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Spurious resonant phenomena of circumferential Lamb wave in axially propagating guided wave excitation by plural sensors located on the pipe girth

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1. Introduction

In dry-coupled guided wave sensor with multiple transverse vibration sensor elements (SEs) installed on the pipe girth, circumferential Lamb wave is excited simultaneously and spurious resonance occurs at a specific frequency due to the spatial periodicity of the SEs [1,2]. In this presentation, the characteristics of the resonance obtained with SEs installed at equal and unequal intervals on the girth are experimentally obtained and compared with the theoretically derived relationship between the spatial arrangement of SEs and the resonance frequency. It is useful to optimum installation of the SEs to avoid the spurious Lamb wave resonance.

2. Theory of resonance

To present the resonant intensity due to the arrangement of SEs, introduce a function $L(\theta)$ that takes 1 when an SE is present at position θ on the circumference and 0 otherwise; the Fourier transform $F_T(p)$ of $L(\theta)$, as shown in eq. (1), is a function that indicates the degree of periodicity due to the arrangement of SEs. The angular wavenumber p indicates that the circumference is divided into p divisions, e.g., p=4,8 indicates periodicity at 90˚ and 45˚ intervals, respectively.

$$F_T(p) = \frac{1}{N}\int_0^{v_g t_d} L(\theta) e^{-ip\theta} d\theta, \quad (1)$$

where v_g, t_d and N are the group velocity of the circumferential Lamb wave, duration time of excitation, and cumulative number of SEs involving in excitation, respectively. **Figures 1(a) and 1(b)** show examples of 90˚ equal and 100˚ unequal arrangements (see Figure 3). In Fig. 1, Fourier transform and Fourier series indicate the resonant intensities due to integrating the Lamb wave amplitude in the four and infinite laps range, respectively. By using the dispersion relation of the circumferential Lamb wave between the angular wavenumber p and the frequency f, **Figures 2(a) and 2(b)** show resonant intensities as a function of frequency regarding a 4-cycle burst wave. The duration time t_d differs for each frequency, and the number of superpositions is higher at lower frequencies. Since the SE is sensitive only to vibrations in the θ direction, the theoretical particle displacements u_θ and u_r of the circumferential Lamb wave were taken into account. The areas near 10, 20, 60, and 80 kHz in Fig. 2 correspond to the angular wavenumbers p = 3, 4, 7, and 8, respectively, in Fig. 1.

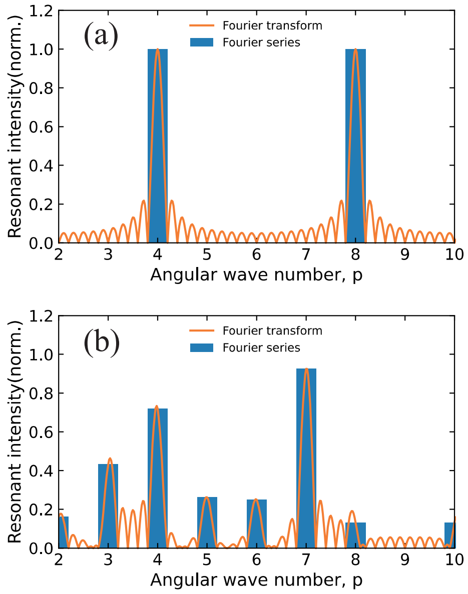

Fig. 1 Resonant intensity as a function of angular wavenumber in SE configuration conditions, (a) 90˚ equally and (b) 100˚ unequally.

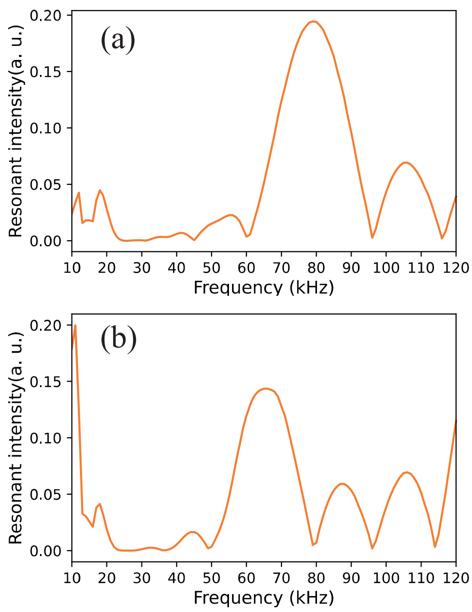

Fig. 2 Resonant intensity as a function of frequency.

