Application of Gaussian Beam to Ultrasonic Testing

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Introduction. The demand for welding technologies are increasing as multi-materialization and sophistication of products are advancing. There are several non-destructive methods including ultrasonic inspection, radiographic testing, and magnetic particle inspection. Ultrasonic testing (UT), which detects ultrasonic waves that have reflected on a defect, is one of the most popular non-destructive inspection technologies. This technique usually utilizes pulse waves, and hence it is easily affected by noise and attenuations. Therefore, the measurement result depends on a skill of an operator. Moreover, a long inspection time for a wide area is required because the probe has to scan.

In the present study, Gaussian beam theory is introduced. The theory is able to define the expansion of a wave and to calculate its amplitude and Time-of-Flight (ToF) to the certain point. Furthermore, we use continuous waves to reduce noise. The method can distinguish metallographic defects such as intermetallic compound layer and heat-affected zone, which transmit the sound wave. By observing and simulating the wave behavior inside a material with discontinuous interface. This study reveals how the continuous waves propagate inside materials.

Theory. Gaussian beam is expressed as follows

\[ \Psi(r, z) = \Psi_0 \frac{w_0}{w(z)} e^{-\frac{r^2}{2w(z)^2}} e^{i \text{tan}^{-1}\left(\frac{z}{r_0}\right) - \frac{kr^2}{2R(z)}} \]  

(1)

\( \Psi_0 \) is amplitude of the sound at an position \( z \), \( r \) represents the offset of centers of the sound source. Some parameters required to determine the beam amplitude and phase are expressed as

\[ z_0 = \frac{\pi w_0^2}{\lambda} \]  

(2)

\[ R(z) = \frac{z^2 + z_0^2}{z} \]  

(3)

\[ k = \frac{2z_0}{w_0^2} \]  

(4)

where \( z_0 \), \( R(z) \), and \( k \) show the Rayleigh length, the radius of curvature at \( z \), and the magnitude of the propagation vector, respectively. \( \lambda \) and \( w_0 \) are wave length, and a radius of the sound.

Experiment. Figure 1 shows the experiment setup to measure the propagation of continuous wave. Three aluminum alloy plates (AA5052, 5 mm thick) are layered, assuming a material with an internal defect. The middle plate has a 5mm diameter aperture. An acoustic transmitter and receiver with the diameter of 10mm are used for a receiver and a transmitter. Sinoidal sound wave with the frequency of 5MHz is applied to the transmitter. The receiver is moved in 5mm step from the initial position. The parameters of \( w_0, z, \) and \( r \) are 6 [mm], 15 [mm], and 70 [mm]. ToF is obtained from the phase difference between the applied and received waveforms using an oscilloscope.

Results. Figure 2 shows a comparison of experimental and theoretical data of ToF and the signal amplitude. The horizontal axes represent position of receiver, \( r \) [mm]. ToF (Fig.2(a)) exhibits a great gap between theory and experiment. This may be because the experiment data contains phase difference exceeding one period. This issue can be solved by making the step size of \( r \) small enough to determine where the phase differences occur. While the amplitude is in rough agreement with the theory. A fluctuation of amplitude in the theoretical value is may be due to diffraction of the wave at the discontinuous interface, resulting in an interference of diffracted waves.

References.

(1) Sanichiro, Y., Waves, IOP Concise Physics (2017), 2-16 – 2-19