Study on Relationship between Amplitudes of Reflection Signals and Positions of Magnetostrictive Transducer

Lihua SHEN, Yuemin WANG *, Fengrui SUN, Fan ZENG, Chuanjun SHEN
College of Ship and Power; Naval University of Engineering;
NO. 717, Jiefang Road, Wuhan 430033 China
Tel: +86-27-83443273, Fax: +86-27-83443273
E-mail: yuemin_wang@163.com

Abstract:

As one of key techniques for guided waves NDT based on magnetostrictive effect, the transducer is a "bridge" which plays an important role in practical inspection. In the experiments, we find that the guided wave echo-signals detected in pipes are affected by the position of the magnetostrictive transducer. First, guided waves' generation mechanism and its propagating characteristics in pipes are theoretically analyzed. Second, several experiments are carried out to verify this theory. At last, the relationship between amplitudes of the refection signals and positions of the transducer are discussed.

For a given detected steel pipe, when the transducer is installed on different position of pipe, the varieties of guided wave signals are detected and analyzed using computer. The various curves between amplitudes of the refection signals and positions of the transducer are obtained , and the "wave crest" and "wave trough" appeare periodically. In the practical inspection, the positions where the "wave crest" appeares in the curves should be selected as location of the transducer. To generate and receive the most perfect signals whose wave energy is stronger and the signal-to-noise ratio increased greatly, the positions of guided wave transducer should be optimally selected according to different type pipes. The experimental results are very well agreed with the theoretical analysis.

Keywords: Guided wave, magnetostrictive transducer, NDT, pipe

1. Introduction

As one new digital non-destructive testing technology, the guided wave NDT, which has the advantage of inspecting the whole wall thickness and spreading long distance of pipe from a single probe position, has been applied widely in long pipe inspection [1-3]. At present, two main guided wave testing methods, which are based on piezoelectric effect [4] and magnetostrictive effect [5-7] respectively, are studied mostly by the researchers. These differences are the methods of exciting and receiving guided waves, while the propagating characteristics of guided wave are same. The generation of guided wave and inspection of echoes are realized by the guided wave transducers, and the modes of guided wave generated can also be controlled by the alteration of transducer's configuration.

In the experiments, the guided wave echo-signals detected in pipes are changed as the position of magnetostrictive transducer moves along the axial direction of the pipe and the amplitudes of echo-signals and SNR are also affected by the transducer's position located at the pipe. The detected signal waveforms are received when the transducer is installed on different position of a given steel pipe. The various curves between amplitudes of the refection signals and positions of the transducer are obtained by analyzing these received signals.

2. Fundamental of magnetostrictive guided wave transducer

A time-varying magnetic field is applied to the ferromagnetic pipe, which has been magnetized by static bias magnet, and mechanical guided wave is generated along the pipe via magnetostrictive or Joule effect. When the elastic (or mechanical) wave passes by the receiving transducer, the magnetic induction of the pipe changes because of the inverse-magnetostrictive (Villari) effect. The changes in magnetic induction bring about an electrical voltage signals in the receiving transducer via Faraday effect. The induced electrical voltage signals involve the information that whether cracks corrosion or defects existed in the steel pipe.

The exciting and receiving of guided waves, and the magnetization of inspected steel pipe, are all realized by the magentostrictive transducer. Exciting transducer, receiving coil and static bias magnetic field, which make up of the sensor, realize the corresponding function respectively. A bias magnet applies a DC magnetization to the steel pipe and maintains ferromagnetic materials in a magnetized state. The DC magnetization is necessary to enhance the efficiency of the sensor, which converts electrical energy into mechanical energy, and maintain a linear transduction between the electrical signals and the elastic waves [7,8]. When the guide wave propagates along the steel pipe, there are three modes: longitudinal mode *L*(0,m), torisonal mode *T*(0,m), flexural mode *F*(n, m). When the bias magnetic field is parallel to the coil magnet field, longitudinal guided wave can be generated along the ferromagnetism pipe.

