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Remote detection of deposits in pipes by laser ultrasonics

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1. Introduction

The decommissioning is currently underway at the Fukushima Daiichi Nuclear Power Plant. To proceed with the decommissioning work, it is necessary to cut and remove many pipes that obstruct the work, but the internal conditions are often unknown, causing problems that prevent the work from progressing as planned. Therefore, before cutting pipes, it is necessary to determine the internal conditions, such as the presence or absence of deposits and liquids, and the concentration of radioactive materials and hydrogen.

Ultrasonic pulse echo technique is often used in conventional structural testing, but the range that can be inspected in a single measurement is limited to the area directly under the transducer, making it time-consuming and costly to inspect the entirety of a large structure such as piping. Our research group has been studying the imaging of wall thinning and deposit on the back surface of thin materials and the inner surface of pipes using a scanning laser source (SLS) technique[1)-2)]. In SLS, elastic waves are excited by irradiating a laser beam onto an object to be inspected, the irradiated points are scanned, and the amplitude spectral peaks of the received waveform at each point are mapped to obtain an image corresponding to the thickness of the plate-like structure. Since SLS can be applied remotely, it is useful as an inspection method in the presence of highly radioactive materials at the inspection site. In our previous study[3)], artificial deposits on the backside of a thin plate and in piping were detected using SLS.

This study considers a more realistic situation and examines the detection of deposits inside pipes in situations where water is present in the pipes.

2. Imaging principle

When a laser is instantaneously irradiated onto the surface of a thin plate material, elastic waves are generated[4)]. In SLS, damage is imaged using the phenomenon that the magnitude of the generated elastic wave varies with the thickness of the plate at the point of laser irradiation. **Fig. 1** shows a schematic diagram of the principle. If the laser irradiation point is on a thicker plate, the elastic waves generated will be smaller. On the other hand, the elastic waves generated by the laser become larger when the irradiated point is a damaged area

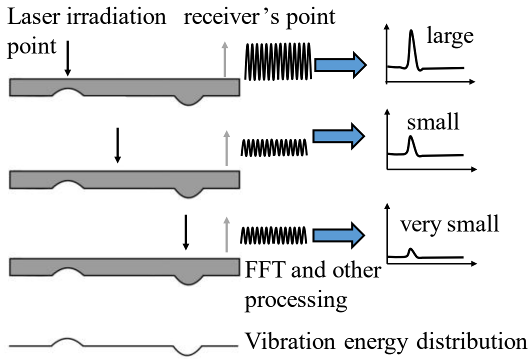

Fig. 1 Principle of imaging by SLS

with a thin plate thickness. By mapping these changes in magnitude two-dimensionally, a damage image can be obtained.

The ultrasonic energy generated by damage or wall thinning in the plate-like structure changes in the low frequency band where the vibration generated by laser irradiation is in the Lamb wave A0 mode. However, in this low-frequency band, multiple reflected waves from the structural wall are measured due to the low attenuation and long wavelength, making it difficult to analyze the waveforms of only the directly arrived waves. Hayashi's work on SLS imaging showed that by using the wavefield after diffusion, it is possible to image internal wall thinning even in complex geometries such as branching pipes, independent of the receiving position[1)].

When a deposit exists on the back of a thin plate structure, the local bending stiffness increases due to the presence of the adhesion, and the energy generated as A0 mode of Lamb wave is reduced when the laser is irradiated at the area of the deposit[3)].

3. Experimental set-up and signal processing for the imaging

Fig. 2 shows a schematic figure of the experimental setup. When a modulation signal is given to the fiber laser, elastic waves of the frequency corresponding to the modulation signal are excited. The modulation signals of multiple frequencies are connected in series, and the corresponding laser outputs are obtained from an external source to simultaneously excite elastic waves of multiple frequencies. The laser irradiation point is scanned within the imaging area by moving the mirrors with the rotation stages, and the elastic wave excitation and waveform measurement are repeated at each irradiation point. The waveforms

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measured with an infrared laser vibrometer (Polytec VFX-F 110/VFX-I-160, 1550 nm) are amplified by an amplifier and then captured by a PC through an AD converter for image processing. To obtain an image, the waveform for 20 ms after laser irradiation is subjected to fast fourier transform (FFT), the frequency spectrum peaks that appear near the frequency of the excited elastic wave are acquired, the peaks are averaged, and the values are mapped to obtain an image. The image can be obtained by averaging these peak values and mapping them. Aluminum pipes with wall thicknesses of 3 mm and 6 mm, diameter of 115 mm, and length of 1000 mm were prepared as test specimens, and circular epoxy putty with a diameter of 50 mm and a thickness of 10 mm was attached to the inside as an artificial deposit. In this study, both ends of the aluminum pipe were connected with water supply pipe using strab grips, and the deposit was imaged with the aluminum pipe hollow and filled with water.

