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A Study on Advanced Ultrasonic Measurement of Flaw Length

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Abstract

Nondestructive flaw sizing is one of the most important matters to predict the remained life of the structure or pressure equipment in industrial fields. The area of flaw, height and length of flaw, should be considered from the point of view of fracture mechanics. Although several techniques to measure flaw height have been developed, there have been quite few investigations for the measurement of flaw length. For decades measuring the length of the flaws has been carried out using conventional techniques such as dB drop or DAC level technique. However the accurate extremity along flaw length cannot be determined by these techniques directly.

This paper proposes an advanced ultrasonic technique for measuring flaw length by determining the extremity directly. Two angle probes both of which are connected to a pulsar receiver with the parallel circuit receive diffraction wave from the extremity of flaw. When the probes are scanned along the flaw, the locus curves are displayed on the B-scan image and the intersection of the locus curves obtained by two probes indicates the extremity of the flaw accurately. This technique, called Twin Diffraction Waves Technique hereinafter, was applied to several test specimens and the practical advantages of the technique were confirmed experimentally.

Key words: ultrasonic testing, flaw length, B-scan image, diffraction wave

1. Introduction

A measurement method of flaw length well known is dB drop method based on the amplitude, but it cannot be said that this method measures flaw length accurately. The estimation of the size of flaw length depends on numbers of factors, such as transfer losses, beam width and so on. The one of the best methods that can measure flaw length accurately is TOFD method. Dr. SILK described the sizing method of the flaw length that referred to curved profiles on screen of TOFD [1]. Every technique has its limitation and TOFD is no exception. TOFD method has to be carried out by placing probes on both sides of the weld with high sensitivity. Therefore, the noise from the weld might make sizing difficult. Kim Young-Gil et al. introduced sizing technique of the flaw length using index tool with tip echo technique[2]. The difficulty of this technique is to identify the signal from the edge of the flaw. The amplitude of the tip diffraction echo is much less than other reflected echoes; therefore, identification of tip diffraction signal among the other echoes is not easy. The identification of the flaw depends on the ability and experience of the inspection engineer.

In this paper, the new technique using double probes called as Twin Diffraction Waves Technique is proposed. The technique can be performed from one side and signal from the extremity of flaw can be easily identified on the B-scan image. Acquired data are based on transit time; therefore, the test result can be very accurate.

2. Twin Diffraction Waves Technique

The angle beam probes are connected with the parallel circuit to a pulsar receiver as shown in Figure 1. Each probe transmits pulse signal at the same time. When probes approach the edge of the flaw, each probe receives the diffraction wave from the flaw edge. The relation between the position of probes and the propagation time of the diffraction wave from the edge of the flaw is shown in Figure 2. When the edge of the flaw comes to center of both probes, each probe picks up the signals from edge of the flaw at the same time. The signal from the tip echo obtained from probe A and B intersects with the signal of the corner reflected echo because these are signals have the same transit time from the point of the flaw edge. Figure 3 shows an image obtained by applying this technique to the test specimen with slit. The signal from the edge of the flaw length is plainly obtained.

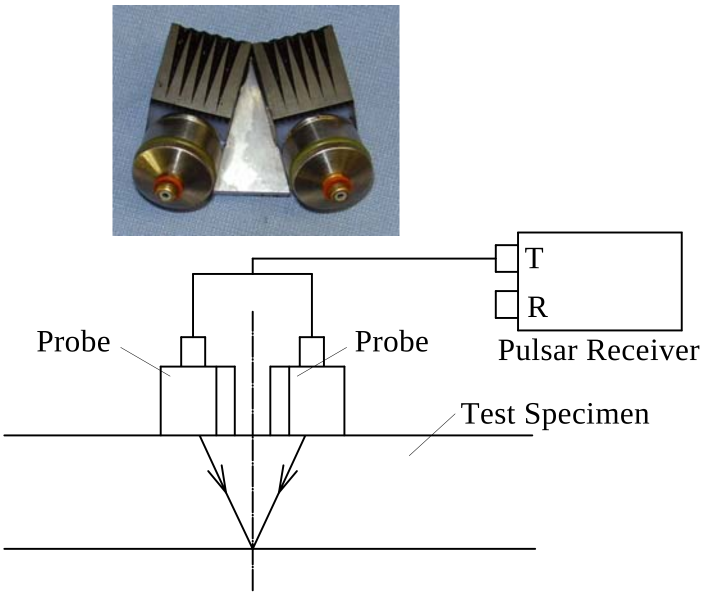


Figure 1. Setting of probes

(Angle probes are connected with the parallel circuit)

