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MULTI-FREQUENCY WAVENUMBER ANALYSIS OF WALL-THINNED METAL PLATES WITH IDT-BASED SLDV

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ABSTRACT

The Lamb wave-based Scanning Laser Doppler Vibrometry (SLDV) method using continuous excitation is a promising method for visualizing defects in plate-like structures. To visualize defects, the A_0 mode is commonly used because of its sensitivity to the thickness variations, i.e. wave speed changes according to the thickness. However, for thick plates, the A_0 mode is found to be less sensitive to thickness variations compared to thin structures. Recently, to address this issue, inter-digital transducer (IDT)-based SLDV is introduced to efficiently generate the symmetric mode for damage detection of thick plates. It was demonstrated that the detectability of shallow defects using IDT-based SLDV in a thick plate was improved to that when using the A_0 mode. However, it is hard to cover whole thickness (0.3 ~ 6 mm thickness) of a carbon steel plate of 6-mm thickness with a tapered defect using a single symmetric mode. To measure whole range of thickness of the carbon steel plate, multi-frequency excitation is needed based on analysis of wavenumber sensitivity and degree of separation between mode (DSM). It is demonstrated that the detectability of defects in a thick plate using IDT-based SLDV is improved compared to that when using the single S_0 mode.

Keywords: IDT-based SLDV, Lamb wave, wavenumber sensitivity

NOMENCLATURE

k	wavenumber
S_{f_0}	wavenumber sensitivity
S_M	degree of separation between modes (DSM)

1. INTRODUCTION

SLDV has been developed using a local wavenumber estimation for NDE applications [1]. Continuous sinusoidal excitation by the PZT transducer is used, and its reception by the LDV is used for scanning. SLDV is beneficial in using a single-frequency excitation and reception with LDV that amplifies the energy in the structure, increasing the SNR significantly without requiring repeated measurements, and operation safety is ensured with low power class 1 laser.

However, the variation in the wavenumber is too small for thick plates to detect defects compared to that for thin plates using SLDV [2]. This means that early wall-thinning defects cannot be detected by wavenumber analysis. For this reason, ≥30% wall-thinning defects in plate and pipe structures has been studied [1, 3]. Kang et al. investigated shallow wall-thinning in a plate and found overestimations for 30% wall-thinning [4]. These were attributed to the small wavenumber variation, a dispersion characteristic of Lamb waves in thick plates using the anti-symmetric A_0 mode. To resolve this problem, Kang et al. [2] adopted IDT based SLDV to excite suitable mode that can represent shallow wall-thinning well, the wavenumber sensitivity and the DSM are used to optimize the mode-tuned IDT. IDT is designed and <20 % wall-thinning defects in plates visualized well based on wavenumber sensitivity and DSM. It is difficult to image the entire range of a slanted defect because the IDT has narrow band excitation. [2]. This is due to wavenumber sensitivity is localized at certain frequency.

To visualize entire range of depth of a defect, multi-frequency excitation is needed. In this study, we proposed multi-frequency image fusion based on wavenumber sensitivity analysis to enhance image quality with IDT based SLDV measurement and effective generation of mode tuned Lamb wave. To validate proposed method, a plate of 6-mm-thick carbon steel (300 mm × 300 mm, 6 mm thick) with eight size defect sizes (square defects with the length 2c of 40 mm and depths a/h of 5, 10, 15, 20, 30, 40, 50, and 60% is prepared, and it is demonstrated that the detectability of defects in a thick plate using IDT-based SLDV is improved compared to that when using the single S_0 mode.

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2. MULTI-FREQUENCY IDT BASED SLDV

It is hard to cover whole thickness (0.3 ~ 6 mm thickness) of a carbon steel plate of 6-mm thickness with a tapered defect using a single symmetric mode. To measure whole range of thickness of the carbon steel plate, excitation frequency is optimized based on analysis of wavenumber sensitivity and DSM. It is demonstrated that the detectability of defects in a thick plate using multi-frequency IDT-based SLDV is improved compared to that when using the single S_0 mode.

