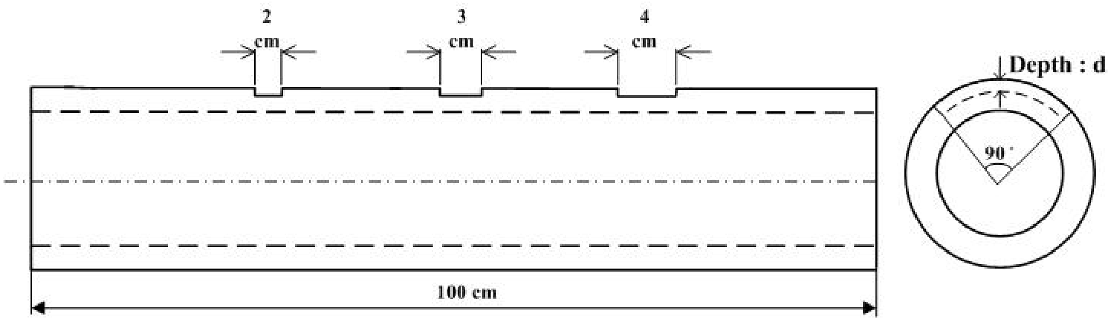
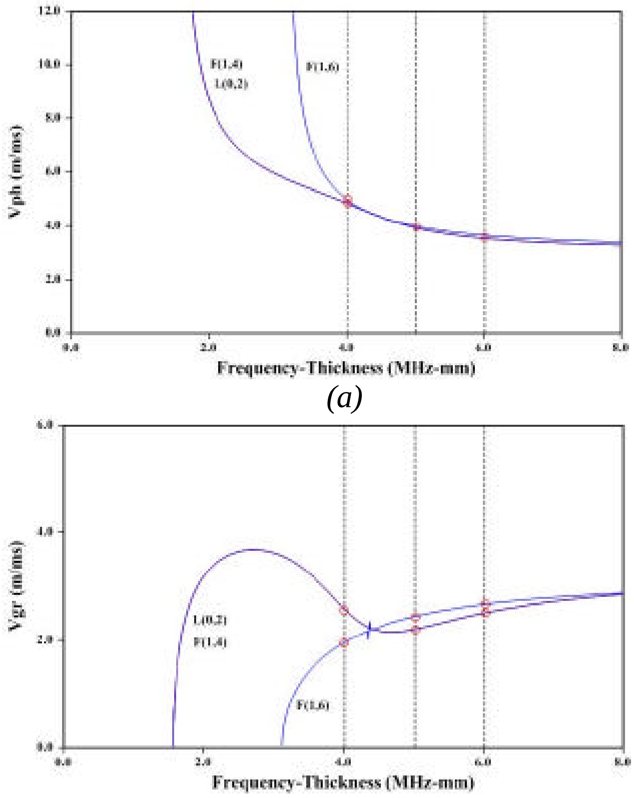


Figure 1 – Experimental setup.



(a) *(b)*

Figure 2 –Artificial defects; (a) with different axial length on the pipe, and (b) circumferential section.



(a)

(b)

Figure 3 – (a) Phase velocity dispersion curves, and (b) group velocity dispersion curves of the testing pipe [17].

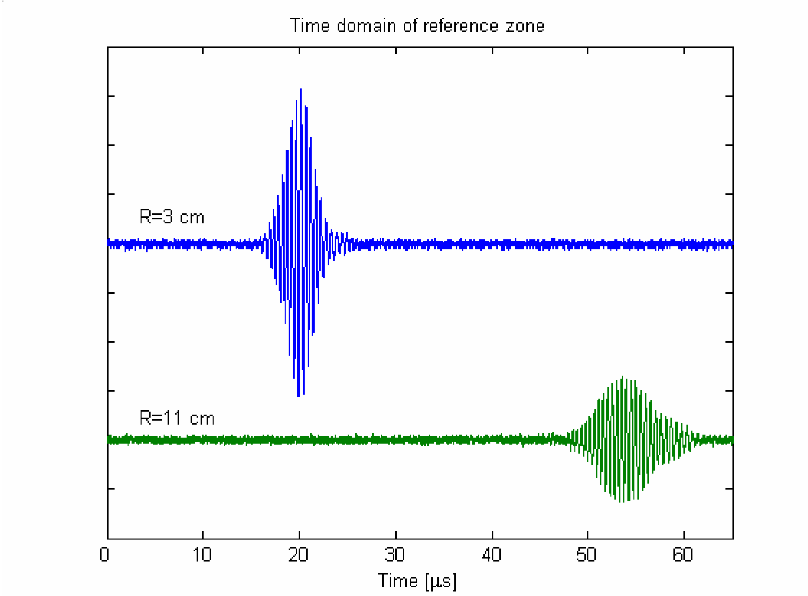


Figure 4 –In reference zone, results for receiver away from transmitter 3 cm and 11 cm.

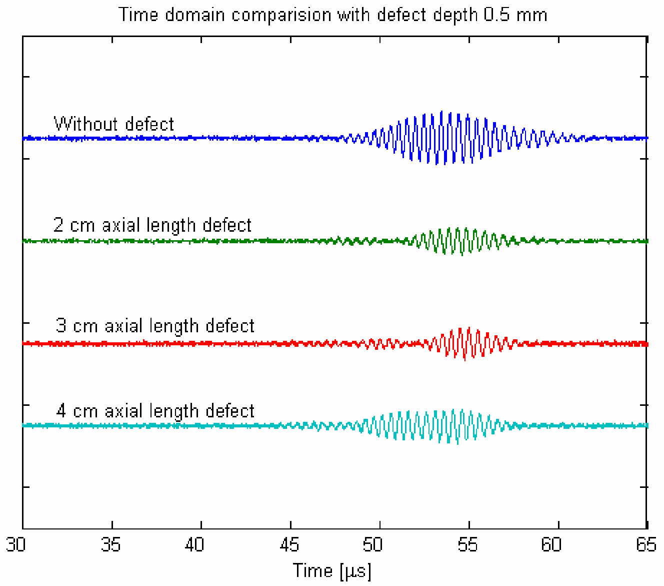


Figure 5–In defective zone 1, results for receiver away from transmitter 3 cm and 11 cm.

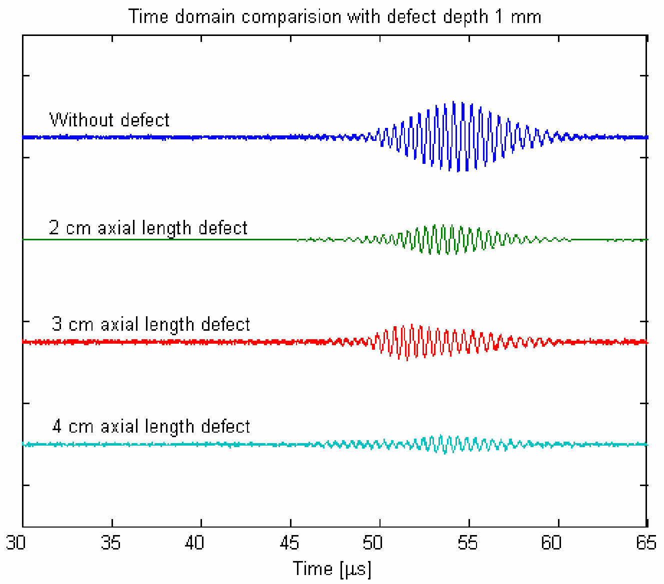


Figure 6–In defective zone 2, results for receiver away from transmitter 3 cm and 11 cm.