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Transfer Characteristics between Transmitter and Receiver in Scanning along Rectangular Surface
矩形表面に沿う走査における送–受トランスデューサ間の伝達特性

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1. Introduction

Primary casting products, like steel billets, may have defects which deteriorates the quality of final products, and ultrasonic non-destructive testing is necessary for improving their quality. Among ultrasonic testing methods, ultrasonic transmission method for testing steel billet has been investigated [1).

In this method, a time-of flight (TOF) of the longitudinal waves transmitting through the testing object is measured using transducers attached on the testing object.The defects are visualized as a decrease in apparent sound velocity because the TOF increases because of diffraction at the defects. This method needs the received signal data at every point scanned for reconstitution by ultrasonic computerized tomography.

In defect detection using the transmission method and CT, it is unable to disregard the effect of transducer directivity. Fluctuant amplitude of received signals may bring errors such as artifacts in reconstruction. Received signal amplitude depends on the positions and angles of the transmitter and reciever [2). To figure out transfer characteristics between the transmitter and receiver for ultrasonic testing using transmission method, we verify amplitude characteristic in consideration of directivity of both the transmitter and receiver by analysis, considering insertion loss.

2. Principle

We focus on the sound field in which the sound pressure, P(r), radiates from a circular transducer as shown in **Fig. 1**. We consider the case that the aperture of a circular transducer vibrates uniformly. Sound pressure, $P(\boldsymbol{r})$, is expressed by convolution of aperture vibration velocity and spatial impulse response, as shown in following equations [3).

$$P(\boldsymbol{r}) = -j\rho\omega V \int_{-\infty}^{\infty} \omega_{\mathrm{IR}}(\boldsymbol{r}) \exp(-j\omega t)dt \,, \tag{1}$$

$$\omega_{\mathrm{IR}}(\boldsymbol{r}) = \begin{cases} 0 & (ct < z_{\mathrm{r}}) \\ c & (z_{\mathrm{r}} \le ct \le r_1) \\ 0 & (r_1 < ct) \end{cases} \quad (l = 0), \tag{2}$$

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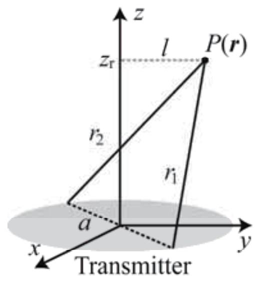

Fig. 1 Calculating setup of a circular transducer

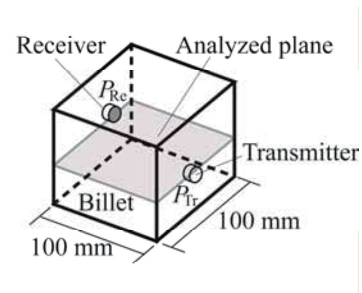

Fig. 2 Outline of analyzed field

$$\omega_{\mathrm{IR}}(\boldsymbol{r}) = \begin{cases} 0 & (ct < z_{\mathrm{r}}) \\ c & (z_{\mathrm{r}} \le ct \le r_1) \\ \dfrac{c}{\pi}\cos^{-1}\left\{\dfrac{(ct)^2 - z^2 + l^2 - a^2}{2l\sqrt{(ct)^2 - z^2}}\right\} & (r_1 < ct \le r_2) \\ 0 & (r_2 < ct) \end{cases} \quad (0 < l \le a), \tag{3}$$

$$\omega_{\mathrm{IR}}(\boldsymbol{r}) = \begin{cases} 0 & (ct < r_1) \\ \dfrac{c}{\pi}\cos^{-1}\left\{\dfrac{(ct)^2 - z^2 + l^2 - a^2}{2l\sqrt{(ct)^2 - z^2}}\right\} & (r_1 \le ct \le r_2) \\ 0 & (r_2 < ct) \end{cases} \quad (a < l), \tag{4}$$

where ρ, V, $\omega_{\mathrm{IR}}(\boldsymbol{r})$, and c are the density of propagation medium, angular frequency of transmitted wave, spatial impulse response of transducer, and sound velocity of longitudinal waves, respectively. **Figure 2** shows the outline of the analyzed field. We define acoustic pressures on the transmitter and the receiver as P_{Tr} and P_{Re}, respectively. These are derived from integration of acoustic pressure on each aperture. Directivities of the transmitter and the receiver are included in P_{Tr} and P_{Re}. The insertion loss, IL, is defined by following equation.

$$IL = -20 \log_{10}(|P_{\mathrm{Re}}| / |P_{\mathrm{Tr}}|). \tag{5}$$

3. Simulation

3.1 Condition of Simulation

Figure 3 shows the analyzed plane. We simulate a sound propagation in a square billet which is 100 mm on a side and made of duralumin. Diameter of transducer's aperture is 5 mm.