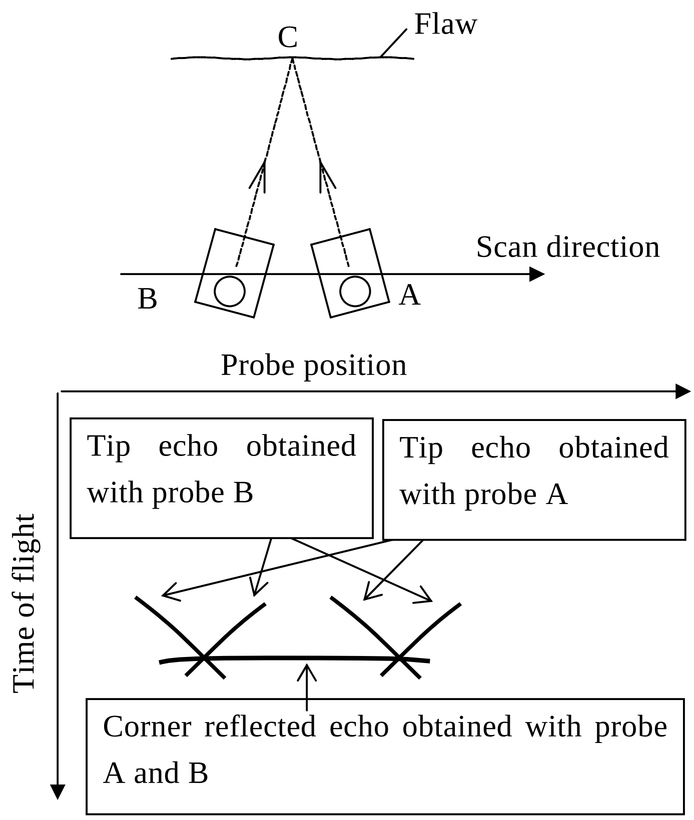


Figure 2. aRelation between the position of probes and the propagation time of the diffraction wave from the edge of the flaw

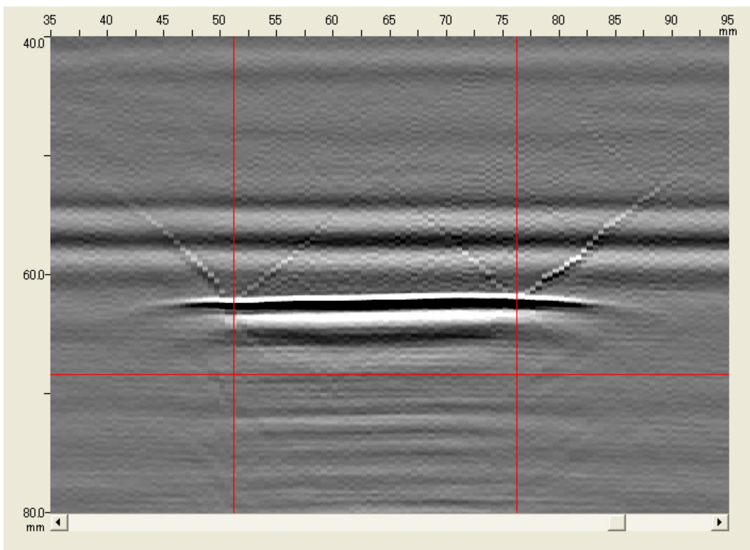


Figure 3. Example of the image of Twin Diffraction Waves Technique (Actual length: 25.0mm, UT result: 25.0mm)

3. Setting and dimension of probes

Figure 4 represents the setting and dimension of probes. The width of probe is 2*a* mm, the distance between probe index and front end is *b* mm, the angle of refraction is *θ* degree, the distance of the two probes separation is 2*c* mm and the swivel angle is *α* degree, then the depth of beam intersection *d* is:

$$d = \frac{c}{\tan\theta \cdot \sin\alpha} \quad \text{----------------} \quad (1)$$

When *θ* is 60 degree and *α* is 15 degree, the relation of probe separation 2*c* and distance of the depth of beam intersection *d* is shown in table 1. For the following experiments a wedge of 60 degrees of shear wave is used, the swivel angle is 15 degrees, and probe separation (2*c*) is 26 mm. Though the beam intersection of this probe is 29mm in depth, this probe could be applied to test specimen which has thickness from 14mm to 50mm for the measurement of flaw length.