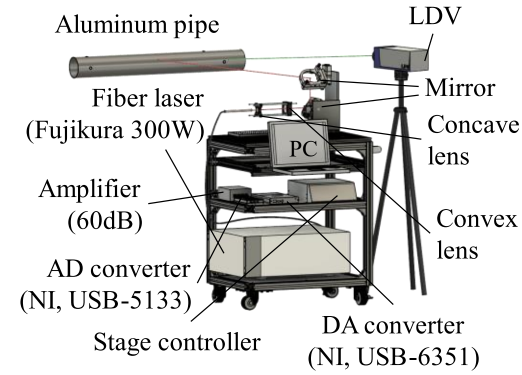
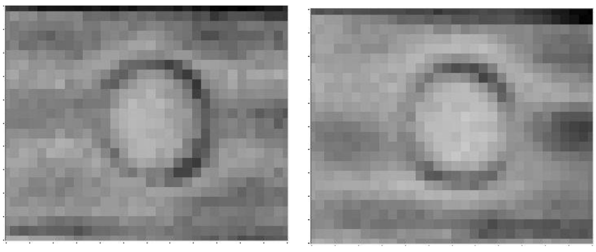


Fig. 2 Experimental device

4. Results and discussion

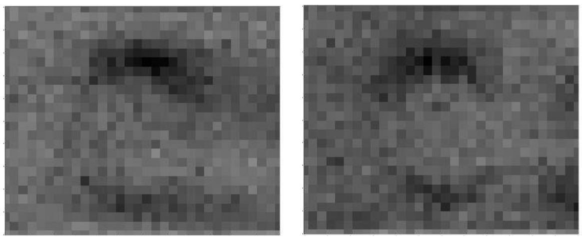
Figs. 3 and **4** show averaged images of an aluminum pipe with wall thicknesses of 3 mm and 6 mm, respectively, in an area of 120 × 100 mm^2, where elastic waves were excited at frequencies of 3 kHz, 5 kHz, and 7 kHz, varying by 2 kHz ((a) without water and (b) with water). In both Fig. 3 and Fig. 4, the arcs indicate the position of the attached deposit. These results confirm that SLS can be used to detect deposits on aluminum pipes even when they are filled with water. It was found that the resonance patterns were different between the hollow and water-filled conditions. We believe that this is because the presence of water in the aluminum pipe causes the excited elastic waves to decay faster than that without water.



(a) without water (b) with water

Fig.3 Experimental results for an aluminum pipe with wall thickness of 3 mm

The thicker the wall thickness, the smaller the excited acoustic waves become, and thus the effect of noise is larger than in the case of the aluminum pipe with a wall thickness of 3 mm. Therefore, it was expected to be difficult to image the deposits on a 6 mm-thick aluminum pipe, but Fig. 4 shows that it is possible to image the deposits, although the image is blurred compared to a 3 mm-thick pipe. On the other hand, the results of this experiment did not reveal whether water was present inside the pipe or not, although the deposits could be visualized. In the future, it will be necessary to study imaging using SLS for expected deposits on pipes used in actual inspections.



(a) without water (b) with water

Fig.4 Experimental results for an aluminum pipe with wall thickness of 6 mm

5. Conclusion

In order to understand the internal condition of pipes during decommissioning work at the Fukushima Daiichi Nuclear Power Plant, we attempted to apply the imaging technique using the scanning laser source technique to deposits inside pipes proposed in a previous study. In this study, imaging experiments were conducted by attaching an adhered object to the inside of an aluminum pipe. It was shown that the technique can acquire images of deposits appropriately in the presence of water as well as in the absence of water inside the pipe. In the future, imaging experiments will be conducted on pipes in use to image the expected deposits.

Acknowledgment

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