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Numerical Study of Defect Detection in Square Billet by Transmission Method with Linear Scanning

直線走査と透過法を用いた角鋼片内部欠陥検出シミュレーション

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1. Introduction

In our modern daily lives, steel products are essential. These products are made of semifinished products – steel billets. Steel billets sometimes include defects caused by remaining gas such as CO_2 during manufacturing processes[1]. Because these defects degrade the final products quality, it is desirable to detect defects inside steel billets nondestructively. To detect defects inside steel billets, pulse echo method is commonly used in manufacturing line[2]. However, it is still challenging to detect defects inside high-attenuation billets by pulse echo method because the level of returned echo falls below measurement limits.

Ultrasonic computerized tomography (CT) method using time of flight (TOF) of longitudinal wave has been proposed by the authors[3-4]. In this method, transmission method is employed to keep enough level of the received signal. Moreover, by using CT method, defects can be detected acculately. However, this method takes long time for measument because it requires number of paths as shown in **Fig. 1(a)** in exchange for precise measurement.

Therefore, we propose a defect detection in steel billet by transmission method with linear scanning as shown in Fig. 1(b). This mehod is expected to reduce measument time because measurement paths could be reduced compared to that with CT. In defect detection by ultrasonic transmission method using TOF, the performance depends on input frequency[5]. In this paper, performance of detection by transmission method with linear scanning is evaluated in simulation by varying defect size and transmission frequency.

2. Principle of Defect Detection

Figure 2 shows the outline of TOF measurement for defect detection. If a defect locates on the ultrasonic propagation path, TOF increases by $\Delta\tau$ due to diffraction at the defect[3].

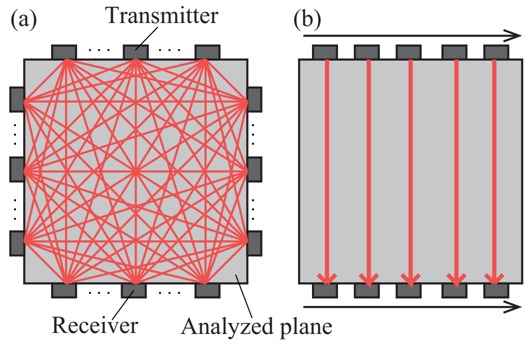

Fig. 1 Propagation paths of methods;
(a) CT method and (b) Proposed method

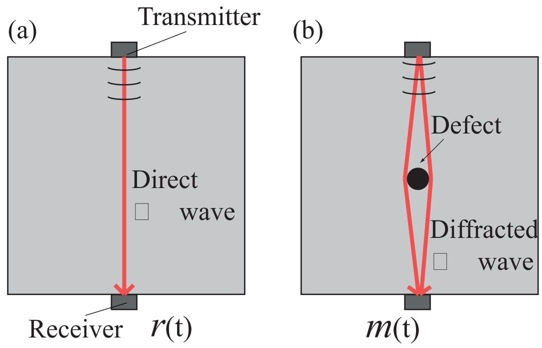

Fig. 2 Outline of TOF measurement;
(a) Reference plane,(b) Measurement plane.

Increase of TOF, $\Delta\tau$, can be obtained by calculating the cross-correlation function between the reference signal $r(t)$ and the measurement signal $m(t)$. $r(t)$ and $m(t)$ are measured in the reference plane with no defects and in the measurement plane, respectively as shown in Fig. 2[4].

In the proposed method, TOF is measured by linear scanning as shown in Fig. 1(b). Compared with the ultrasonic CT method as shown in Fig. 1(a), the proposed method only measures the paths in which transducers are facing. For example, linear scanning requires only around 100 paths for TOF measurement while ultrasonic CT requires 60,000 paths, if we test a billet of 100×100 (mm^2) with scan pitch of 1 mm. Therefore, measurement time is expected to be reduced which results in increase of testing efficiency in manufacturing line.

