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Evaluation of Wall Thickness in a Pipe Using a Laser Source Scanning Technique

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1. Introduction

Residual thickness is the most important parameter for maintenance of pipe networks in any industries. However, the bulk wave technique used to find the critical thickness is very time consuming and difficult to apply for pipe inspection on high structures. This study describes a guided wave inspection using scanning laser source technique to enable remote inspction of pipe. Guided waves are excited on pipe with laser ultrasonic and measured the *L*(0,1) mode using 8 angle beam transducers to create a thickness distribution image in pipe.

2. Guided waves modes for measurement of residual thickness

In our prevoius studies [1], amplitude of the A0 mode of low-frequency Lamb wave that introduced in a plate shows large amplitude displacement when propagating over a thinned region like a defect in a plate (see **Fig. 1(a)**). According to the reciprocal theorem, when the A0 mode was excited around the defect by using a laser scource scanning technique, large amplitude of the A0 mode can also be measured at the same location of the angle beam transducer (see **Fig. 1(b)**).

On the other hand, the guided wave propagation in pipes is more complicated than one in plates, and the technique cannot be applied directly for the evaluation of thickness distribution in pipes. **Fig. 2** shows group velocity dispersion curves for an aluminum pipe (outer diameter: 110 mm, thickness: 3.5 mm, longitudinal wave velocity, v_l: 6260 m/s, transverse wave velocity v_t: 3080 m/s)

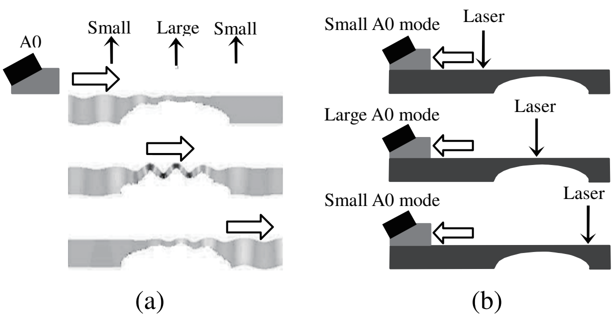

Fig. 1 Excitation and propagation of A0 mode around a defect in a plate. (a) Propagation of A0 mode through a defect. (b) Excitation of A0 mode around a defect.

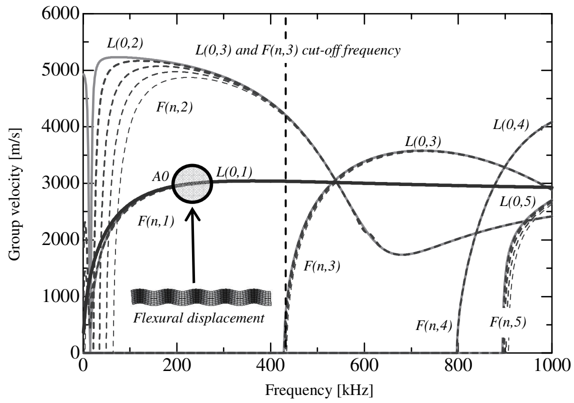

Fig. 2 Group velocity dispersion curves.

together with a dispersion curve for the A0 mode of an aluminum plate of the same thickness (bold black line).

At frequencies above 20 kHz, the modes labeled *L*(0,1) (gray line) and *F*(n,1) (dashed lines) in the pipe have very similar dispersion curves to the A0 mode. Moreover, the wave structures of the *L*(0,1) and *F*(n,1) modes in the pipe cross section are also similar to the A0 mode which vibrates in the thickness direction, as shown in the dispersion curves. Therefore, we can assume that these modes have similar characteristics to the A0 mode in a plate, and this study describes the prospective of using *L*(0,1) mode for evaluation of thickness in pipes.

3. Measurement of thickness distribution

Figure 3 shows the experimental set up, the pipe used in this study, and the propagation paths of guided waves in the pipe. A laser beam was emitted from a Q-switched Nd/YAG pulse laser (Quantel Brilliant Ultra; wavelength: 532 nm, repetition rate: 20 Hz, pulse width: 7.2 ns, maximum pulse energy: 32 mJ) and it passed through an attenuator, a 1-mm slit, and a two-axis galvano laser scanner. The 1-mm slit converted the 3-mm-diameter laser spot into an approximately 3 × 1 mm^2 line to improve the signal-to-noise ratio of the signals and the spatial resolution of the images. The line source was moved in the axial (*X*) and circumferential (*Y*) directions by the two-axis galvano laser scanner at

