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Experimental evaluation of non-contact ultrasonic thickness gauging method using compact transducer for underwater steel structure

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1. Introduction

In recent years, the maintenance and management of the entire social infrastructure, including river and port facilities, has become a very important and urgent national issue, and the development of efficient inspection and diagnosing methods is required. In particular, it is essential to develop inspection and diagnosing methods for inaccessible, such as underwater or underground.

Steel pipe piles and steel sheet piles, which are the main components of underwater steel structures, deteriorates with time and the wall thickness becomes thinner, get a hole. Corrosion is a serious deformation that can lead to a reduction in the safety of a facility and ultimately contribute to its collapse.

Therefore, we have been conducting research and development of a non-contact ultrasonic thickness gauging system (non-contact method) to measure the thickness of steel without removing shells and periphyton [1]. Several signal analysis methods are also being considered [2]. However, this system could not be used where divers could not operate.

The purpose was to develop a new system for diver-less non-contact thickness measurement in rivers, lakes and in places where divers could not operate. In this report describe basic experiments for miniaturization of ultrasonic transducers and laboratory experiments on rusted steel plates.

2 Thickness Gauging Method

The non-contact method measure propagation time of the reflected wave from the surface and the reflected wave that propagates to the back surface without the ultrasonic probe being in contact with the materials surface.

Next, the analysis method for thickness is shown **Fig. 1**, the following equation is calculate the thickness,

$$D_{thickness} = \frac{t_i \times c}{2} \quad (1)$$

where $D_{thickness}$ is thickness of steel material, t_i is multiple reflection spacing in steel and c is speed of sound of steel. **Fig. 1** shows images of received wave for one transmitted wave, "surface reflection detect," "multiple reflection detect," "multiple reflection interval calculation," and " thickness deviation comparison from the surface side. Two or more thickness are calculated from a single transmitted wave and the average is adopted as the thickness. The thickness calculated from multiple transmitted waves is then averaged to become the wall thickness measurement. The experiments in this paper were analyzed for thickness in a similar manner.

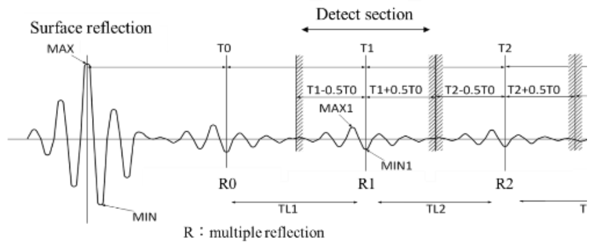

Fig. 1 Example of received signal and analysis approach

3. Experimental method

Fig.2 shows the non-contact ultrasonic thickness gauging system. The system consists of an underwater sensor unit and a land-based operation unit. The operation unit consists of an arbitrary waveform generator, power amplifier, noise filter, preamplifier, and matching circuit [3]. To investigate the miniaturization of the sensor unit, two 1.5-inch diameter ultrasonic transducers (OLYMPUS, A392S-SU 1 MHz center frequency and A395S-SU 2.25 MHz center frequency) were used in the sensor unit.

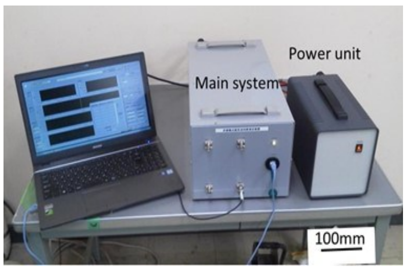

Fig. 2 Non-contact ultrasound thickness gauge (Operation unit)

Fig.3 shows the experimental setup. The ultrasonic transducer was fixed to the x-z stage so that it was perpendicular to a steel plate placed in a

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technical water tank (600mm×300mm×350mm). First, an experiment was conducted to confirm the steel plate thickness that can be measured with a non-contact method. The steel plates used in the experiments are the same material used in steel sheet piles and steel pipe piles, ranging in thickness from 4 mm to 10 mm. To investigate the effect of the distance between the transmitter and the steel plate (hereafter referred to as "measurement distance") on the accuracy of the measurement, the measurement distance was varied from 20 mm to 200 mm. Next, the effect of rust on measurement accuracy was examined using a rusted steel plate 9 mm thick. The measured rusted steel plate is shown in **Fig.4**. The locations numbered 1 to 4 shown in **Fig.4** were measured. Number 2 and 4 are thinly rusted as if the surfaces were rough. Number 1 is the area with thicker rust and spread over a wide area. Number 3 has floating rust, and there are minute gaps between the rust and the surface of the steel plate.