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3. Experiments and results

Experimental observations of the resonances (f = 30~120 kHz) were carried out in several SE configurations shown in **Fig. 3** using the aluminum pipe specimen with outer diameter of 40 mm and wall thickness of 2 mm shown in Fig. 4. The time domain signal for the 100° SE configuration is shown in **Fig. 5.** Large wave packets at around 0 ms indicate the excited T(0,1) mode. Wave packets with a long duration can be seen near 60 kHz. In addition, small wave packets after the excited T(0,1) mode are observed near 30 kHz and 100 kHz, respectively. These are spurious resonant signals caused by the circumferential Lamb waves.

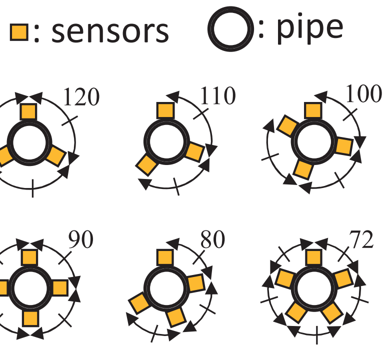

Fig. 3 Sensor element configuration conditions.

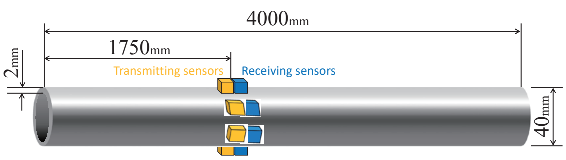

Fig. 4 Experimental layout

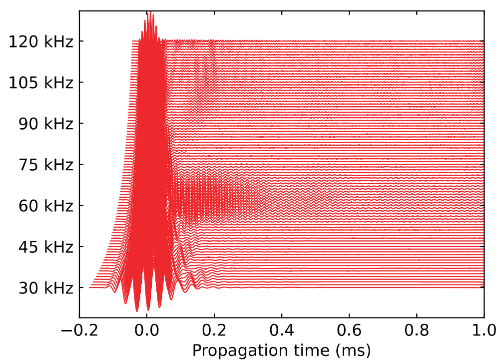

Fig. 5 Frequency variation of time domain signals.

Figures 6(a) to 6(f) show the experimental and theoretical results for resonant intensities for all the SE configuration conditions. Error bars in the experimental results show the standard deviation of five trials. The experimental values are difficult to compare with the theoretical values in absolute terms because the amplitude values are subject to fluctuations depending on the installation condition of the SEs. The experimental resonance intensity was adjusted to compare the two so that the total observed intensity in the frequency range of 30 kHz to 100 kHz takes the total theoretical intensity. It is confirmed that the intensities and frequencies of the peaks observed in the experiments are coincided well with the theoretical resonances.

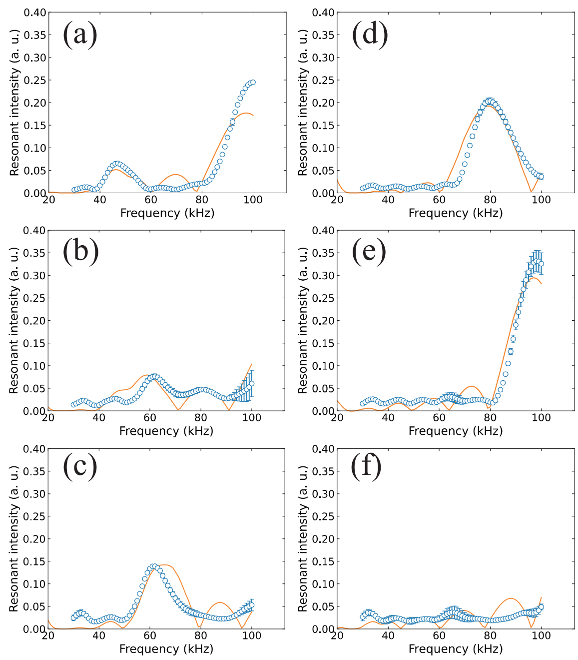

Fig. 6 Experimental and theoretical resonant intensities in the SE configuration conditions.

4. Conclusion

A comparison of experimental and theoretical results shows that the resonant phenomena of the spurious circumferential Lamb wave, which occurs simultaneously with the excitation of the axially propagating T(0,1) mode guided wave, depends on the sensor element (SE) configuration and the two were in good agreement. The theory of resonance is useful for designing its configuration that reduces spurious resonances for the axial mode guided wave required originally in the required frequency range.

Acknowledgement

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References

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2) H. Nishino, K. Iwata, and M. Ishikawa, Jpn.J.Appl.Phys.55 (2016) 07KC07.