17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Development of Ultrasonic Line-Focus SH-Wave Probe

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Abstract

A line-focus ultrasonic SH-wave probe is developed for possible application to TOFD method. The probe is composed of a quarter- or half-cylindrical wedge and a piezoelectric transducer adhered to the cylindrical surface of the wedge. An SH-wave pulse with cylindrical wave front is generated by the transducer, transmitted to the wedge, and focused on a line at the bottom surface of the wedge. Hence, the SH-wave is incident on the specimen surface at all angles from zero to 90 degrees simultaneously. The directivity of the probe is examined and compared with that of the line-focus P-wave probe developed previously.

Key Words: Ultrasonics, SH-wave, Line-focus, Directivity, TOFD method

1. Introduction

In recent years, non-destructive testing has attracted more attention from industry than before in terms of managing the safety and integrity of aged machines and structures. Ultrasonic non-destructive testing is one of the most widely used techniques among others. However, further improvement of accuracy and reliability in detecting and sizing various kinds of flaws is still demanded. Development of new-type ultrasonic probe is certainly one of the most effective ways to achieve such improvement.

From such viewpoint, our research group has been developing a new-type ultrasonic probe called contact-type line-focus probe during the past ten years. This probe is composed of a quarter- or half-cylindrical wedge and a piezoelectric transducer adhered to the cylindrical surface of the wedge. A P-wave pulse with cylindrical wave front is generated by the transducer, transmitted to the wedge, and focused on a line at the bottom surface of the wedge. Hence, the P-wave is incident on the specimen at all angles from zero to 90 degrees simultaneously. It has been shown that this probe can excite and detect Rayleigh, Lamb and generalized Lamb waves without adjusting the incident angle to the testing object[1,2].

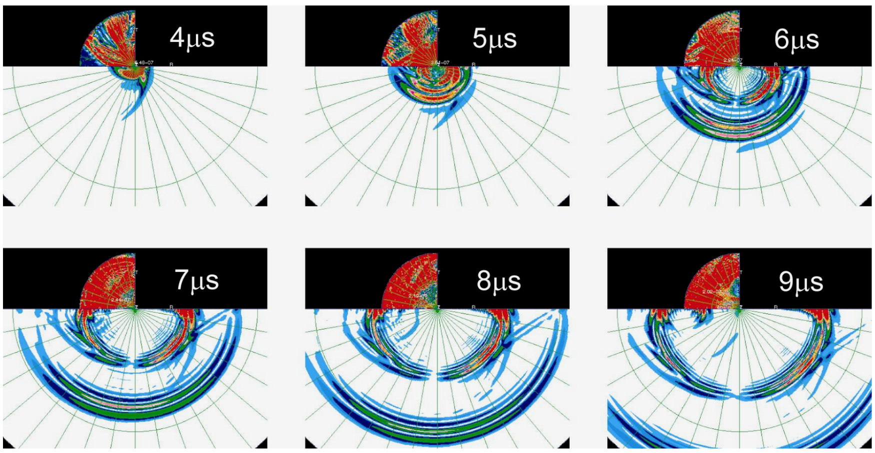

Figure 1: Numerical simulation of P- and SV-waves excited by the line-focus P-wave probe

It has been also shown that the line-focus probe can excite P- and SV-waves in bulk specimen in all directions of refraction angles from -180 to 180 degrees simultaneously[2] as shown in Figure 1. Such a wide directivity of P-wave is suitable for application to the TOFD method. The applicability of the line-focus probe to the TOFD method has been studied and it has been confirmed that crack length can be sized by using the line-focus probe with accuracy comparable to those obtained by angle beam P-wave probes on the market. Although P-wave having such wide directivity can be excited using phased array probes nowadays, the line-focus probe has a structure much simpler than the phased array probe and can be used in the same manner as conventional angle beam probe.

The TOFD method usually utilizes P-waves traveling along the top surface (lateral wave), diffracted at the crack tip, and reflected at the bottom surface. The crack length is then calculated from the differences between traveling times of these P-waves. However, there exist many other waves such as Rayleigh wave traveling along the top surface and mode-converted SV-waves generated by refraction at the wedge-specimen interface, diffraction at the crack tip, and reflection at the bottom surface. These waves often cause difficulty in identifying the traveling time of each P-wave used in the TOFD method.