The general elastic wave equation with a magnetostrictive forcing term is expressed as Eq.(2.1) [9].

$$\rho \ddot{u}_i = \frac{\partial \sigma_{ik}}{\partial x_k} + f_i^{em} + f_i^{ms} \tag{2.1}$$

where ρ is the density of the metal; $\ddot{u}_i$ is the *i*-th elastic wave displacement f_i^{ms} is the magnetostriction force; f_i^{em} is the electromagnetic force; σ_{ik} represents the *ik*-th element of the elastic stress tensor; x_k is the Cartesian coordinate. In our experiment, the low frequencies of the guided wave (up to a few hundred kHz) are excellent for inspection [8]. At low frequencies, $f^{ms} >> f^{em}$. So the f^{em} is ignored in the equation (2.1) generally.

The magnetostrictive force f_z^{ms} can be calculated by Eq. (2.2):

$$f_z^{ms} = -\frac{1}{2}(3\hat{\lambda} + 2\hat{\mu})(1-2\upsilon)\frac{\partial \lambda}{\partial M_0}\frac{\partial m_z}{\partial z} \tag{2.2}$$

Where $\hat{\lambda}$、$\hat{\mu}$ are Lame coefficient, υ is Poisson's ration, λ is linear magnetostrictive constant, M_0 is the static magnetization, m_z is the alternating magnetization.

$$u(k,x,t) = \frac{\lambda u_r}{2E}\int_0^l H(\xi) e^{jk(\xi - x + ct)} d\xi \tag{2.3}$$

Where E is Young's modulus, $c = \sqrt{E/\rho}$, the velocity of the longitudinal sound wave in the medium.

$H(x)$ is the magnetic field distribution function, l is the length of the receiving coil, μ_r is the reversible permeability,

The voltage detected by the receiving coil can be written as follows:

$$V_0(k,t) = -4\pi\mu_r \lambda ns \int_l^{d+l} e(x) \frac{\partial^2 u}{\partial x \partial t} dx \tag{2.4}$$

Where $e(x)$ is the efficiency ratio of the receiving coil; n is the circles of receiving coil per mile, s is the cross section area of coil.

The above equations are integrated together to the fundaments of the magnetostrictive longitudinal transducer. From above functions, we can see that the transducer' position " d " is one of factors which affect the receiving voltage of guided wave. In order to insure the best inspecting position, the next two parts of this article would be devoted to discussing the effect to receiving of guided wave because of the transducer' position.

3. Experimental arrangements

A steel pipe of inside diameter 33mm, outside diameter 38mm and length 6.5m was used as the inspecting object. There were three artificial defects of different diameter(φ5mm, φ10mm, φ12mm) in the experimental pipe as shown in Fig.1.

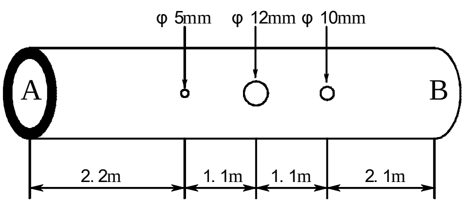


Fig. 1 The sketch of steel pipe used in experiment

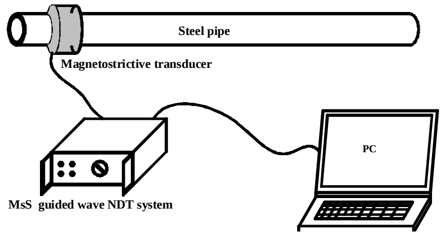


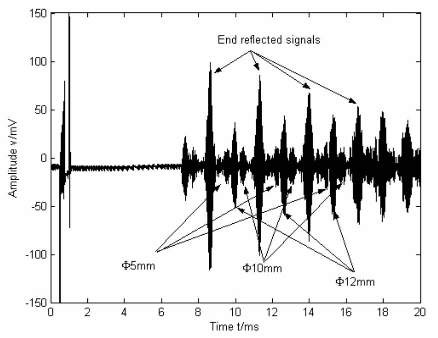
Fig. 2.The schematic diagram of the experimental set-up

The above pipe was inspected experimentally by the magnetostricitve guided wave NDT system developed by us. The fundamental frame had been detail discussed in [6, 7] and a schematic diagram of the experimental set-up is shown in Fig.2. The 20kHz frequency guided wave was generated in the pipe by making use of the guided wave NDT system. The magnetostrictive transducer' position changed along the pipe by 1cm per step relative to the end A as shown in Fig. 1. The corresponding guided wave signals, when the transducer located at different position of pipe, were received by the mangentostrictive sensor.

