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A method of the wall thickness measurement using resonant phenomena of the circumferential Lamb waves generated by plural transducers located evenly on the girth

円周に等間隔に設置したトランスデューサで励起した円周ラム波の共鳴による肉厚測定法

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1. Introduction

We reported [1)] a novel method of measuring the pipe wall thickness using the resonance of the circumferential (C-) Lamb wave [2)] generated by the piezoelectric ring-shaped sensor (PRS). The PRS is the special device for the axially propagating torsional wave, nevertheless the C-Lamb waves are also generated as spurious signals at the same time. Especially in the resonant conditions determined by the specific frequencies, the C-Lamb waves are dominantly generated, which distort the axially propagating wave. In this method, this troublesome spurious signals are used effectively for the measurement of the wall thickness. The further experimental verifications were carried out in comparison to the previous report [1)]. Four different resonant conditions and two different tone burst cycles, 13 and 25, were experimentally investigated to verify the method. The experimental results were compared with the theoretical calculations.

2. Resonance and wall thickness estimation

The resonance of the C-Lamb wave occurs when the standing wave along the girth is generated. Figure 1 illustrates the four resonant standing waves for the angular wave numbers (AWNs) 1, 2, 4, and 8 along with the pipe cross-sections and the transducer elements. The PRS consists of eight transducer elements for the 50A pipe[1)]. The AWN is the value that is defined as number of wavelengths within the girth. Clock-wise and counter-clock-wise arrows in Fig. 1 indicate the same- and anti-phases of the input burst signals, respectively, applied to the corresponding elements. According to the dispersion relation of the C-Lamb wave shown in Fig. 2, the resonant frequency is obtained when the AWN takes a natural number. The dispersion relation changes with the wall thickness as shown in Fig. 2. This means that the wall thickness is able to be estimated by measuring the resonant frequency. This is the principle of the wall thickness estimation.

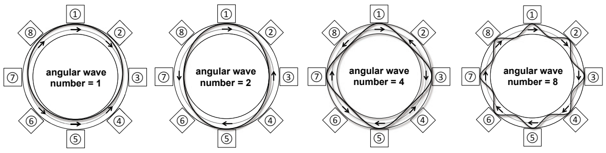

Fig. 1 Four resonant conditions depicted along with the pipe cross-sections and the transducer elements located evenly on the girth.

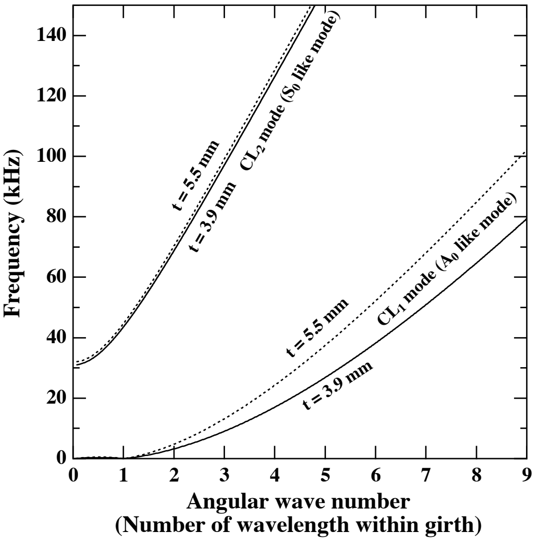

Fig. 2 Dispersion relation of the CL_1 and CL_2 modes of the circumferential Lamb wave of 60.5 mm outer diameter aluminum pipe (c_t=3160 m/s, c_l=6400 m/s).

3. Experiments

60.52 ± 0.01 mm outer diameter (OD) and 3.94 ± 0.02 mm wall thickness (c_t = 3170 ± 5 m/s, c_l = 6396 ± 5 m/s) and 60.47 mm OD and 5.51 ± 0.06 mm wall thickness (c_t = 3153 ± 7 m/s, c_l = 6406 ± 7 m/s) aluminum (Al) pipes were used respectively for the specimens 1 and 2. The eight transducer elements and the other one were used, respectively, for the generators and the receiver of the C-Lamb waves. The receiver element was located axially 30 mm away from one of the generators. 13 and 25 cycle tone burst signals were used. The CL_1 mode was used for the AWN 8 and the CL_2 mode was used for the AWNs 1, 2, and 4 (see Fig. 1).

