2P2-10

Proceedings of Symposium on Ultrasonic Electronics, Vol. 37 (2016)
16-18 November, 2016

Estimation of defect position and size in billet using time-of-flight deviation of ultrasonic bottom echo
超音波対面反射波の伝搬時間変動に着目した角鋼片内部欠陥の位置および径推定

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1. Introduction

We have proposed defect detection method in billet using ultrasonic transmission method and time-of-flight (TOF) of longitudinal wave.[1,2] These methods detect defects from deviation of TOF caused by diffraction at the defects. By employing transmission method, larger intensity of the received signal can be obtained compared with conventional pulse echo method.[1] The defects near the surface of a billet can be detected by using TOF of longitudinal wave.[2] However, transmission method complicates measurement equipment because it requires both transmitter and receiver, while pulse echo method uses single transducer.

Therefore, we have proposed a billet inspection method using TOF of bottom echo which can performed by single transducer.[3] Although bottom echo is used in the pulse echo method for just an indicater of the bottom position, it also has information of defects as well as transmission method with TOF. This method is expected to be used for high attenuation billet because intensity of bottom echo is lager than echo from a defect. It is also expected that defects near the surface of a billet can be detected by using TOF of bottom echo regardless of arrival time of the echo from the defects. Although it was found that this proposed mehod can detect a defect at the center of a cross section of a billet, the effects of the position and size of the defect on TOF deviation have not been investigated yet.

In this study, the relationship between the position and size of a defect and TOF diviation of bottom echo is numerically evaluated, and estimation of the defect position and size is also considered.

2. Principle of defect detection

Figure 1 shows a scheme of defect detection by the proposed method. Ultrasonic signals are projected to a billet from a transducer and echoes

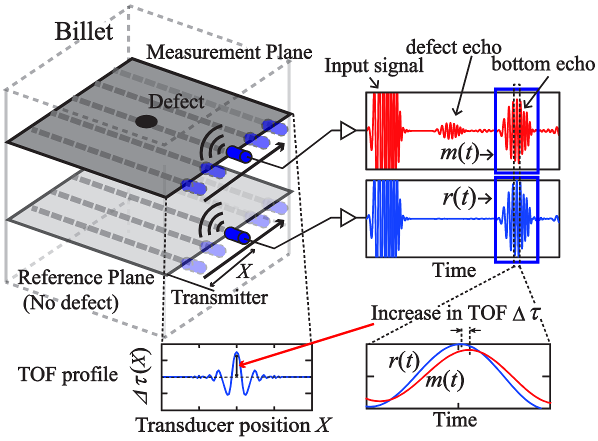

Fig. 1 Outline of defect detection by time-of-flight deviation of bottom echo.[3]

are received by the same transducer. In this method, defects are detected by TOF deviation of bottom echo caused by diffraction around the defects. If there is a defect on the ultrasonic propagation path, the TOF deviates by $\Delta\tau$, which is defined as a time shift between $m(t)$ and $r(t)$ as shown in right hand side of Fig.1. $m(t)$ is the bottom echoes measured at measurement plane which may contain defects. $r(t)$ is the echo measured at reference plane which is defect free. $\Delta\tau$ is obtained by cross-correlation method using $m(t)$ and $r(t)$. A cross section of a billet is measured by linear scanning of a transducer, and TOF profile, which is the relationship between transducer position X and $\Delta\tau$, is acquired as shown in Fig. 1. From this TOF profile, defects are detected.

3. Numerical simulation

To simulate the wave propagation for defect detection by the proposed method, two-dimensional finite-difference time-domain (FDTD) method for elastic wave in solid was emproyed.[4] In this simulation, isotropic elastic material was assumed. **Figure 2** shows the condition of the simulation. Tested billet was assumed to be steel which has cross section of 100×100 mm^2, the density was 7,700 kg/m^3, and the velocities of longitudinal wave

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and shear wave were 5,950 and 3,240 (m/s), respectively. The surface and a defect of a billet was assumed to be a free boundary, on which stress is zero. The mesh size and the time step was 0.1 mm and 1.12 ns, respectively. The input signal was up-chirp signal, whose frequency is 0.5-1.5 MHz with duration of 10 μs windowed by Hann window. To obtain $\Delta\tau$ only considering bottom echoes, the received signals between 33 and 45 μs were used for the calculation of the cross-correlation function. A defect with diameter D exists at (x, y), as shown in Fig. 2. A transducer with an aperture of 6 mm were located at (X, 50). Scanning pitch of the transducer was 0.5 mm.