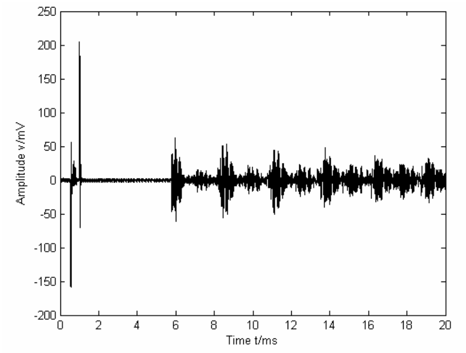
4. Results and discussions

The representative reflected guided wave signals, when the transducer located at the position d=0cm、d=9cm、d=13cm、d=17cm、d=34cm、d=160cm from the end A, were given as shown in Fig.3. By analyzing the information given by the waveforms, we can see that the received signal of reflected guided wave varied markedly when the transducer was installed on the different detecting position of pipe. The dissimilarities were mainly the amplitude of reflected signal and SNR mostly. As the mangentostrictive sensor located at the optimal detected position, the amplitude of signals was bigger and vivid to distinguish the flaw signals of different diameter as shown in Fig. 3-a、Fig. 3-c. However, as shown in Fig. 3-b and

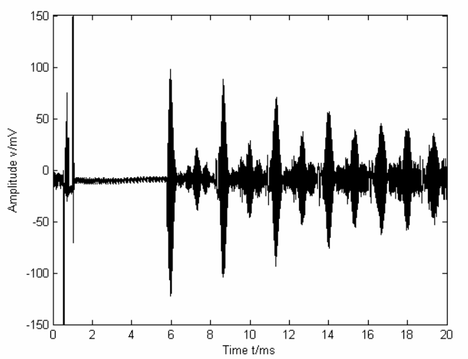
Fig.3-e the signals' amplitude and the SNR decreased obviously to distinguish the flaw signal difficultly when the sensor located at the position where it was unfavorable for detecting. The reflected signals of two pipe ends shown in Fig.3-f, which received by the transducer, covered the defect signals completely as the transducer moved to the middle of pipe gradually. The existence of detects can't be distinguished in the signal waveforms.



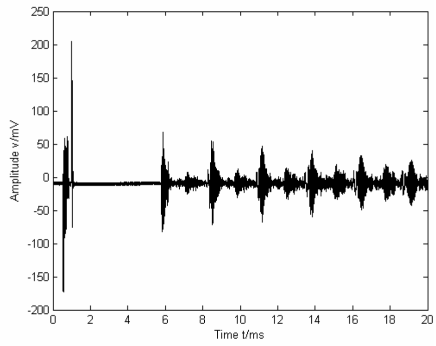
(a) d=0mm



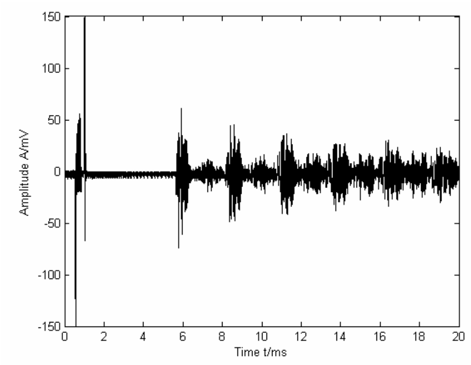
(b) d=9mm



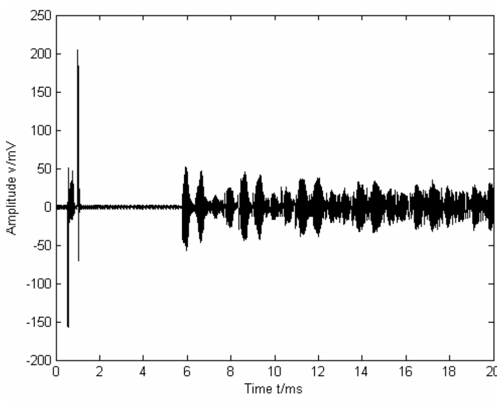
(c) d=13mm



(d) d=17mm



(e) d=34mm



(f) d=160cm

Fig. 3 Detected guided wave signal waveforms when transducer installed on the different position of pipe