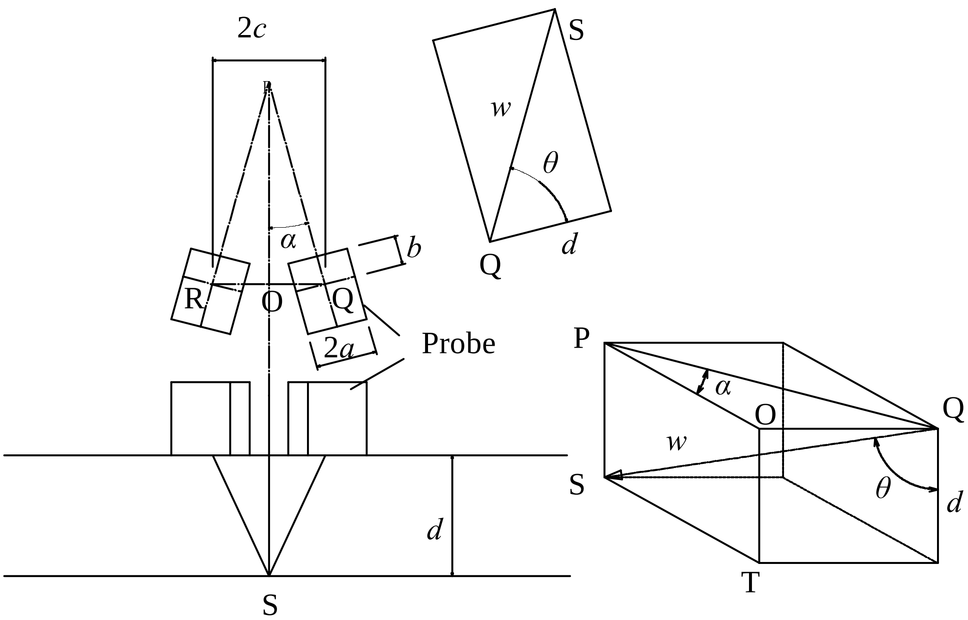


Figure 4. Setting and dimension of probes

Table 1 : The relation of probe separation 2*c* and distance of the depth of beam intersection *d*

Angle of refraction: *θ*(deg)	Swivel angle: *α*(deg)	Probes separation: 2*c*(mm)	Beam intersection: *d*(mm)
60	15	13	14.5
60	15	26	29.0
60	15	52	58.0

4. Test specimens

The following test specimens shown in table 2 were used for this experiment. The slits were inserted to the plates by electrical discharge machining method. Test specimens with cracks are shown in figure 5 and figure 6.

Table 2： Test specimens used for this experiment

Thickness of specimen (mm)	Materials	Flaw	Length of flaws (mm)
14.0	SUS	Slit(rectangle)	25
25.0	CS	Slit(arched shape)	30
40.0	CS	Slit(tilt angle: 0deg)	10
40.0	CS	Slit(tilt angle:30deg)	10
50.5	CS	Fatigue crack (implant)	10, 11
20.2	SUS	SCC	39

