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Experimental study of guided wave propagation and damage detection in large diameter pipe filled by different fluids

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ABSTRACT

A series of experiments on damage detection of large-diameter (88 mm diameter) pipe with and without liquid by guided waves have been conducted. Two types of liquid as water and machine oil are chosen to fill in pipe for detecting the influence of filler. The influences of liquid types on guided wave propagation, dispersion and attenuation characteristics have also been studied. The mode conversion phenomenon of reflection waves exists regardless filling state of pipe, but it is most serious in water-filled pipe, and weakest in vacant pipe. The defect wave signal could be distinguished from converted wave mode by time-frequency analysis, and the time-frequency distributions of the two type signals are different. The relationship between defect length and defect reflect signal strength is linear in vacant pipe and nonlinear in liquid-filled pipe. With the defect length increasing, the defect signals of liquid-filled pipe increase too, but the rate of increment are reduced.

1. Introduction

Industrial and civil life pipes for fluids transporting, such as gas, water and oil, have been widely distributed all over the world. The pipelines are the third major transport method in the world. However, for some exceptional cases, such as nuclear steam generator tubing [1] and underground buried pipes [2], it is uneasy to use traditional ultrasonic A-scan to scan defect of the pipe by point-to-point way on the outline of pipe. The guided waves are a series of longitudinal propagation wave packets, which different from the traditional ultrasonic wave mainly focus on local area in depth direction, could be excited in a local section of pipe wall to detect defect of pipe in longitudinal direction [3].

Lowe et al. [4] employ the long-range guided waves to detect defects in unfilled pipe firstly. It reveals the potential application prospects of guided wave on damage detection. Then, the dispersion curves and wave modes analysis of unfilled pipe have been conducted by Wilcox et al. [5]. They notice that there are several types of wave modes exist in pipes when guided wave propagating. Therefore, the existence of mode conversion and the occurrence pattern of it become a focus of current research. The mode conversion of notch echo has also been studied by them in succession [6,7]. Their research shows that the reflect mode F(1, 3) as strongly as the axially symmetric L(0,2) mode when the notch length is short, and the F(2,3) also received in reflection. On the other hand, the pipes inevitably filled with liquids in practice. Thus, there are many researchers have studied the dispersion characteristics of guided waves in water-filled cylindrical pipe by theoretical analysis [8,9] and numerical calculations [10,11]. They conclude that the dispersion curves of water-filled pipe are very different from the unfilled one. The guided waves in water are approximate plane-wave motion. The research of Aristégui et al. [12] indicate that there is a α mode exists in water-filled pipe as the water mode which generated by leaked guided waves [13] from pipe wall. And the experiments of guided waves propagate in small diameter (6.8 mm) and thin thickness (0.7 mm) copper pipe with different liquids inside and outside of pipe have been done by them. Their research results show that α mode is nearly a constant in water filled pipe at low frequencies, the guided waves decrease more rapid than outer wall at high frequencies due to wave leakage into inside and surrounding water. The pipe filled by viscosity fluid (castor oil) and signal attenuation of it have also been discussed in their report. It could conclude that the guided waves in liquid-filled pipes are very different from that of vacant pipes. And the mode characteristics of guided wave in liquid-filled pipe are influenced by several factors. Long et al. [2] make experimental and numerical analysis investigate on symmetric (longitudinal) and non-axis-symmetric (flexural) modes attenuation of guided wave in

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water-filled pipe. They also obtain dispersion curves of large-sized (152.4 mm diameter and 5600 mm in length) iron water pipe. The results of their works point out that α mode of water is frequency-radius independent. L(0,1) and F(1,1) modes are low frequencies characterized modes; L(0,2), F(1,2) and F(1,3) modes are higher frequencies characterized modes of it. By contrasting their works with Aristégui et al. [12], it notices that the pipe dimension, such as diameter and thickness, has effects on propagation modes of guided wave. Due to the diversity of modes in liquid-filled pipe, the research of mode selection for guided wave excitation and acquisition are conducted by many researchers. The guided wave mode selection in liquid-filled pipe by dispersion characteristics has been researched by Liu et al. [14]. Their experimental results indicate that the low frequency band with weak dispersion of guided waves and the higher the frequency, the richer the guided wave modes. Song et al. [15] have made a numerical simulation on damage detection of water-filled and unfilled pipe by guided wave. The simulation employ fluid-solid coupling algorithm to obtain the wave dispersion and attenuation characteristics changings between water-filled and unfilled pipe. Elvira-Segura [16] makes a theoretical and numerical analysis of Kirchhoff's propagation constant and attenuation of acoustic wave in viscous liquid-filled pipe, and the viscous attenuation mechanism has been addressed as the wave energy absorption of viscous liquid and momentum transport of the viscous boundary layer in side of pipe (close to pipe wall). Recently, Wöckel et al. [17] conduct the experiments of guided wave propagating in a PVC (viscoelastic) pipe with water filling inside at a very low frequency. Their research find that a deterministic jumping of the wave modes and dispersion characteristics of liquid could be caused by an additional fluid phase. Leinov et al. [18] apply the guided wave testing on a full-scale large-sized pipe buried in water-saturated/drained sand to measure the signal attenuation and modes changing over a range of sand conditions. The research show that the detection signal attenuation phenomenon in buried pipes result from energy leakage into embedding media. Djili et al. [19] use L(0,2) mode of guided wave with high frequency to detect the damage on cooper pipe filled with static water immersed in water. This research proved this damage detection method is valid for liquid filled and surround pipe. A numerical contrasted study of guided wave propagation in vacant and fluid-filled pipe has been conducted by Deng et al. [20]. Their analysis modal takes the flow of the liquid into consideration, and the effect of fluid velocity are also been discussed. The research shows that velocity of the fluid only affects the wave velocity before the sharp drop points. It should be notice that there already lots of research could reveal that guided wave modes are influenced by pipe dimension and mode conversion exists in pipe when guided wave propagating. It also could conclude that the guided waves in liquid-filled has its own features. However, there is few reference mentions the experiments contrast or theoretical analysis on guided wave propagation and damage detection in large diameter pipes filled by different states: vacant, ideal fluid-filled and viscoelastic fluid-filled. And the influences of liquid types on mode conversion of guided wave propagation characteristics are also less