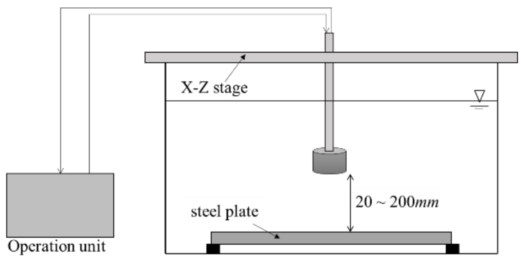

Fig. 3 Experimental setup

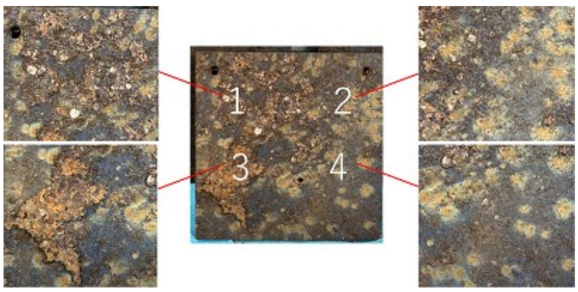

Fig. 4 Rusted steel plate for measurement

4. Results and Discussions

Fig.5 shows the results of measurements at different measurement distances on a 10 mm steel plate using 1MHz and 2.25MHz ultrasonic transducer. In the case of 1 MHz, the measurement error from the true thickness ranged from -0.05 mm to -0.01 mm, and the error was on the dangerous side in all measurement distance. At 2.25 MHz, the measurement error from the true thickness was -0.03 to +0.01 mm, and almost all the measurement results were close to the true thickness. For the flat ultrasonic transmitter, the thickness was close to the true thickness at all measurement distances. The results of the measurements at each frequency showed that 4 mm and 6 mm steel plates could not be measured at 1 MHz, 8 mm and thicker could be measured. At frequencies above 1.5 MHz, all steel plates were measured with thickness close to the true thickness.

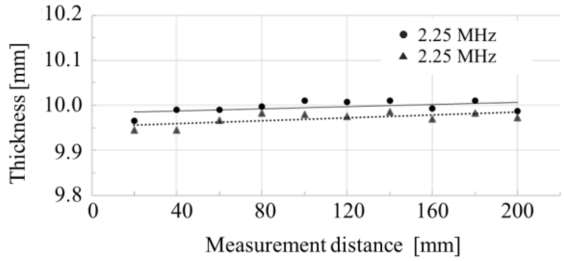

Fig. 5 Result of Measurement distance at thickness 10 mm

Fig.6 shows the waveforms of the results measured on the not rust and rusted steel plate. Surface reflections and multiple reflections could be confirmed, but the rust reduced the sound pressure. The measurements resulted in a 4.5% error to the thin side for numbers 1, 2, and 4. In No. 3, where there was floating rust, multiple reflected waves were observed, but thickness could not be measured by the analysis method. This result is thought to be the result of attenuation and scattering caused by the unevenness and gaps in the floating rust. In addition to the effect of rust, the thinning of the steel plate due to rusting is also considered to be a factor that caused the thickness to be on the hazardous side.

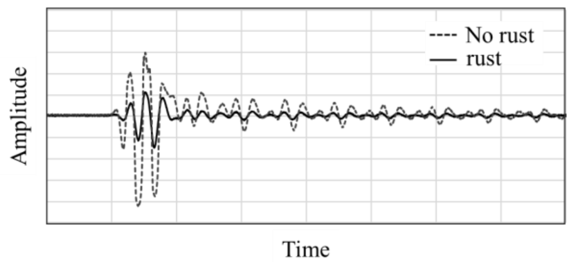

Fig. 6 Result of Rusted steel plate for measurement

5. Conclusion

In this paper, basic experiments were conducted to study the miniaturization of underwater sensor units and to measure rusted steel plates. Experimental results showed that thicknesses close to the true value can be measured at any distance, and even rusted steel plates can be measured within 5% of the true thickness. Thickness could not be measured on the steel plate with floating rust. In the future, we will further measure and examine the rust condition, and also examine the irradiation angle.

References

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3. K.Abukawa et al: IEICE Tech Rep. 117 (2017) 41