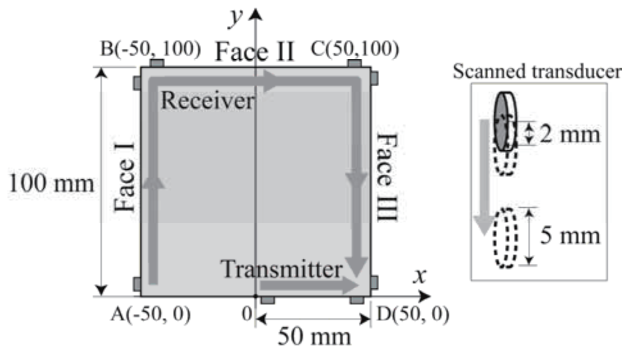

Fig. 3 Analyzed plane

Transmitted signal is sine wave whose frequency is 1, 2, 3, or 5 (MHz). The transmitter scans the billet from (x, y) = (1, 0) to (47, 0) (mm) every 2 mm. Receiver is moved from point A to D by way of point B and C, at intervals of 2 mm for each signal frequency.

3.2 Calculated insertion loss

Figure 4 shows the *IL*s obtained by calculation when the transmitter locates from (1, 0) to (47, 0), as shown in Fig. 3. When transmitted signal frequency is 1 MHz, which meet the condition of $a > \lambda$, where λ is wavelength of transmitted signal, *IL* is smaller and more stable than the others. The higher the frequency is, the more the number of the dips increases, and the sharper directivity becomes. The maximum *IL*s for 1, 2, 3, and 5 (MHz) are 39, 78, 80,and 84 (dB), and the most difference is 44.6 dB between 1 MHz and 5 MHz. Larger *IL*s make signal-to-Noise Ratio (SNR) worse and measurement of the received wave difficult. However, lower frequency may cause lowering of spatial resolution in visualization because of longer wavelength.

According to Fig. 4, there are discontinuity at point 'B' and 'C' regardless to the signal frequency, and *IL*s drop to a lower value in face II. This discontinuity are expected to be is caused by receiver's sensitivity due to angle of the aperture. The *IL*s on face II are lower than those on the other faces although the distance between the transmitter and the receiver is longer. In particular, around point D, although the distance is small, *IL*s are not so large, little less than the minimum on face II. The *IL*s on face II, derived from surface integration, are greater since the received signal waves on face II are more coherent than those on face I and II. This result suggests that the insertion loss mainly depends on the aperture angle of the receiver to the transmitter.

4. Conclusions

We analyzed amplitude characteristic in consideration of directivities both the transmitter and the receiver by radiated sound field in billet to figure out quantitatively transfer characteristic

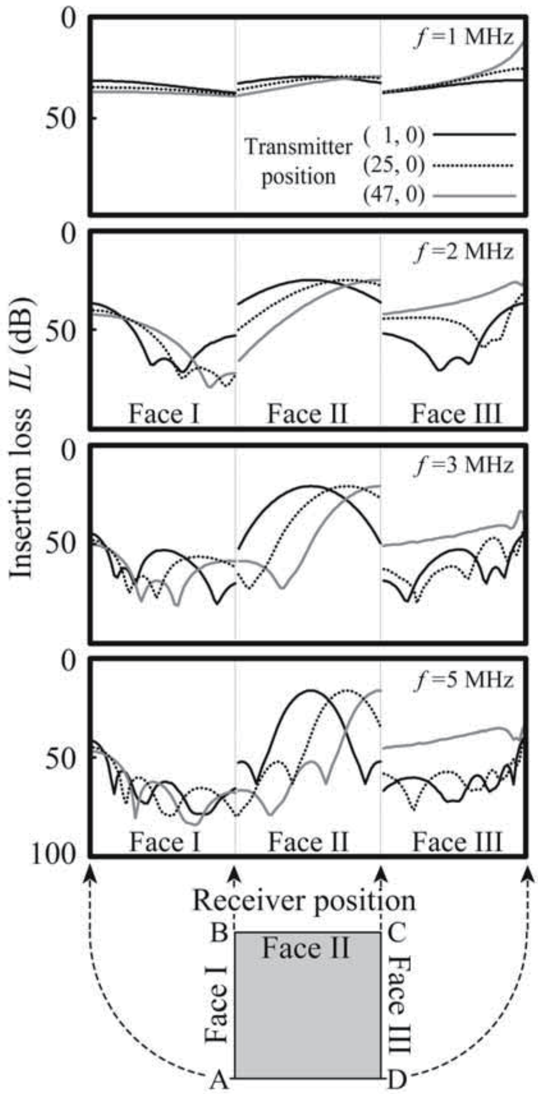

Fig. 4 Insertion loss from transmitter to receiver in billet

between the transmitter and the receiver for non-destructive testing of steel billet We calculated the insertion loss in billet, changing transmitted frequency and found out that the lower the frequency is, the less the insertion loss is. When the receiver moves to the other face, the insertion loss is discontinuous. This is because the received waves on face II are more coherent than those on the other faces. The angle of receiver's aperture to transmitter's affects the insertion loss much. Therefore it is necessary to consider these factors in measurement along rectangular surface.

References

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