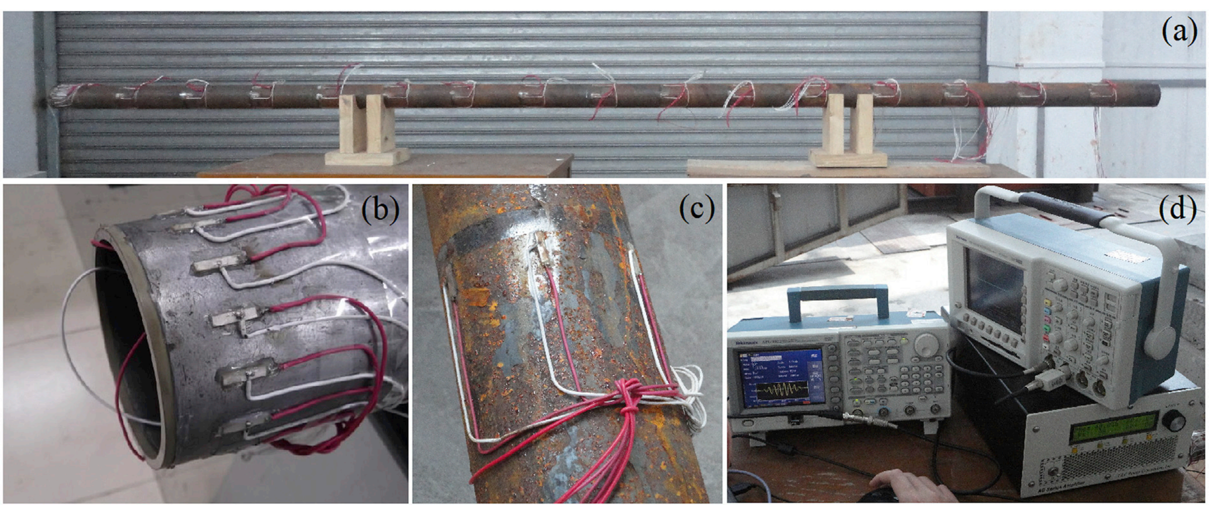

Fig. 1. Experiments setup.

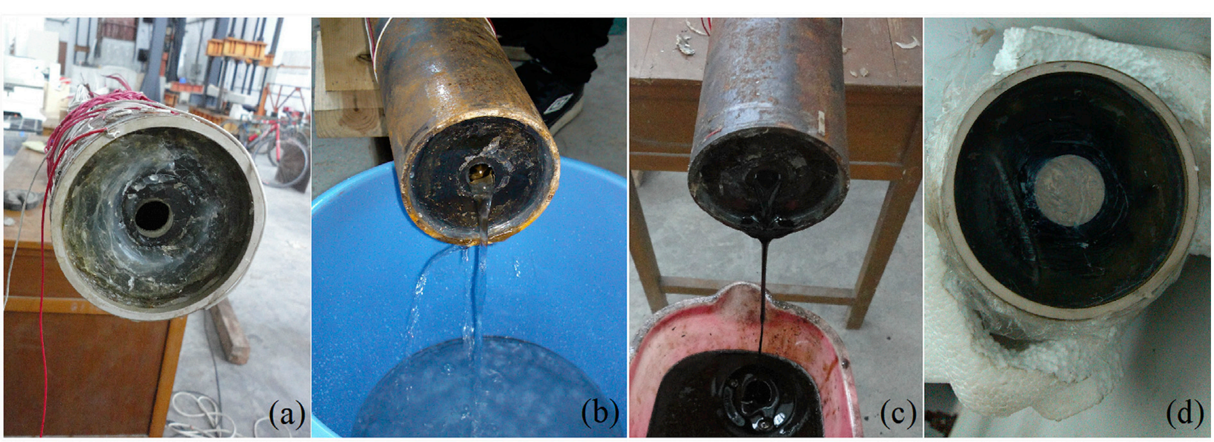

Fig. 2. Pipe filled by different filling state: vacant, water and oil.