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Development of underwater experimental apparatus to confirm the principle of longitudinal wave sound speed CT

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1. Introduction

A computed tomography method using ultrasonic propagation time data has been proposed to nondestructively evaluate the health of wooden and concrete structures.[1)] Various simulation and measurement experiments have been conducted on solid objects, but there was a problem that the abnormal areas in the tomographic images were outwardly displaced from the actual ones. In addition, there was a problem that circular artifacts were generated on the sides of the cylinder as areas where the sound velocity was slow.

We concluded that the circular artifact on the side surface was caused by the large-amplitude surface waves generated when ultrasonic waves propagate in a solid, which prevented accurate estimation of the speed of the longitudinal wave. They also speculate that the generation of these transverse waves also affects the misalignment of the anomaly area. We have believed that this effect also causes the misalignment of the anomalous area.

In order to support this speculation, we have developed an underwater experimental apparatus, and by placing the transmitter and receiver completely underwater, we will conduct actual measurement experiments under conditions in which surface waves and transverse waves are eliminated.

2. Methods

2.1 Experimental Apparatus

In this study, we measured 306 paths of ultrasonic transmission/reception data in water, using 36 equal sections of a 0.32 m diameter circumference in the water as the measurement points as shown in **Fig.1**. **Fig.2** shows the measurement paths.[2)] The equipment used for the measurements is shown below.

・Oscilloscope DSO-X2002A (Agilent)
・Arbitrary Waveform Generator 33210A (Agilent)
・Power amplifier 4020 (NF circuit design block)
・Tub (0.6m in diameter)
・walfront stepper motor linear stage slide
・quimat tb6600 stepper motor driver
・Raspberry Pie 3
・Power supply (kenwood tmi)
・Ultrasonic transducer: Fuji Ceramics 1Z10D-SY2(C-64) Diameter 10mm center frequency 1 MHz
・Aluminum pipe (diameter 0.02m)

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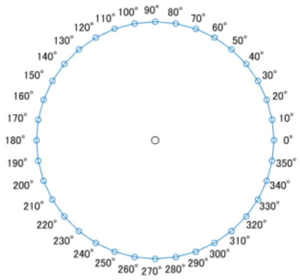


Fig. 1 Measurement point image

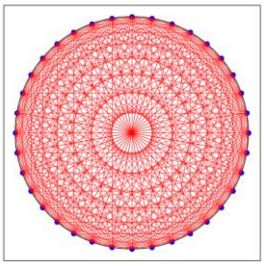


Fig. 2 Image of all measurement paths

Table. 1 Experiment 1 Conditions

Frequency: 1MHz
Amplitude: 300mVpp
Number of cycles: 3
Sampling rate: 40MHz
Waveform storage: USB
Diameter of measured circle: 0.32m
Anomaly: 0.02m diameter aluminum pipe
Location of anomaly: 0.09m from the center

Table. 2 Experiment 2 Conditions

Location of anomaly 2 (left): 0.07 m from the center
Location of anomaly 2 (right): 0.09 m from the center

2.2 Experimental Methods

As shown in Fig.1, this system has 36 measurement points on the circumference for one cross-section. The ultrasonic data of the path connecting these measurement points is measured as shown in Fig.2, and TOF is estimated from the received waveform obtained by threshold processing.

For TOF measurement by threshold processing, 10% of the maximum amplitude of the received waveform in each pass was set as the threshold amplitude for that pass, and the TOF was defined as the point when that value was first exceeded. Image reconstruction is then performed using the FPB method.[3] In this study, the conditions shown in **Table 1** and **2** were set and the sinusoidal waves were transmitted. The area indicated by the yellow circle in **Fig.3(a)** and **(c)** is the actual measurement circle with a diameter of 0.32m. In (a), an aluminum pipe is placed at one location as an anomaly site, and in (c), two locations are placed.

3. Results and Discussion

The obtained TOF data were used to reconstruct a cross-sectional image using the FBP method. The reconstructed images are shown in **Fig.3(b)** and **(d)**. The pipes are shown as solid blue lines with the same size at the location where they were placed. In the reconstructed images, it was possible to accurately determine the location and size of the anomalous area in both Experiment 1 and Experiment 2. Specifically, in Experiment 1, the actual position was 0.09 m from the center, while the reconstructed image was 0.0915 m. In Experiment 2, the actual position was 0.07 and 0.09 m, respectively, while the reconstructed image was 0.0675 and 0.0938 m.

4. Conclusion

In order to confirm the principle of longitudinal sound velocity CT, we developed an underwater experimental apparatus that can eliminate the problem of TOF misestimation caused by the generation of transverse waves, which had been considered to be the cause of the problem. The CT images obtained by this experiment showed no circular artifacts, which had been conventionally generated, and this confirmed that the cause of the problem was the generation of transverse waves. In addition, in the reconstructed image obtained from this experiment, the abnormal area was detected at the same position as the actual installation position without shifting outward significantly, which is thought to be due to the suppression of the generation of transverse waves.

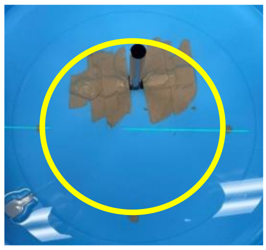
References

1) H. Fujii, K. Adachi, H. Yanagida, T. Hoshino, and T. Nishiwaki. Improvement of the Method for Determination of Time-of-Flight of Ultrasound in Ultrasonic TOF CT. SICE JCMSI. 2015; 8: 363.

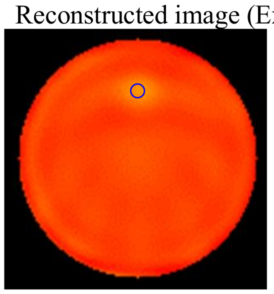
2) Y. Tomikawa, Y. Iwase, K. Arita, H. Yamada, "Non-Destructive Inspection of Rotted or Termite-Damaged Wooden Poles by Ultrasound", Jpn. J. of Appl. Phys. 24 187 (1984).

3) Mimura, Yuki (2020), "Advanced Estimation of Ultrasonic Propagation Time Using Deep Learning.

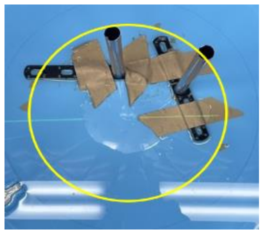
(a) Actual measurement circle (Experiment 1)



(b) Reconstructed image (Experiment 1)



(c) Actual measurement circle (Experiment 2)



(d) Reconstructed image (Experiment 2)

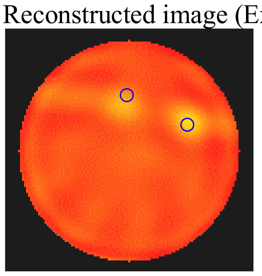


Fig. 3 Results of experiments