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3. Simulations

3.1 Simulation condition

Figure 3 shows the simulation condition. To simulate the longitudinal wave propagation, Finite–Difference Time-Domain (FDTD) method was employed. The propagation velocity in steel was assumed to be 5,950 m/s. The size of the measurement plane was 100×100 (mm^2), with mesh size of 0.1 mm. A defect, whose diameter D, exists in the center of the measurement plane. To evaluate the relationship between input signal frequency and defect detection performance, the bandwidth and time of input up-chirp signals were varied as 0.5-1.5 1.0-3.0, and 2.0-6.0 (MHz) and 10, 5, and 2.5 μs, respectively. To keep the directivity of transducers regardless to the above condition, the transducer was assumed to have a constant open area ratio, λ/a, where λ and a are the wavelength of the center frequency and the diameter of transducer, respectively. To simulate the actual measurement, white Gaussian noise were added with signal-to-noise ratio (SNR) of 10 dB. Note that the power of the signal was based on the power of the received signal. $\Delta\tau$ was calculated by calculating the cross-correlation function between received signals on the reference and the measurement plane.

3.2 Results and discussions

Figures 4 and 5 show the difference of TOF, $\Delta\tau$, on each path obtained by the simulation. In Fig. 4, $\Delta\tau$ increases as the frequency decreases. One of the reasons considered is the effect of the interference among direct, scattered, and diffracted waves. Considering above fact, it was found that it is effective to perform defect detection by the proposed method using a signal of low frequency. Fig. 5 indicates the effect of the noise. We could observe the change of $\Delta\tau$ when we use a signal of low frequency even in noisy environment. In high frequency case, there are no significant changes in $\Delta\tau$ regardless to the existence of the defect. Therefore, it was found that the proposed method may detect defects effectively by using a signal of low frequency and transmitter of wide diameter.

4. Conclusions

In this paper, we evaluated the performance of the defect detection by transmission method with linear scanning in simulation. As a result, signal of low frequency and transducer of wide diameter were found to be desirable. The obtained results suggest that a defect of 0.5 mm is expected to be detected by using a signal of 0.5-1.5 (MHz). In future works, the proposed method will be verified by practical experiment.

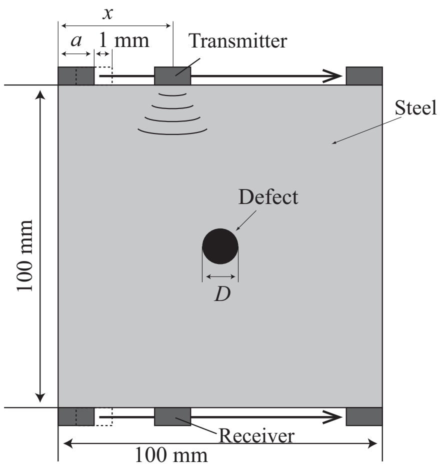

Fig. 3 Simulation condition

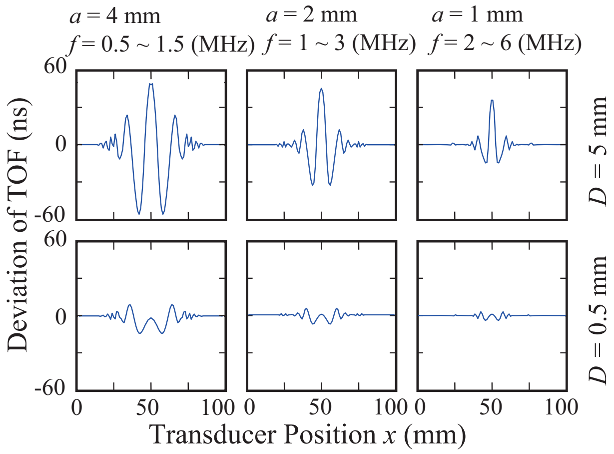

Fig. 4 Simulation results without noise

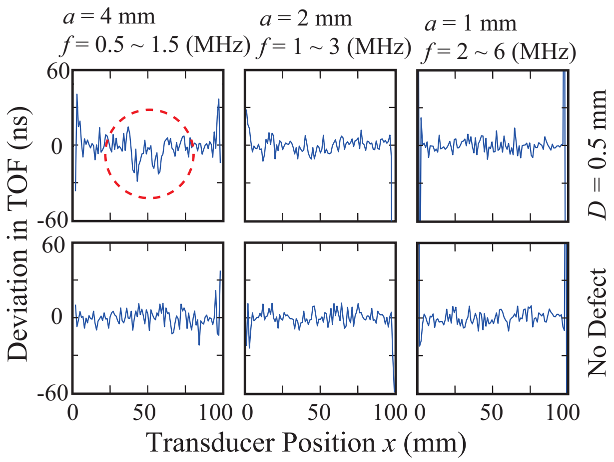

Fig. 5 Simulation results with noise

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