Ultrasonic waves transmitted from the probe and phenomena caused by edge waves

探触子から送信される超音波とエッジ波により発生する現象

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1. Introduction

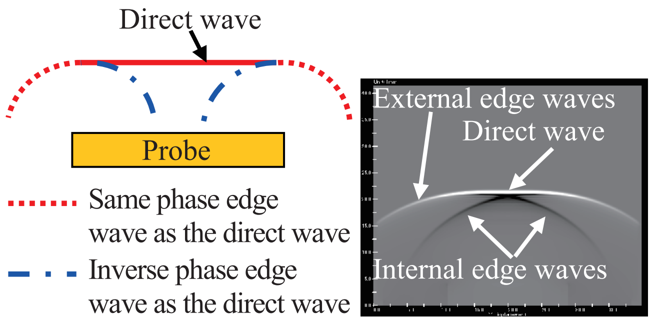
Ultrasonic wave transmitted from the probe is a direct wave of the same shape as the probe surface, and edge waves are generated by the edge of direct wave. Edge waves are generated respectively at the inside and the outside of the direct wave. Various phenomena are caused by overlapping direct wave and edge wave. These phenomena of ultrasonic propagation is known the side robe, the zero radiation angle, the variation of amplitude in near field and the grating lobe at the phased array scanning. These phenomena are caused in the case of continuous wave by overlapping the edge wave or the direct wave, but these phenomena are not caused when the pulse wave is transmitted. Ultrasonic propagation of continuous wave and pulse wave has been reported so far [1]. In this paper, we describe direct and edge wave transmitted from the probe, further it is described that phenomena caused by overlap these waves.

2. Direct wave and edge waves

Ultrasonic which is transmitted from the probe is direct wave with the same shape as the transmitting surface, as shown in Fig. 1, and the edge waves are generated by the both edges of the direct wave. The edge wave which generated outside at the direct wave is same phase as the direct wave, and the edge wave which generated inside at the direct wave is inverse phase as the direct wave. Figure 1(b) shows a simulation (eCompute, SWAN21) image applying a positive pulse, white shows positive amplitude and black shows negative amplitude. It can be seen that the internal edge wave is inverse phase as the direct wave. Although this figure shows ultrasonic propagation of a pulse wave with wave cycle 1, as the wave cycle increases, the direct wave and the edge wave overlap and the amplitude varies.

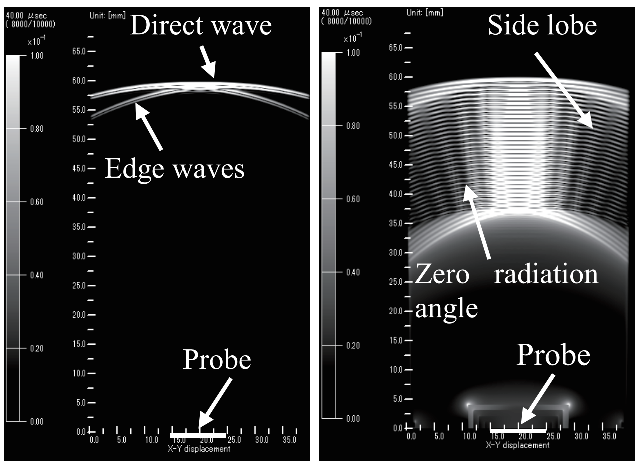
3. Overlap at direct wave and edge wave

Amplitude varies when the direct wave and edge waves are overlapped. At first, figure 2 shows the sound field when ultrasonic with 1 cycle and 30 cycles waves is emitted from the 10 mm width ultrasonic probe. Frequency is 2 MHz. At the



(a) Direct and edge waves (b)Simulation

Fig. 1 Ultrasonic emitted from a probe.



(a)Pulse wave (b)Continuous wave

Fig. 2 Sound fields of pulse and continuous waves.

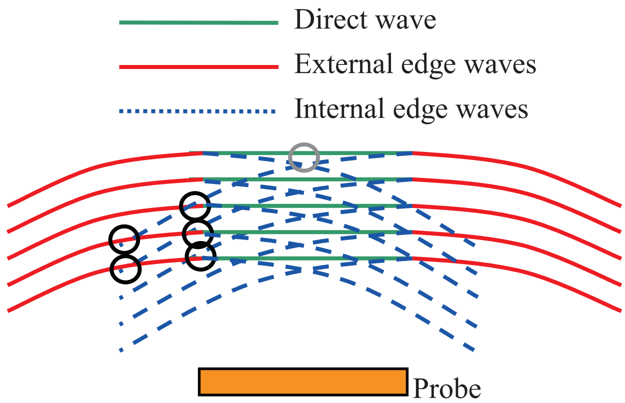


Fig. 3 Overlapped direct and edge waves.