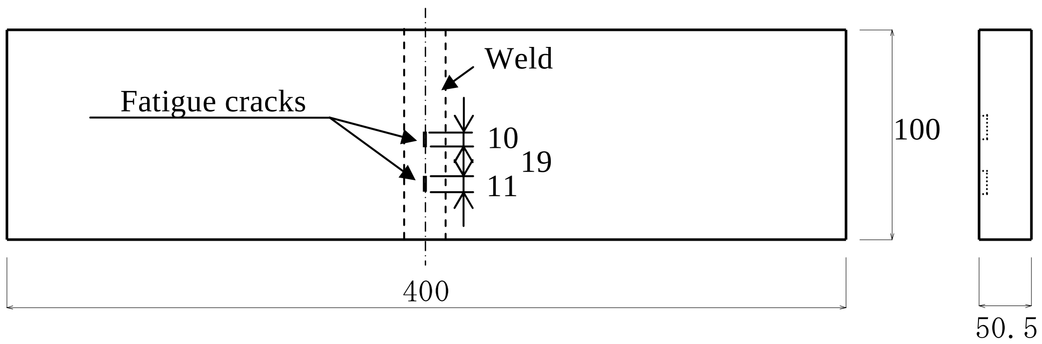


Figure 5. Test specimen in which fatigue cracks are implanted

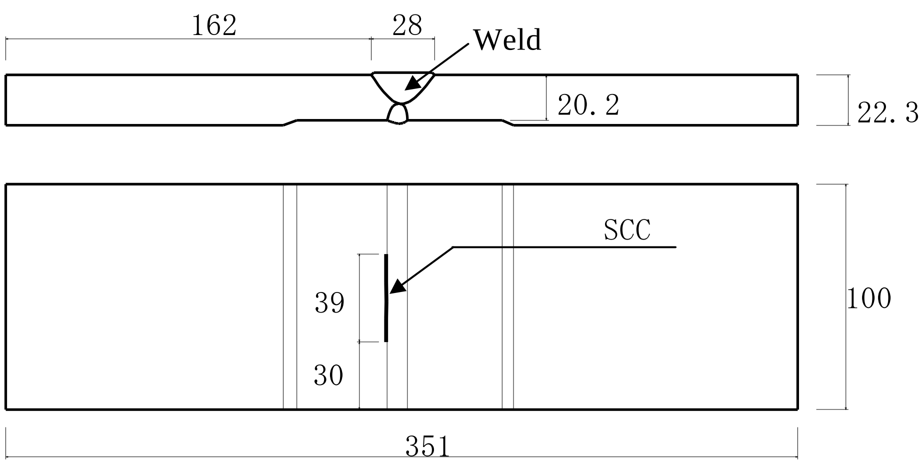


Figure 6. Test Specimen with SCC

5. Application results

5.1 Application results to the test specimens with slit

First of all, this technique was applied to measure the length of two types of artificial slit perpendicular to the back surface shown in figure 7 top. Shear wave angle probes, 5MHz in frequency, 60degs in refraction angle, were