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Study on propagation characteristics of ultrasonic guided wave

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1. Introduction

Guided wave technology, which has the advantages of withstand high sensitivity, low attenuation, quickly and efficiently detection etc, is widely used in Nondestructive Testing (NDT) field. To effectively detect the defects, it is necessary to study the propagation characteristics of guided wave.

As guided wave propagating in the waveguide, the reflection occurs at the upper and lower interface. The characteristic of the reflected wave depends only on solid elastic parameters of the waveguide and regardless of the nature of the volatility itself. According to the elasticity theory, when the material properties of the media is constant, the phase velocity and group velocity of guided wave vary with frequency changing, this phenomenon is called as the dispersion phenomenon of [1].

Dispersion curve is used to describe and predict the relationship among the phase velocity, group velocity, frequency and thickness. Excitation, reception and defect discrimination of guided wave are based on solving of the dispersion equation, drawing and analysis of dispersion curves. The curves of phase velocity dispersion is helpful to find the excitation condition of optimal mode, and the curves of group velocity dispersion can be used to predict the propagation velocity of ideal mode [2].

For a steel plate (or tube) of a certain thickness, there are frequencies of two or more guided wave mode at each frequency point, and the number of modes of guided wave also increases rapidly as the frequency increases. The phenomenon is called multi-modal phenomenon of guided wave. Multi-mode characteristics of guided wave cause a lot of trouble in the process of solving practical problems. In the practical application of the electromagnetic ultrasonic flaw detection, it is needed to stimulate a single mode or fewer modes of guided waves, so as to detect plate, rail and pipeline defects effectively.

In this paper, the dispersion characteristics and multimode characteristics of guided waves in the pipe are studied by the disperse simulation software, and the variation rule of dispersion curve is analyzed by the geometric parameters of steel pipe. This is helpful to the mode selection, excitation frequency and transducer structure.

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2. Basic theory of guided wave in the tube

When ultrasonic propagating in the tube, the feflection occurs in the surface of inner and outer walls, forming guided waves as a result of interference. The same phase velocity corresponds to the different ultrasonic wave frequencies, which makes guided wave propagating with different modes. As the wave frequency changes, the phase velocity changes, the guided wave propagation in tube is dispersive. The guided waves in tube own three different propagation modes: longitudinal mode, torsional mode and flexural mode, represented with L (0, m), T (0, m) and F (n, m) respectively, among which the circumferential order n=1,2,3… and the mode number m=1,2,3,…. Circumferential order n indicates the propagation formation when guided waves spiral transmitting around the pipe wall, corresponding to non-axisymmetric mode of guided waves. The mode number m reflects the vibration formation in the thickness direction of the pipe. The L(0,m) mode and T (0, m) mode are axisymmetric, while the F (n, m) mode is non-axisymmetric. The L(0,m) mode and T (0, m) mode are all uncounted when n=0, and each F (n, m) mode is uncounted when n=1,2,3,….. When wall thickness is thin and radius is large, the L(0,m) mode corresponds to Lamb wave and the T(0,m) mode to SH wave in plate.

3. Simulation of dispersion curves of guided wave in the steel pipe

(1) Steel pipe wall thickness impact on guided wave dispersion curve

Assuming the object of study is steel pipe, whose density is 7.932g/cm and the inner diameter is 50mm. The longitudinal velocity is 5.96m/ms, and the shear velocity is 3.26m/ms. The guided wave dispersion curves is simulated within 0-5MHz when the wall thickness of pipe are 1 mm-4mm, respectively. The results are shown in the Table1.

Observing the dispersion curve horizontally, we can draw conclusions that there exists two mode L(0,1)and L(0,2) at low frequencies. The guided wave mode number is increasing with the increasing of frequency.

Comparing the dispersion curve vertically, when the wall thickness of steel pipe changes from 1mm to 4mm, the frequency band where only exist L(0,1) and L(0,2) is becoming narrow, and the upper limit frequency is becoming low.

A nonlinear relationship exists between narrowing of frequency band and the increasing of wall thickness. At the same time, with the guided wave mode number increasing in specific frequency, the dispersion curves become more intensive and complex.

Table 1 Dispersion curve data in steel pipes with different wall thickness

Wall thickness (mm)	1	2	3	4
The frequency band where only exist L(0,1) and L(0,2) (MHz)	0-1.7	0-1	0-0.6	0-0.5
The number of guided wave mode under 5MHz	7	14	21	23

(2) Steel pipe inner diameter impact on guided wave dispersion curve

Assuming the object of study is steel pipe, whose density is 7.932g/cm and the wall thickness is 1mm. The longitudinal velocity is 5.96m/ms and the shear velocity is 3.26m/ms. The guided wave dispersion curves is simulated within 0-5MHz when the inner diameters of pipe are 50mm, 100mm, 150mm and 200mm, respectively.

Table 2 Dispersion curve data in steel pipes with different inner diameters

Inner diameter mm	50	100	150	200
Number of cut-off curves	0	2	5	5
Cut-off frequency of L(0,1) mode (MHz)		4	2.3	1.6
Cut-off frequency of L(0,2) mode (MHz)		4	3	2.7
Cut-off frequency of other modes(MHz)			3.5 4.8 4.8	2.9 4.5 4.5

The simulation results show that the inner diameter have a great effect on dispersion curves. when the wall thickness is stable, the distribution trend of dispersion curves is approximately invariable with the increasing of inner diameter, and some curves appear cut-off with the increasing of frequency. The numbers of cut-off curves and cut-off frequency are shown in Table 2.

Analyzing the dispersion curve vertically, when the wall thickness of steel pipe is same and the inner diameter changes from 1mm to 4mm, some modes which can be excited at low frequencies can't exist at high frequencies any more. With the increasing of inner diameter, the cut-off frequency of these curves is becoming low.

4 Conclusions

With the help of the Disperse software, the guided wave dispersion curves is simulated, and the effect of wall thickness and inner diameter to the dispersion curves in guided wave propagation is studied. The main conclusions of this paper are summarized as follows:

(1) When the inner diameter remaining the same and with the increasing of wall thickness, the frequency band where only exist L(0,1) and L(0,2) is becoming narrow and the upper limit frequency is becoming low. At high frequencies, the number of guided wave mode is becoming large.

(2) With the inner diameter changing from 50mm to 200mm, the distribution trend of dispersion curves is approximately invariable at the same wall thickness. At the same time, some modes which exist at low frequencies can't be excited at high frequencies, and cut-off frequency is becoming low.

Ultrasonic testing needs to select frequency band with fewer dispersion and smaller mode number. Thin steel pipe own good dispersion property and multimode characteristics, especially the L(0,2) mode, reducing the difficulty of signal processing. At the same time, dispersion curves can accurately provide phase velocity at the specific frequency and cut-off frequency of each mode, offering fundamental basis to the selection of transducer parameters, working point and excitation frequency of guided wave.

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