To overcome this disadvantage of the TOFD method using P-waves, Rao et al. considered use of SH-wave[3]. When SH-wave is used, other waves such as Rayleigh, P- and SV-waves do not appear as far as two dimensional wave propagation in the B-scan plane is considered. In addition, the crack size evaluation is expected to be more accurate because the wavelength of SH-wave is shorter than P-wave as pointed out by Rao et al[3]. Since TOFD method using SH-wave has not been established yet, it is worth considering the use of SH-wave further more. For this purpose, it would be beneficial to develop an SH-wave probe suitable for TOFD method.

In this paper, a line-focus SH-wave probe is developed for possible application to TOFD method. The directivity of the probe is examined and compared with that of the line-focus P-wave probe developed previously.

2. Structure of Line-Focus SH-Wave Probe

Figure 2 shows the basic structure of line-focus SH-wave probe developed in this study. A piezoelectric ceramic transducer is adhered to the cylindrical surface of the wedge made of polystyrene. The size of the wedge is 10 mm in radius and 10 mm in width. Two pairs of probes were produced in this study: one having half-cylindrical wedge as shown in Figure 2 and the other having quarter-cylindrical wedge. The nominal resonance frequency of the ceramic transducer is 1 MHz.

When a electric pulse is applied to the transducer, an SH-wave pulse with cylindrical wave front is generated by the transducer, transmitted to the wedge, and focused on a line at the bottom surface of the wedge. Hence, the SH-wave is incident on the specimen at all angles from zero to 90 degrees simultaneously. Judging from the previous experience on the line-focus P-wave probe, it is expected that SH-wave is excited in the bulk specimen in all directions of refraction angles from -180 to 180 degrees simultaneously. Such a wide directivity of SH-wave would be suitable for application to the TOFD method.

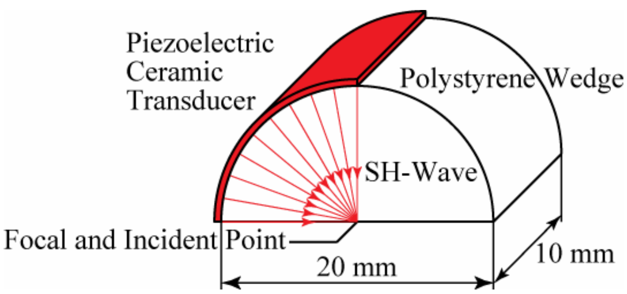

Figure 2: The basic structure of line-focus SH-wave probe with half-cylindrical wedge

3. Evaluation of Directivity

3.1 Method

The directivity was evaluated for the line-focus SH-wave probe as well as the line-focus P-wave probe with different transducers (piezoelectric ceramics or composites) and wedges (half- or quarter-cylindrical). Table 1 shows specifications of line-focus probes evaluated in this study.

The probe to be evaluated was put on a half-cylindrical steel specimen (100 mm in radius and 70 mm in width) as shown in Figure 3. The incident (focal) point of the line-focus probe was positioned at the center of the specimen. The P-wave, SV-wave and SH-wave excited in the specimen were received using electro-dynamic P- or S-wave probes (WAZAU) at the cylindrical surface of the specimen. The directivity was evaluated by the maximum amplitude of signal received at each refraction angle from -85 to 85 degrees.

Table 1: Specifications of line-focus probes evaluated in this study

Probe ID	Wave Type	Transducer	Wedge Shape	Frequency [MHz]
A	P	Ceramics	1/2 Cylinder	2
B	P	Ceramics	1/4 Cylinder	2
C	P	Composites	1/2 Cylinder	2
D	P	Composites	1/4 Cylinder	2
E	SH	Ceramics	1/2 Cylinder	1
F	SH	Ceramics	1/4 Cylinder	1