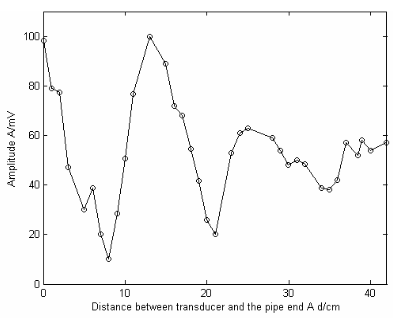


Fig. 4 The various curve between the amplitudes of pipe end

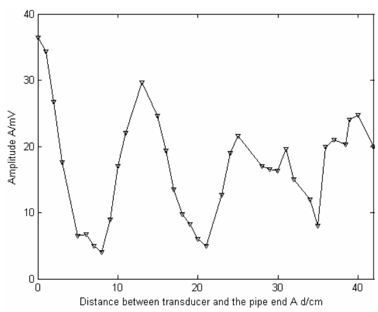


Fig. 5 The various curve between the amplitudes of detect signal

reflected signal and the transducer's position and the transducer's position

The relation curve between amplitude of pipe end reflected signals and the position of the transducer was shown in Fig.4. It indicated that signals amplitude presented the collapsing trend as a whole with the changing distance between transducer and pipe end A. The "wave crest" and "wave trough" appeared periodically. As shown in Fig. 5, the relation curve between the amplitude of Φ12mm defect echo-signals and the changing distance d was similar to trend expressed in Fig. 4. During the changing process, defect echo-signals, the "wave crest" and "wave trough" appeared periodically in the same way.

The ideal waveforms should be similar to Fig. 3-a and Fig. 3-c in the practical engineering, in which the amplitude of signals is high, and the signal-noise ratio is also high. Whether the defects exist in the pipe can be conveniently and clearly differed from the waveforms by analyzing experiment results with the computer. It is concluded that the position of the magnetostrictive transducer had the great influence on the response of guided waves NDT. For this reason, the characteristic of the magnetostrictive transducer should be considered adequately in order to improve the testing effectiveness and the testing response. If the position configuration of the transducer is improper, it may cause the undetected error and dispensable loss. The pipe end signals cover the defect signals as denoted by the waveform of Fig.3-f, and it is difficult to distinguish defect signals from other signals. We should optimize construction of transducer to control the propagation path of guided wave, which only receive the echo signals from one direction and constrain the signals from the other direction, so that it is convenient for analyzing the signals and recognizing all kinds of signals. According to the regulation of signal amplitude appearing periodically that denoted by the Fig. 4 and Fig. 5, the proper transducer's position, where the "wave crest" appeared, should be selected as the detecting region to gain the best waveforms which had the highest amplitude and best SNR.

5. Conclusions

The transducer position is one of factors affect the receiving voltage of detected guided wave signals by analyzing the fundaments of exciting and receiving guided wave. Plenty of experiments are conducted to prove the consequences in this article. The experiment results agree very well with the theoretical conclusion. For a given steel pipe, the varieties of guided wave signals are detected and analyzed using computer when the transducer was installed on different position of pipe. The various curves between amplitudes of the refection signals and positions of the transducer are obtained by analyzing experimental data. In the curve the "wave crest" and "wave trough" appeared periodically. At the same time, the pipe end reflected signals covered the defects information when the sensor moved to the middle of given detected pipe. In this case it was hard to distinguish the flaws. In the practical inspection, the positions where the "wave crest" appeared in the curves should be selected as location of the transducer. To generate and receive the most perfect signals whose wave energy is stronger and the signal-to-noise ratio increased greatly, the positions of guided wave transducer should be optimally selected.

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