The method for measuring the thickness of a wall-thinned plate with multi-frequency IDT based SLDV and its configuration is illustrated in Fig. 1.

1) Determine the range of thickness of materials: To determine frequency and number of IDT sensor, range of thickness of materials has to be set
2) Draw wavenumber sensitivity in dispersion curve: Specific wavenumber sensitivity is well fit for different frequency and thickness
3) Choose optimal wave mode and frequency according to wavenumber sensitivity and DSM
4) Design and fabrication of IDT sensors
5) Inspection of the materials with IDT based SLDV
6) Imaging of a wall-thinned plate

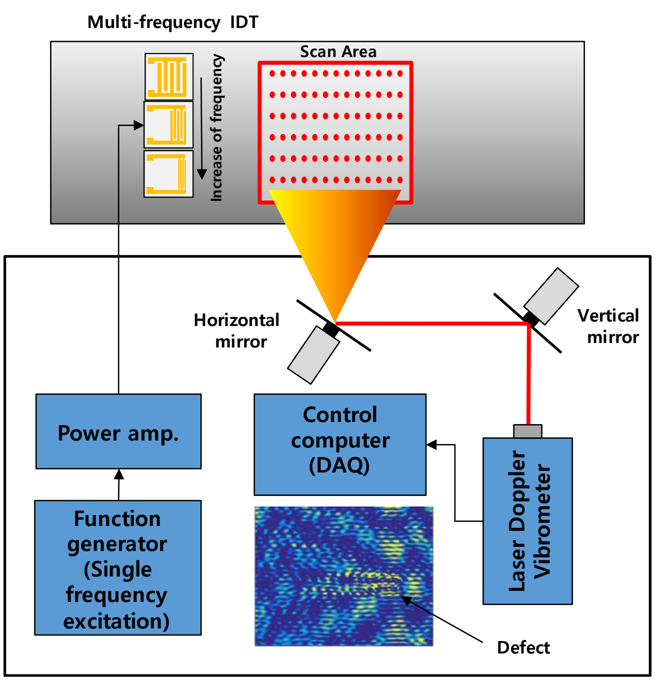

FIGURE 1: CONFIGURATION OF MULTI-FREQUENCY IDT BASED SLDV

3. RESULTS AND DISCUSSION

A plate specimen (300 mm × 300 mm, 6 mm thick) with eight size defect sizes (square defects with the length 2c of 40 mm and depths a/h of 5, 10, 15, 20, 30, 40, 50, and 60% is prepared as shown in Fig. 2. The longitudinal velocity is 5.96 mm/µs, and the shear wave velocity is 3.26 mm/µs for a carbon steel plate. The test specimen is excited with an IDT at 200, 450, and 600 kHz in the scanning range measuring 150mm × 150 mm, interval of 0.5 mm, and speed of 5000 m/s

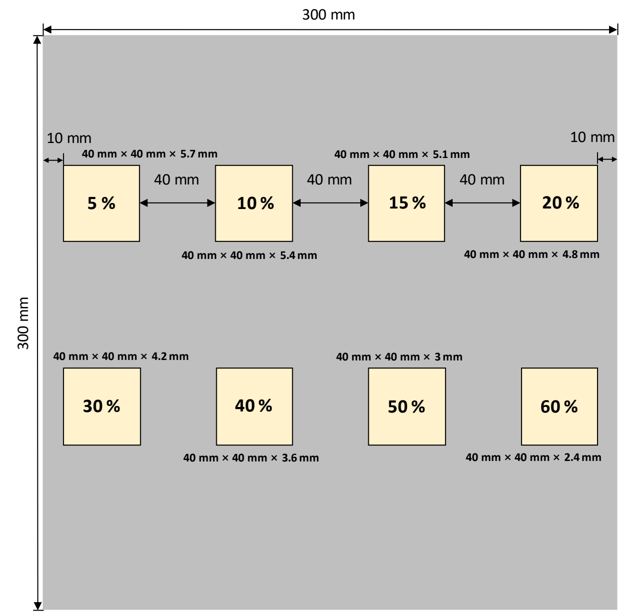

FIGURE 2: A CARBON STEEL PLATE (300 MM × 300 MM × 6 MM THICK) WITH EIGHT DIFFERENTLY SIZED DEFECTS (THE IDT SENSOR IS LOCATED ON THE SIDE OF THE PLATE OPPOSITE THAT OF THE DEFECT)

Fig. 3 shows the image result with 200 kHz A0 mode excitation. ≥30% wall-thinning defects can be detected, and ≤ 20% wall-thinning defects cannot be detected.

