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Comparative Study of Pulse Echo Method and Transmission Method with Computerized Tomography for Defect Detection inside Billet

角鋼片内部の欠陥検出におけるパルスエコー法と CT 法を用いる透過法の比較

Yoko Norose‡, Koichi Mizutani, and Naoto Wakatsuki (Univ. Tsukuba)
野呂瀬　葉子 [1‡], 水谷　孝一 [2], 若槻　尚斗 [2] ([1] 筑波大院・シス情工, [2] 筑波大・シス情系)

1. Introduction

Ultrasonic testing is effective for defect detection inside billets.[1)] A pulse echo method is employed on manufacturing line in steelworks.[2)] Figure 1 shows the schematic view of the pulse echo method. In the pulse echo method, pulse wave is launched into the billet from a transducer and received at the same transducer. When a defect exists on the path, the received signal includes the back scattering wave from the defect. Therefore, the defect is detected on A-mode image. Inside steel, ultrasonic wave is attenuated by diffusion and scattering.[3)] Therefore, the pulse echo method is not suitable for high-attenuation billets, such as those have large grains, because the echo from the defect becomes small.

We have proposed a defect detection method by ultrasonic computerized tomography (CT) using time-of-flight (TOF) of longitudinal wave measured by a transmission method.[4-6)] Figure 2 shows the schematic view of our proposed method. In measurement of TOF, the transmitted wave is received, so it is assumed that the received signal level by the transmission method is higher than that by the pulse echo method. In our proposed method, the defect information is extracted from the propagation time by cross-correlation of received signals. Therefore, the ability of the defect detection does not determined by the signal level, directly. In this paper, we compare the ultrasonic CT using TOF measured by the transmission method and the pulse echo method in terms of the ability of defect detection inside a billet by simulation with scattering attenuation.

2. Numerical simulation

2.1 Effect of scattering attenuation in simulation

Ultrasonic signal attenuates inside a billet. There are two kinds of the attenuation: the diffusion attenuation and the scattering attenuation. The diffusion attenuation is replicated in the wave propagation simulation. In addition, to consider the scattering attenuation, the received wave P is calculated by following equation:

$$P = P_0 \exp(-\alpha_s x).$$

where P_0 is the received signal amplitude by the wave propagation simulation, α_s is the scattering attenuation coefficient, and x is propagation distance.

norose@aclab.esys.tsukuba.ac.jp
mizutani@iit.tsukuba.ac.jp
wakatuki@iit.tsukuba.ac.jp

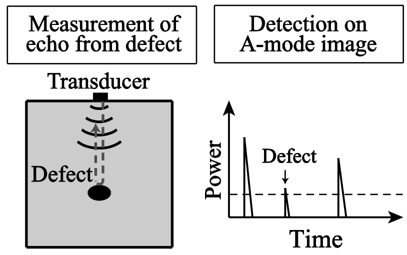

Fig. 1 Schematic view of pulse echo method.

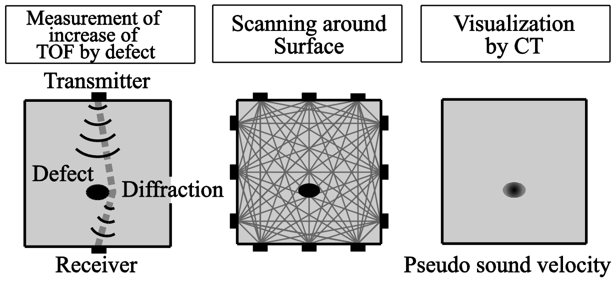

Fig. 2 Schematic view of transmission method with CT

2.2 Simulation condition

Figures 3(I) and 3(II) show the simulation setups. The test piece is assumed to be made of steel, whose sound velocity is 5,950 m/s. The size of its cross-section is 100×100 (mm^2). The defect whose diameter is 2 mm is at (x, y) = (0, 0) or (0, 30) (mm). The transducer is set at (0, 50) in the pulse echo method, and the transmitter and the receiver are set at (0, 50) and (0, -50) in the transmission method. The aperture of the transducer is 5 mm. The input signal is upchirp signal swept from 1 to 3 (MHz). The signal is multiplied by whelch window to simulate the characteristics of the transducer. The scattering attenuation coefficient α_s is varied as 0, 2, and 4 (dB/cm). Wave propagation is calculated by transmission-line matrix method. Considering the actual experiment environment, noise is added to make the signal-to-noise ratio (SNR) at the specific path (from (0, 50) to (0, -50)) 35 dB.