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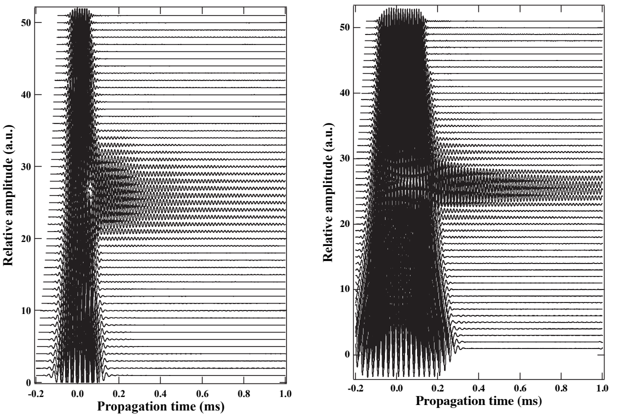
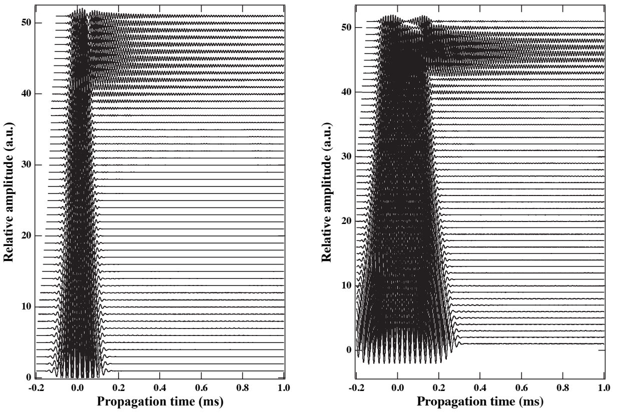


(a) burst cycle 13, t = 3.94 mm (b) burst cycle 25, t = 3.94 mm



(c) burst cycle 13, t = 5.51 mm (d) burst cycle 25, t = 5.51 mm

Fig. 3 Frequency variations of time domain signals of frequency range from 40 kHz (bottom) to 90 kHz (top) at the resonant condition of the AWN 8.

4. Results

Frequency variations of time domain signals for the tone burst cycles 13 and 25 observed with the specimens 1 and 2 in the resonant condition of AWN 8 were shown, respectively, in Figs. 3(a)-3(d). The large wave packets at around 0 ms in all the signals were axial T(0,1) mode guided waves. The resonances could be seen as the gradually attenuating waveforms at around the frequency region from 60 to 70 kHz for the specimen 1 and at those from 80 to 90 kHz for the specimen 2. It was clearly confirmed that the resonant frequency changed with wall thickness. The stronger resonance having higher Q-factor was also clearly observed when the tone burst cycle took 25 rather than 13. Figure 4 shows the amplitude distributions picked up from the time domain signals shown in Fig. 3(b) at the propagation time of 20, 25, 30, 35, and 40 cycle periods for the corresponding frequencies. Center frequencies were extracted using the least-square fitting of the Gaussian curve to the amplitude distributions. Table I shows the experimental and theoretical resonant frequencies. Experimental results agreed very well with the theoretical outcomes.

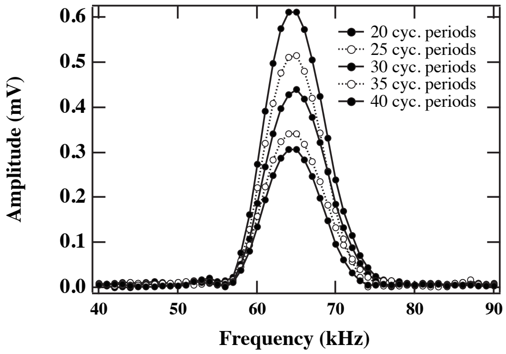


Fig. 4 Frequency characteristics of the resonance.

5. Conclusion

Wall thickness measurement using the resonant phenomenon of the C-Lamb wave generated by the piezoelectric ring-shaped sensor was investigated regarding the several resonant conditions. Experimental results agreed very well with the theoretical calculations

Acknowledgment

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References

1. H. Nishino et al: Proc. USE2011, p.347-238.
2. H. Nishino et al: JJAP **46** (2007) 4568.

Table I Resonant frequency

Pipe size (mm)	Condition	Resonant frequency (kHz)							
		AWN = 1	Error to theoretical	AWN = 2	Error to theoretical	AWN = 4	Error to theoretical	AWN = 8	Error to theoretical
Thickness 3.94 ± 0.02 Outer diam. 60.52 ± 0.01	Theoretical	43.71	-	68.92	-	126.61	-	65.39	-
	Experimental 13 cycle	43.77 ± 0.12	(0.1%)	68.79 ± 0.10	(0.2%)	126.37 ± 0.36	(0.2%)	64.57 ± 0.14	(1.2%)
	Experimental 25 cycle	43.46 ± 0.04	(0.2%)	68.95 ± 0.07	(0.0%)	126.64 ± 0.48	(0.0%)	64.66 ± 0.09	(1.1%)
Thickness 5.51 ± 0.06 Outer diam. 60.47 ± 0.03	Theoretical	44.69	-	70.22	-	128.39	-	84.76	-
	Experimental 13 cycle	44.91 ± 0.24	(0.5%)	70.25 ± 0.12	(0.0%)	129.57 ± 0.06	(0.9%)	84.75 ± 0.10	(0.0%)
	Experimental 25 cycle	44.82 ± 0.05	(0.3%)	70.45 ± 0.08	(0.3%)	128.65 ± 0.18	(0.2%)	85.39 ± 0.09	(0.7%)