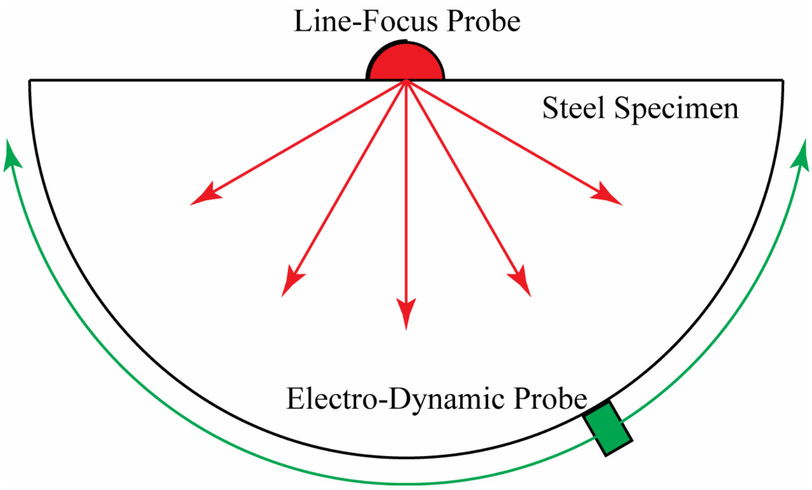

Figure 3: Method of evaluation of the directivity

3.2 Results

Figure 4 shows the directivity of P-wave excited by the line-focus P-wave probe. The maximum amplitude of the signal received at each refraction angle is plotted in this figure, which is normalized by the maximum value for all refraction angles measured. It can be seen that the line-focus P-wave probe has a very wide directivity as demonstrated in the previous study[2]. The maximum amplitude is obtained at refraction angles around 30 to 50 degrees for the half-cylindrical wedges (Probe A and Probe C) and around zero to 30 degrees for the quarter-cylindrical wedges (Probe B and Probe D). In regard to application to the TOFD method, the ultrasonic wave is not necessary to be excited in the direction of negative refraction angles. In other words, it is preferable that the sensitivity in the direction of positive refraction angles is as high as possible. Therefore, the half-cylindrical wedge is more suitable for application to the TOFD method than the quarter-cylindrical wedge adopted in the previous study[2].