To evaluate relationship between defect size D and TOF deviation $\Delta\tau$, a defect was located at center of the cross section (x, y) = (0, 0) and D was varied from 0 to 15 (mm). The results are shown in **Fig. 3**. Figure 3(a) shows TOF profile at D = 2, 5 and 8 (mm). The shape of the profile varies as the size of the defect varies. Figure 3(b) shows the relationship between D and $\Delta\tau$ at transducer position $X = x = 0$ mm, same as defect position x. The blue line shows $\Delta\tau$ of bottom echo and the red line shows that of transmitted wave.[2] $\Delta\tau$ of bottom echo is larger than that of transmitted wave, and the tendency of increasing $\Delta\tau$ as D increases is seen in each method. From this relationship, D can be estimated by $\Delta\tau$ at $X = x$ at least when the defect is at (0, 0).

To evaluate relationship between defect position (x, y) and $\Delta\tau$, a defect of D = 5 mm was located at (x, 0) or (0, y) and varied x or y. Figure 3(c) shows TOF profile at (x, 0), x =0, 30, 45, and Fig. 3(d) shows the relationship between x and $\Delta\tau$ at $X = x$. In Fig. 3(c), the peak position of TOF profile is shifted as the defect position x shifts. This means that defect position in the x direction can be estimated. In Fig. 3(d), deviation of $\Delta\tau$ in bottom echo is larger than that in transmission method. This may be caused by the interference between the echo and reflected wave from surface of a billet (x = 50), and the effect becomes larger at bottom echo than transmitted wave. From this relationship, the error in the estimation of defect size based on Fig. 3(b) becomes larger at $x > 25$.

Figure 3(e) shows TOF profile at (0, y), y =-30, 0, 30, and Fig. 3(f) shows the relationship between y and $\Delta\tau$ at $X = x = 0$ with D = 5 mm. In Fig. 3(e), $\Delta\tau$ varies as y varies even if the defect size is the same. In Fig. 3(f), $\Delta\tau$ of bottom echo increases as y increases. In the range of $y > 0$, deviation of $\Delta\tau$ of bottom echo becomes large, and the error of defect size estimation based on Fig. 3(b) becomes large. Although $\Delta\tau$ of transmitted wave at y and $-y$ are the same as each other, that of bottom echoes take different values. This suggests the possibility of estimation of defect position y.

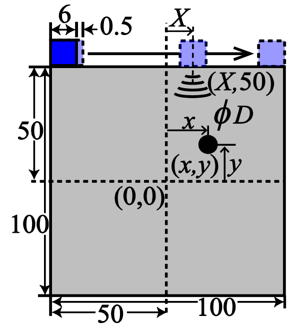

Fig. 2 Simulation condition.

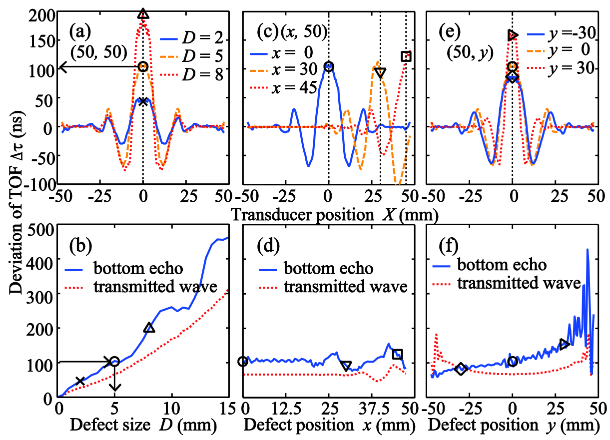

Fig. 3 Deviation of TOF $\Delta\tau$ when the defect size D or position (x, y) are varied: (a) TOF profile at the D = 2, 5, 8 mm, (b) relationship between D and $\Delta\tau$, (c) TOF profile at x = 0, 30, 45 and y = 50, (d) relationship between x and $\Delta\tau$, (e) TOF profile at x = 50 and y = -30, 0 30, and (f) relationship between y and $\Delta\tau$.

However, $\Delta\tau$ are affected by not only D but also x and y. Therefore, other features may be used for precise estimation of defect size and position.

4. Conclusion

In this study, the relationship between defect size, position, and TOF deviation in bottom echo are numerically investigated for estimating defect size and position in a billet. Defect size can be estimated if is in a limited area by the proposed method. Although the effect of defect position appears in TOF deviation, we may use other feature values of TOF profile to know defect position and estimate size precisely.

References

1. Y. Norose *et al*: Jpn. J. Appl. Phys. **53** (2014) 07KC19.
2. R. Miyamoto *et al*: Jpn. J. Appl. Phys. **54** (2015) 07HC11.
3. R. Miyamoto *et al*: Proc. 23rd Int. Congr. Sound and Vibration (2016) T01.RS01-526.
4. M. Sato: Jpn. J. Appl. Phys. **45** (2006) 4453.