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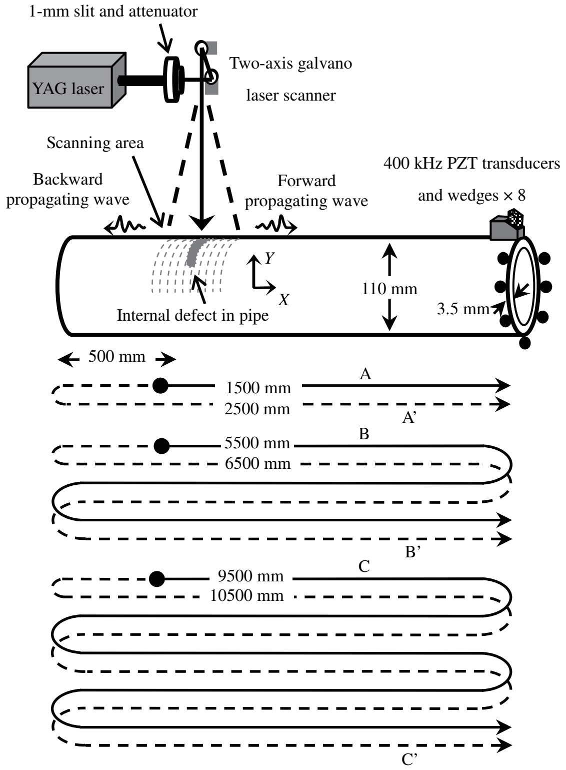

Fig. 3 Scanning laser source on a pipe with a defect.

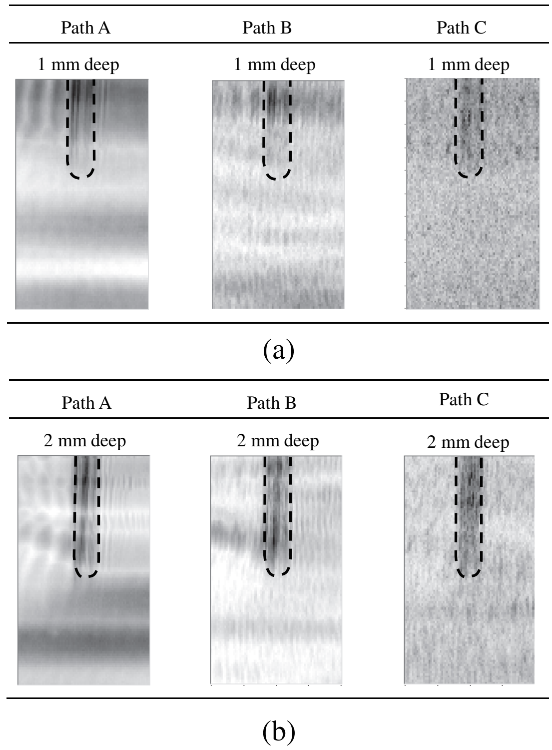

Fig. 4 Amplitude distributions. (a) 1-mm and (b) 2-mm-deep defects.

81 × 101 points over a scanning area of 80 mm × 100° on a 2-m-long aluminum pipe with a diameter of 110 mm and a thickness of 3.5 mm.

Defects with 1- and 2-mm-deep thinned regions in the circumferential direction with a flat defect zone of approximately 160° were machined 500 mm from the pipe ends and used in the thickness evaluation.

4. Results and discussion

Figure 4 shows the variation in the amplitude distributions over 1- and 2-mm deep defects with various propagation distances (1.5 m for path A, 5.5 m for path B, and 9.5 m for path C; see **Fig. 3**). The defect regions denoted by dashed line can be seen clearly in the all figures and indicated the internal defect shapes in pipes.

As seen in the figure, the images for path C are a little more uniform in the defect area than the images for paths A and B. This is probably affected by the ratio of non-axisymmetric mode $F(n,1)$ in the measured signals at C. Since the zeroth-order axisymmetric $L(0,1)$ and the high-order non-axisymmetric modes $F(n,1)$ have different velocities, the waveforms for each mode separate as the propagation distance of the guided waves increases. Consequently, the ratio of the axisymmetric mode (i.e., the mode with the largest group velocity and the smallest dispersion) increases in the gated signals as the distance increases. In contrast, the ratio of non-axisymmetric modes was large for a short propagation distance.

At path C in **Figs. 4(a)** and **(b)** show the amplitude distributions over single defects with depths of 1 and 2 mm, respectively. Larger amplitudes were obtained in the images for the 2-mm-deep defect (i.e., residual pipe wall thickness of 1.5 mm) than in those for the 1-mm-deep defect (i.e., residual pipe wall thickness of 2.5 mm). These results agree with the results obtained for a plate in which the amplitude distributions are approximately inversely proportional to the pipe thickness [1-2].

5. Conclusions

A scanning laser source has been used to visualize the residual thickness over internal defects in pipes. Flexural vibrating modes consisting of $L(0,1)$ and $F(n,1)$ were acquired using 8 transducers around the pipe circumference. The thin region above an internal defect exhibits a large amplitude, and it was used to create an image of the defect for different propagation distances. The amplitude distributions have a smaller non-uniform distribution in the circumferential direction as the signals propagated through a longer distance, but the amplitude became smaller and the amount of noise increased.

References

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2. W. Luo, J.L. Rose, Maters. Eval. **62** (2004) 860.