2P2-19
Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 265-266
3-5 December, 2014

Inspection of Defects in Billet Using Time-of-flight Difference and Time-reversal Wave
時間反転波と伝搬時間差を用いる角鋼片内部の欠陥検査

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1. Introduction

Non-destructive inspection is utlized in various situations from manufacturing of industrial products to diagnostics of buildings. In case of steel billets, inspection of defects in billets is necessary for enhancing reliability of end products. The defects are metallic inclusions or residual gas. Although the required accuracies differ with the kinds, the materials or the use of steel billets, the position, shpe, and size of defect are important information for non-destructive inspection.

Ultrasonic testing is used for inspection in the billet. There are several methods using ultrasound, such as pulse-echo method [1)] that is currently used for actual inspection or computerized tomography (CT) method [2)] that is under research. However, these methods using ultrasound are referable not to meet the required accuracies sufficiently. Aiming to slove this problem, we consider a method using time-reversal (TR) wave [3)] and time-of-flight (TOF) difference. TR wave is used in underwater acoustics or optics as imaging technique, while TOF difference is used in the CT method [4)]. In this paper, we propose the method using both of them. We show the availability of this method by experiment visualizing a defect in a specimen.

2. Inspection Method

The form of billet intended is long square prism. **Figure 1** shows a schematic view of the inspection for this billet. Reference plane is a section that no defect exists and measurement plane is a section that defects possibly exist. Transducers are located around each planes, and ultrasound are transmitted from a transmitter to a receiver. As the path indcated as c in Fig. 1, the received signal in measurement plane includes scattered waves from defects. We can visualize defects by using the scattered waves. In actual inspection, measurement plane is shifted to longitudinal direction of billet.

Figure 2 shows the flow of defect detection using our proposal method. M means all of received signals in measurement plane and R means all of received signals in reference plane. To reduce influences of noises, M and R are filtered by the bandwidth of transmitted signals. From these signals, cross-correlation functions are generated. Time-of-flight differences ΔTOF are calculated from the peak positions of cross-correlation functions. In accordance with ΔTOF, received signals of R are shifted in time, and R* is obtained. From R*, window W is generated by performing the signal processing as shown in Fig. 2. Received signals of M and window W are multiplied with each element, and M* is obtained. Owing to W, signals from

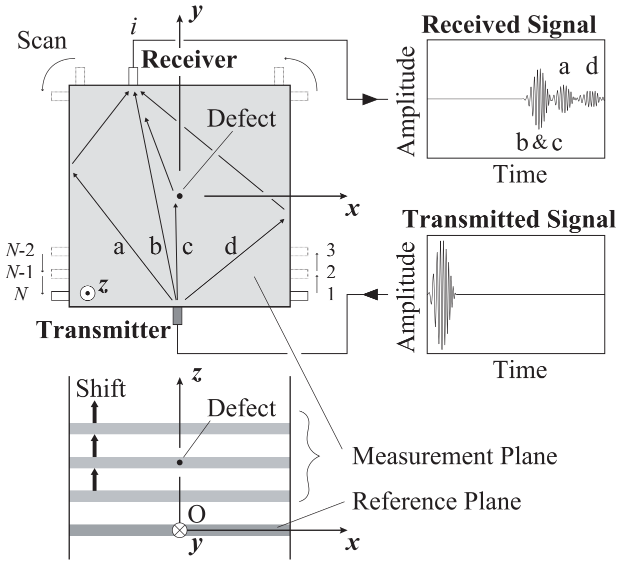

Fig. 1 A schematic view of inspection of billet.

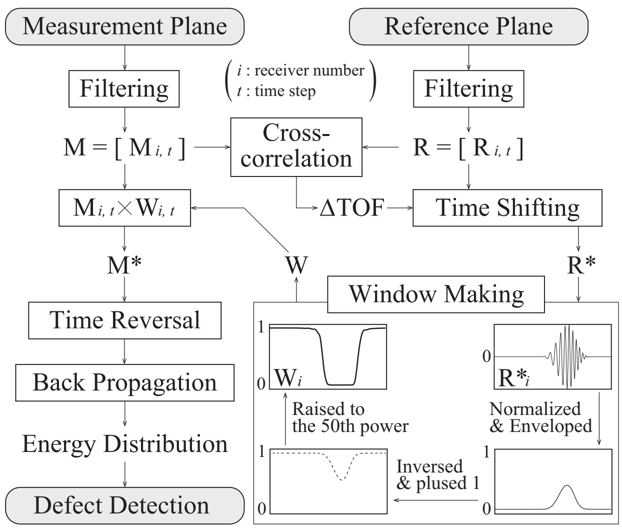

Fig. 2 The flow of defect detection of our method.

sound source (a, b and d in Fig. 1) are suppressed, and signals from defect (c in Fig. 1) are emphasized. By propagating the time-reversal waves of M*, the backpropagation waves converge to the defect position. The energy near defect position increases, and it becomes possible to detect defect.