used for the experiment. B-scan images are obtained from the artificial slit as shown in figure 7. The edge of the rectangular slit can easily be estimated as shown in figure 7 left. On the other hand, an arched slit can also be estimated. Secondly this technique was applied to the tilted slit. Measuring of the defect length is possible from either sides of the tilted slit as shown in figure 8.

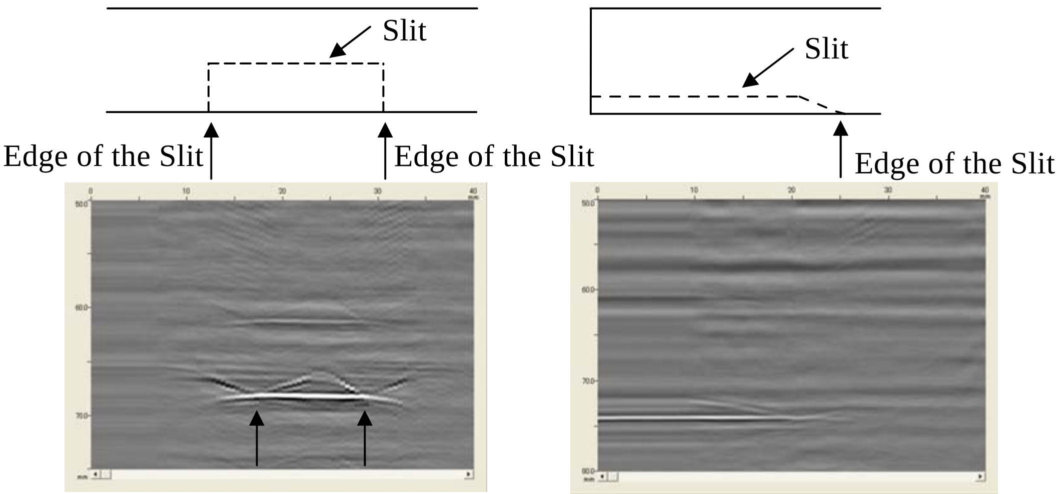
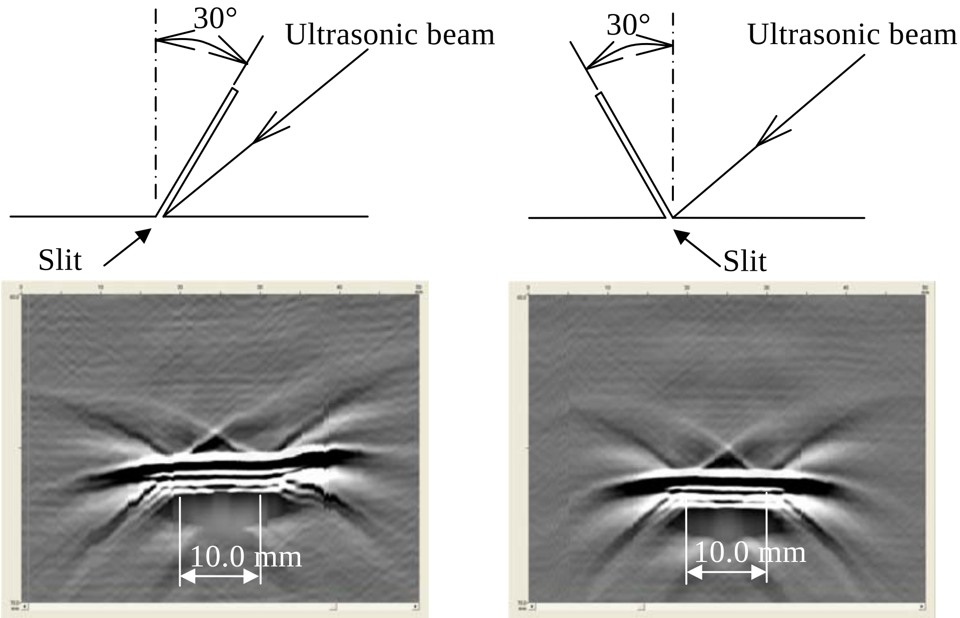