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30 wave cycles ultrasonic, the amplitude varies in except the leading and the end of ultrasonic. This can be explained as Fig. 3. Only the left side edge wave was drawn for explanation. Amplitude varying is caused at the overlapped point (black circle) that the external edge wave generated from the left side of the direct wave and the internal edge wave generated from the right side. Since the external and internal edge waves have inverse phase, the amplitude decreases in the case of overlapping and the amplitude increases in the case of overlapping with a half wavelength shift. The place where the amplitude is large is the side lobe, the place where it is small is called the zero radiation angle and the direction angle. Thus, amplitude fluctuations due to edge waves generate except for the leading and trailing waves, and the above phenomenon causes, but the amplitude decreases as the edge wave spreads. Therefore, the amplitude does not become 0 even at the zero radiation angles with low amplitude. The amount of generated edge waves varies depending on the medium, it generates in water, but hardly generates in the air. Since the transmission directivity is determined by the edge wave, the ultrasonic wave hardly spreads and propagates straight in the air.

Even on the probe centre axis, the amplitude varies with the edge waves. Also in the centre of the probe in Fig. 3, amplitude varying is caused at the overlapped point (gray circle) that the direct wave and the internal edge waves. Since the direct wave and the internal edge wave are in inverse phases, the amplitude decreases when they overlap, and the amplitude increases when propagation distance difference becomes a half wavelength. Even for pulse waves, the amplitude increases when the propagation distance difference becomes half the wavelength. If the propagation distance of the edge wave is E and the propagation distance of the direct wave is X as shown in Fig. 4, the amplitude increases at the following positions.

$$X = \frac{1}{4}\left(\frac{w^2}{\lambda} - \lambda\right) \quad (1)$$

w : Probe width
λ : Wavelength

Assuming that the transducer width w is the transducer diameter D, it is almost the same as the near field limitation equation, and the amplitude increases in the vicinity of the near field limit. Figure 5 shows the measurement results of the amplitude on the probe central axis of 10 mm width and 5 MHz in water using a hydrophone. The near field limit is 83 mm. In the pulse wave, the amplitude was almost constant within the near field, and the amplitude increased in the vicinity of the near field limit. In the continuous wave, the inner edge wave overlapped with the direct wave after the second wave and the amplitude fluctuated in the near field.

Figure 6 shows the results of measuring the amplitude on the probe central axis with an ultrasonic air probe with a diameter of 20 mm and a frequency of 250 kHz with a hydrophone. In the air there is a possibility that the amplitude has increased due to multiple reflection with the hydrophone, but since the generation of the edge wave is small, there is no amplitude fluctuation in the near field even with continuous wave.

4. Conclusion

We explained that direct waves transmitted from the probe and edge waves are generated from the edge and direct waves and edge waves overlap each other and various phenomena are caused.

Reference

[1] Y. Tanaka et al: Acoustic imaging kennkyuukai **AI-2016-26(2016)**. [in Japanese]

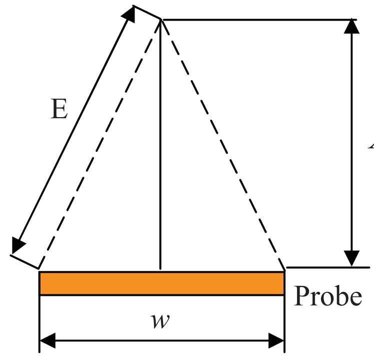

Fig. 4 Propagation of direct and internal edge wave.

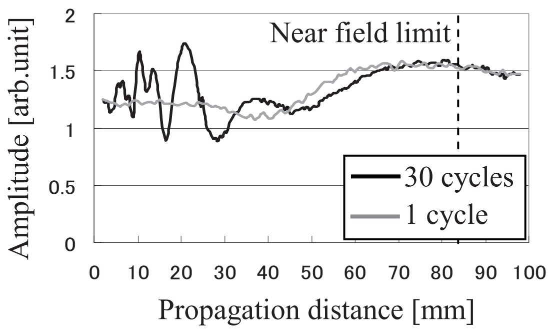

Fig. 5 Amplitude at centre axis of the probe in water.

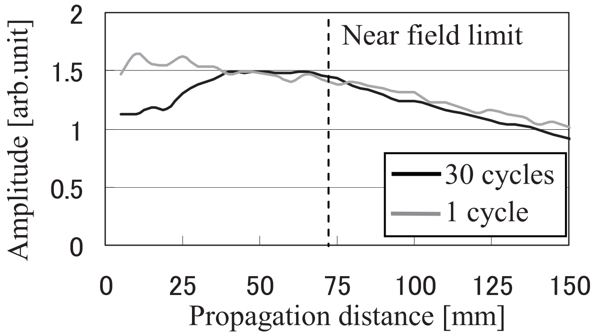

Fig. 6 Amplitude at centre axis of the probe in air.