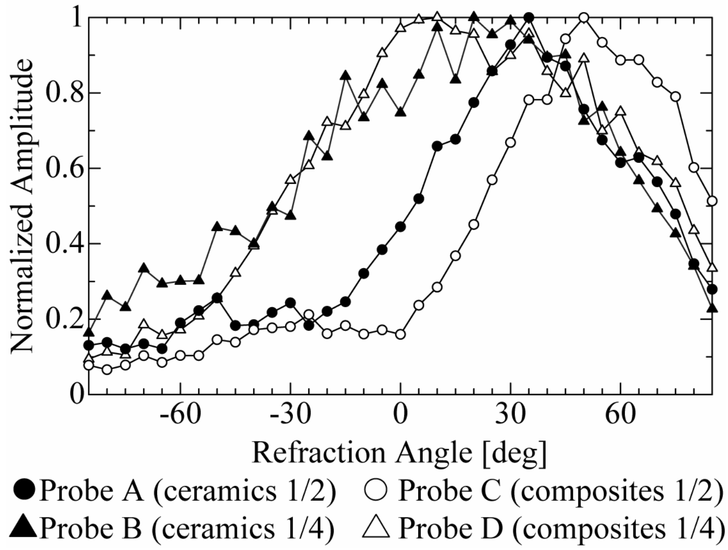

Figure 4: Directivity of P-wave excited by the line-focus P-wave probe

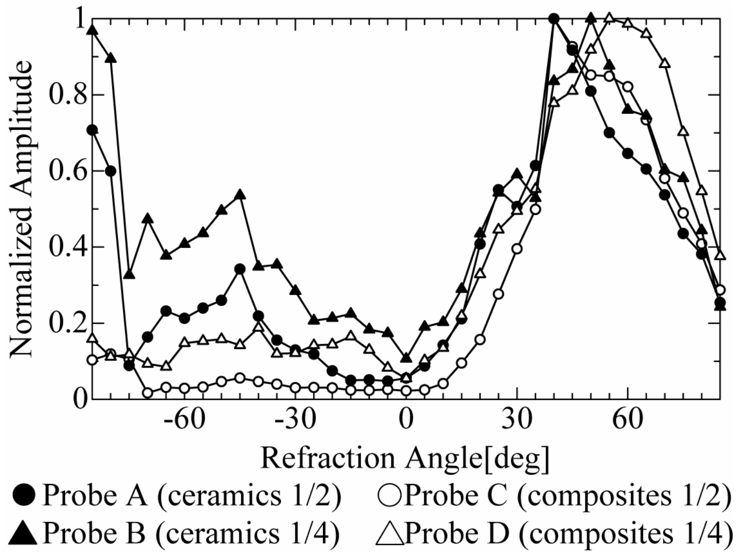

Figure 5: Directivity of SV-wave excited by the line-focus P-wave probe

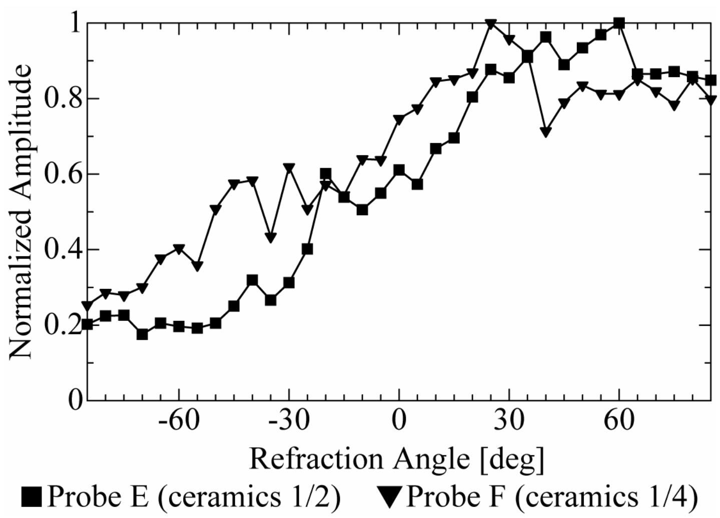

Figure 6: Directivity of SH-wave excited by the line-focus SH-wave probe

It was also confirmed that the absolute sensitivity of composite transducer probes (Probe C and Probe D) is about twice as high as that of ceramic transducer probes (Probe A and Probe B). As a result, Probe C is the most suitable for application to the TOFD method among the four kinds of P-wave probes evaluated in this study.

The directivity of SV-wave excited by the line-focus P-wave probe is shown in Figure 5. The difference between the directivities of the half- and quarter-cylindrical wedges is less significant than in the P-wave case shown in Figure 4. The large amplitude observed at refraction angles around -85 to -80 degrees may be attributed to Rayleigh wave propagating along the top surface of the specimen.

Figure 6 shows the directivity of the line-focus SH-wave probe. Both line-focus SH-probe shows relatively large amplitude at refraction angles from 20 to 85 degrees. The maximum amplitude is obtained at 60 degrees for the half-cylindrical wedge (Probe E) and at 25 degrees for the quarter-cylindrical wedge (Probe F). The half-cylindrical wedge shows higher amplitude at refraction angle larger than a certain value (35 degrees in this case) compared with the quarter-cylindrical wedge. This tendency is the same as in the P-wave probe but less significant. It should be mentioned that P- and SV-waves were not detected by the receiving probe. Therefore, the line-focus SH-wave probe developed in this study has a potential for application to the TOFD method.

4. Conclusions

In this study, a line-focus SH-wave probe was developed for possible application to the TOFD method. The directivity of the developed probe was evaluated and compared with that of the line-focus P-wave probe developed previously. As a result, it was shown that the line-focus SH-wave probe has a potential for application to the TOFD method.

In the future study, the directivity should be evaluated by numerical simulation to confirm and improve the basic characteristics of the probe. Applicability of the probe to the TOFD method should be also examined in practice.

Acknowledgements

The authors would like to appreciate Japan Probe Co., Ltd for offering equipment for the evaluation of directivity. This study was partly supported by Grants-in-Aid for Scientific Research from Japan Society for the Promotion of Science (No. 17560065 and 19560076).

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