2.3 Simulation result

Figure 3 shows the received waveform. Figures 3(a) and 3(b) show the received signal by the pulse echo method when the defect locates at (0, 30), and (0, 0), respectively. Figure 3(c) shows the received signal by transmission method when the defect locates at (0, 0). Figures 3(i)-(iii) show the results when α_s = 0, 2, and 4 (dB/cm), respectively. From Figs. 3(a) and 3(b), the longer the distance between the transducer and the defect is, and the larger the scattering attenuation

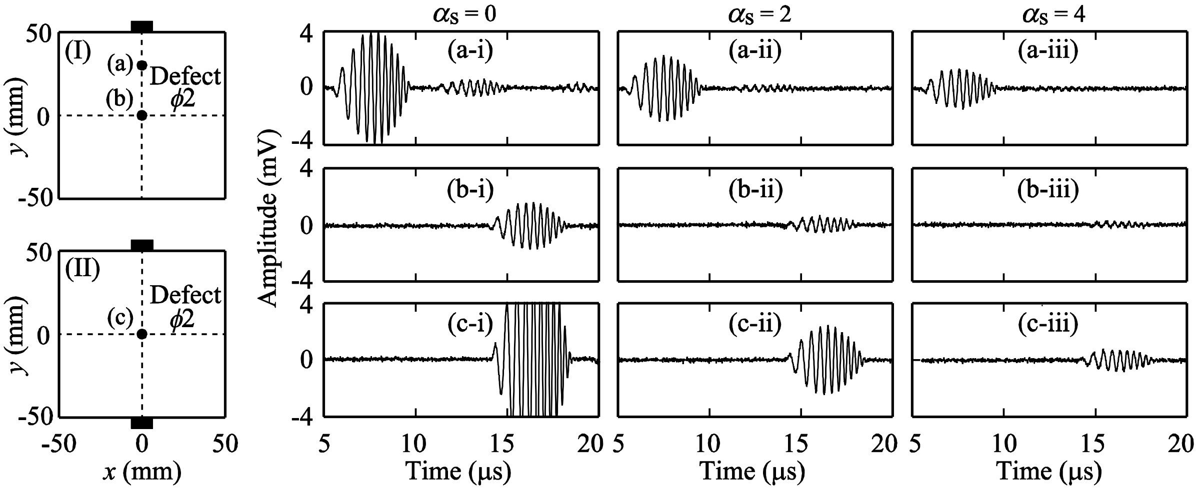

Fig. 3 Simulation setup and received signals. (I) is setup for pulse echo method. (II) is setup for transmission method. (a) and (b) are received signals by echo method when the defect locates at (0, 30), and (0, 0), respectively. (c) is received signal by transmission method. (i)-(iii) are results when scattering attenuation coefficient α_s = 0, 2, and 4 (dB/cm), respectively.

coefficient is, the lower the echo levels become. When α_s = 4 dB/cm and the defect locates at (0, 0), it is difficult to detect the defect from the amplitude because the signal level is the same order as the noise level. From Figs. 3(b) and 3(c), the amplitude of the received signal by transmission method is larger than the echo signal. On the other hand, from Figs. 3(a) and 3(c), when the distance between the transducer and the defect is small, and α_s is large, the amplitude of the echo is larger than that of the transmitted signal. It is found that the effect of the scattering attenuation was growing, as the propagating distance was long.

Figure 4 shows the CT image when the defect locates at (0, 0) and α_s = 0, 2, and 4 (dB/cm). As α_s becomes large, the artifacts in the CT image increase. This is because TOF measurement error increases as the SNR decreases. However, the transmission method with CT can visualize the defect under high attenuation environment although it is difficult to detect the defect by the pulse echo method. It was inferred that our proposed method is more suitable for defect detection of high-attenuation materials.

3. Discussions

There are three advantages on the transmission method with CT. First, from the simulation results, when the distance between the transmitter and the defect is large, the received signal level by the transmission method was higher than that by the pulse echo method. Second, because TOF is derived from pulse compression of the received signals, the effect of noise can be reduced. Third, in the transmission method with CT, because the receivers can be arranged widely against the incidence angle of the signal, the measurement points can be increased, and the defect information can be extracted easily by reconstruction. Consequently, the transmission method with CT is expected to be more robust in measurement for high-attenuation billet than the pulse echo method.

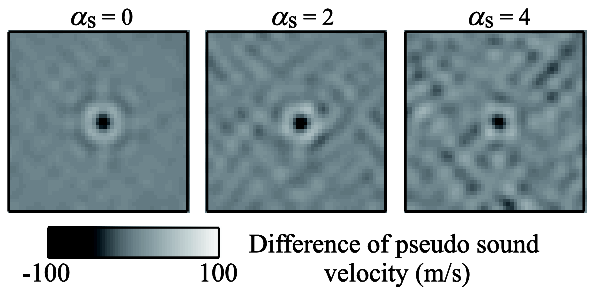

Fig. 4 CT image for scattering attenuation coefficient α_s is 0, 2, and 4 (dB/cm), respectively.

4. Conclusions

We compared the pulse echo method and the transmission method with CT in terms of defect detection performance by the simulation. From the simulation results, it was recognized that it was possible to detect the defect by the transmission method with CT under the condition that the defect was far from the transducer, although it was difficult to detect the defect by the pulse echo method. As a result, it was suggested that the transmission method with CT was effective for defect detection inside high-attenuation materials.

References

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