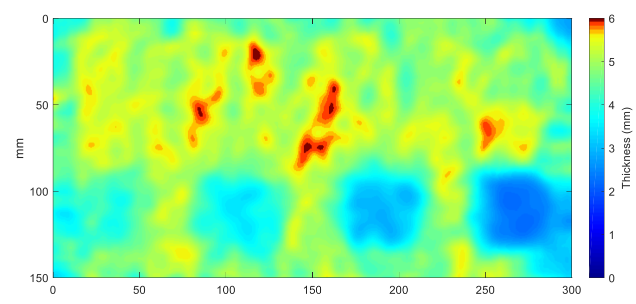

FIGURE 3: IMAGE RESULT WITH 200 KHZ A_0 MODE EXCITATION

Fig. 4 shows the fused image result with 200, 450, and 600 kHz. Compare to Fig 3., all defects can be visualized well.

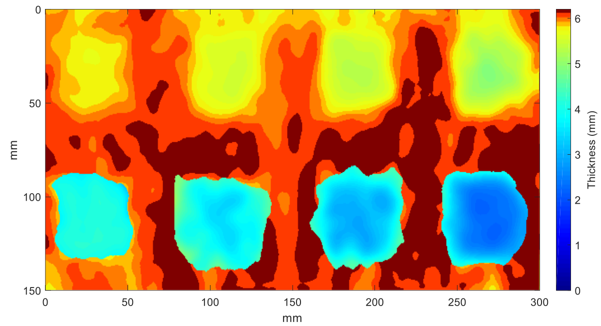

FIGURE 4: FUSED IMAGE RESULT WITH MULTI-FREQUENCY EXCITATION

4. CONCLUSION

In this study, the performance of multi-frequency IDT-based SLDV in a carbon steel plate was evaluated. 200, 450, and 600 kHz is well suited for imaging of a carbon steel plates based on multi-frequency SLDV. guided wave mode is at locally high wavenumber variation, a single IDT-based SLDV is not applicable to visualize wide range of depth of defects in carbon steel plate. To overcome this problem, multi-frequency IDT sensors are adopted to cover wide range of depth of steel plates. Overall, these results imply that cover wide range of thickness of structures, it is needed to employ multi-frequency IDT sensors. However, it is needed several IDT sensors and excitation frequency to cover wide range of thickness of steel plates.

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REFERENCES

[1] Eric, B. Flynn., See, Yenn, Chong., Gregory, J. Jarmer., Jung-Ryul, Lee., "Structural imaging through local wavenumber estimation of guided waves", *NDT & E International* Vol. 59 (2013): pp.1-10.

[2] To, Kang., Seongin, Moon., Soonwoo, Han., Jun-Young, Jeon., Gyuhae, Park., "Measurement of shallow defects in metal plates using inter-digital transducer-based laser-scanning vibrometer", *NDT & E Interntaional* Vol. 102 (2019): pp.26-34

[3] Thanh, Chung, Truong., Jung-Ryul, Lee., "Thickness reconstruction of nuclear power plant pipes with flow-accelerated corrosion damage using laser ultrasonic wavenumber imaging", *Structural Health Monitoring* Vol. 17, No. 2 (2017): pp.255-265.

[4] To, Kang., Jeong-Han, Lee., Soonwoo, Han., Jin-Ho, Park., Gyuhae, Park., Jun-Young, Jeon., "Measuring plate thickness using spatial local wavenumber filtering", *Journal of the Korean Society for Nondestructive Testing* Vol. 36, No. 5 (2016): pp.370-376.