3. Experiment of Defect Detection

A schematic view of experiment is shown in **Fig. 3**. The material of specimen is duralumin whose sound velocity is 6,320 m/s. The section of specimen is 100 × 100 (mm^2). In measurement plane, a defect in 2 mm diameter locates at the coordinate (0, 0). Transmitter is located at *Tx* = 49 mm and receiver is scanned from boundary I to boundary III. Transmitted signal is up-chirp signal applied by Hann window. Frequency of the signal is 1 – 3 MHz and the signal length is 5 μs. For backpropagation, we use finite-difference time domain (FDTD) method. We compare results among three cases following (A), (B) and (C).

(A). The difference between the energy distributions of backpropagations of M and R.
(B). The energy distribution of backpropagation of the difference M and R.
(C). The energy distribution generated by our proposed method.

Received signals and window of our proposed method are shown in **Fig. 4**. M and R are filtered measurement data of experiment. Focusing on M*, it is confirmed the scattered waves by defect are emphasized.

The visualization images in process of (A) to (C) are shown in **Fig. 5**. In (A), we find the energy is high on the propagation paths from sound source postion to the periphery of defect. In (B), the influence of sound source is stronger than that of defect. In (C), the energy is high near defect. Thus, we found the proposed method superior to simple backpropagation methods. In this experiment, the number of measurement points is only 150, this number is 1 / 100 of that required for CT method. Therefore, by increaseing the number of points, we can visualize the defect more accurately. For the reasons stated above, it is shown that our method is effective for the inspection of defect in billet.

4. Conclusions

In this paper, we proposed a method using TR wave and TOF difference and we conducted a experiment of this method using a specimen. In result, the defect is visualized more accurately than simple backpropagation methods. It is shown that our proposed method is available for the inspection of defect in billet.

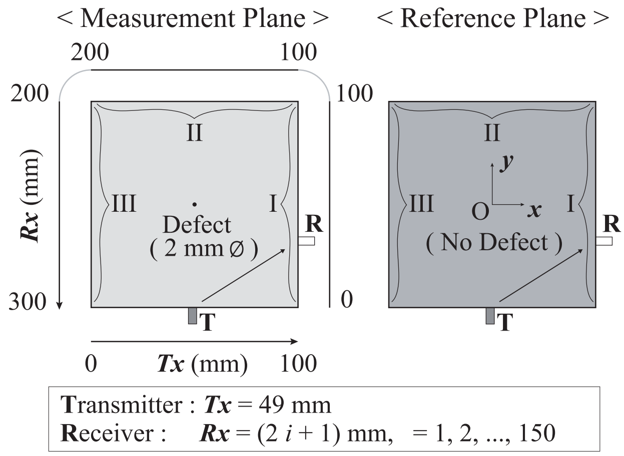

Fig. 3 A schematic of view of experiment.

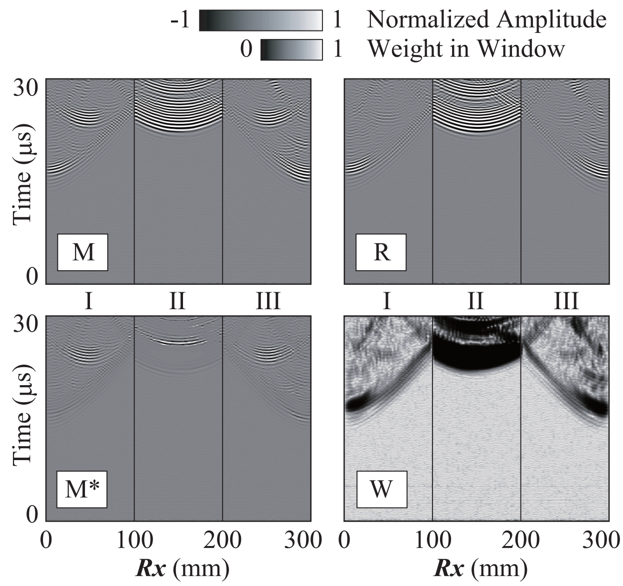

Fig. 4 Received signals and window of our method.

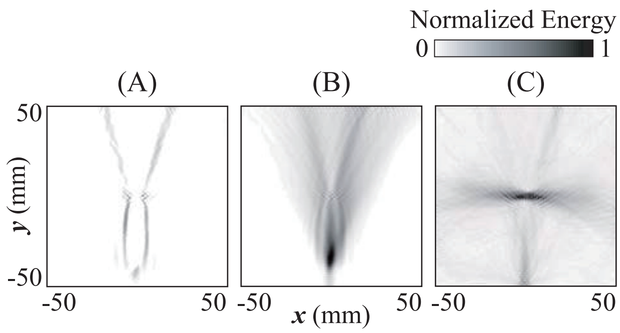

Fig. 5 Visualization images of experiment.

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