Figure 7. Application results to the different tip shape



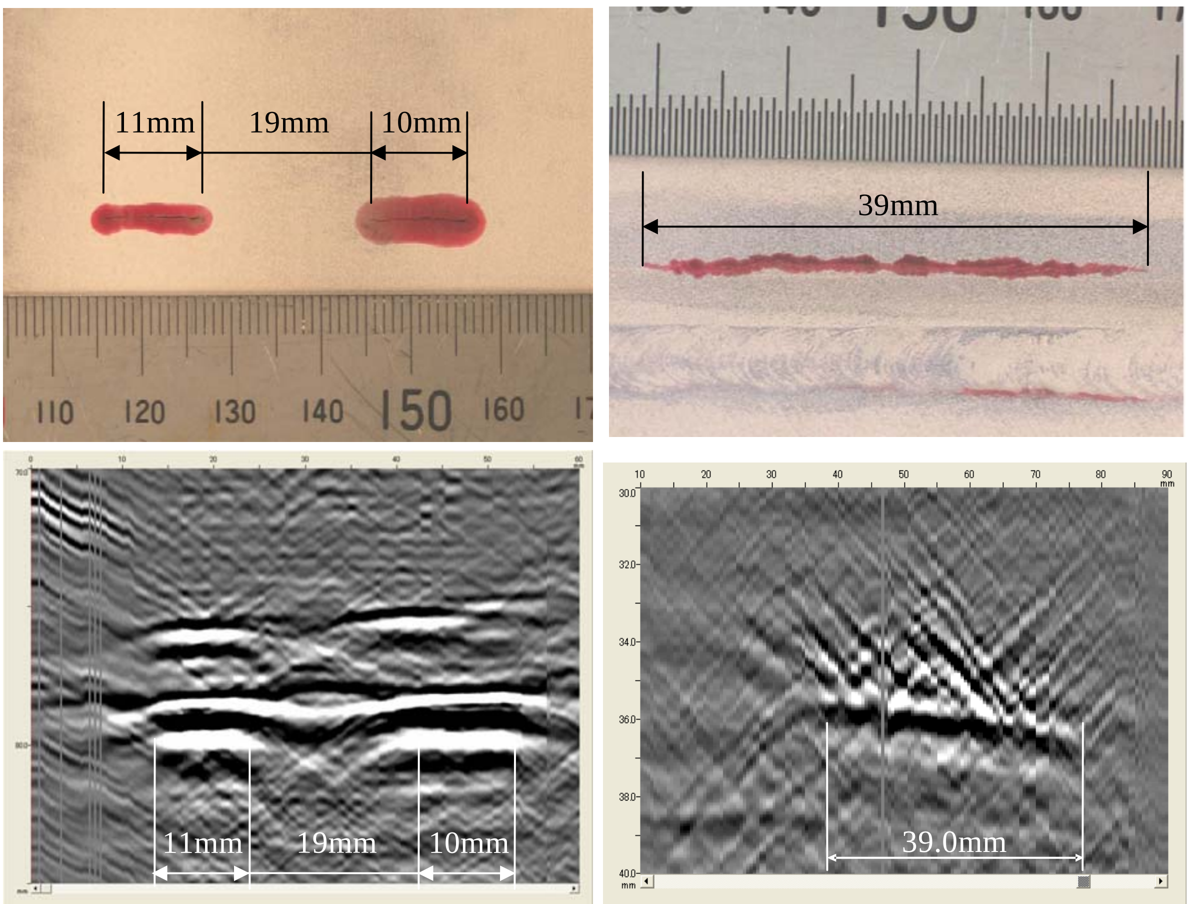
From acute side From obtuse side

Figure 8. Application results to the tilted slit

5.2 Experimental results to cracks

Fatigue cracks shown in figure 9(a) top and SCC shown in figure 9(b) top were examined using this technique. Figure 9(a) shows the test result of applying the technique to the specimen with the embedded fatigue cracks. The measurement results of the flaw length shown in figure 9(a) bottom is corresponding to the liquid penetration test result shown in figure 9(a) top.

The result of applying this technique to SCC is shown in Figure 9(b). In this case, many signals appear one after another as shown in figure 9(b) bottom, because of the rough fracture surface of SCC. The length of such kind of crack should be measured to the longest indication.



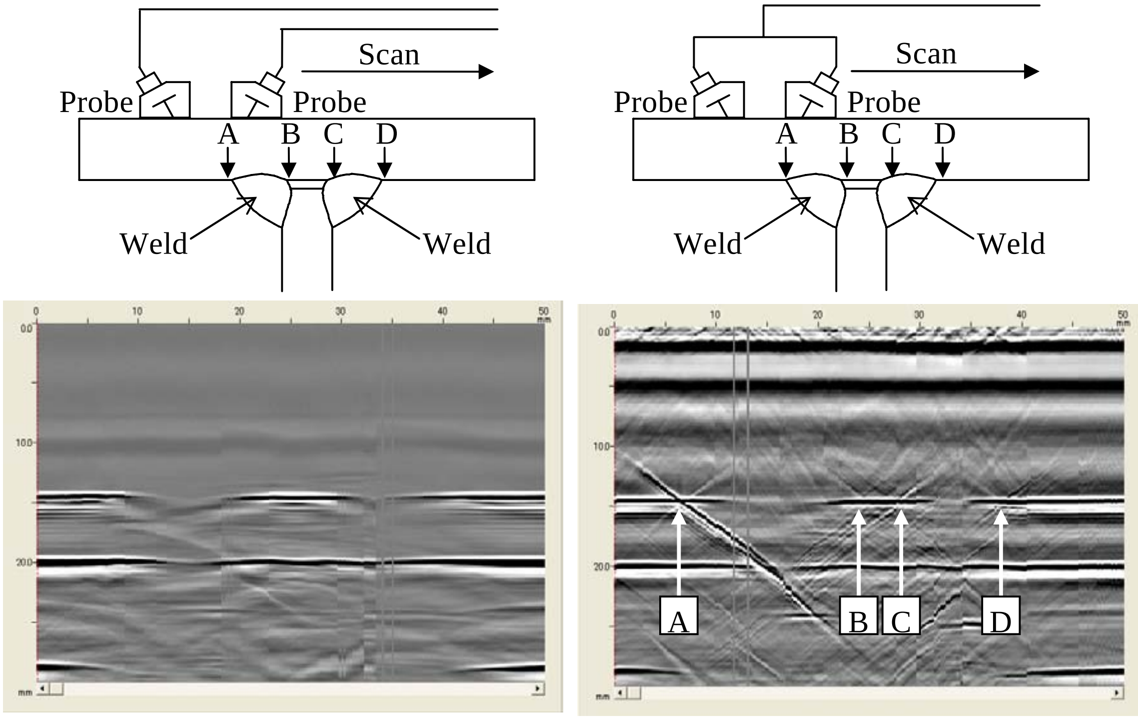
(a) Application to fatigue cracks **(b) Application to SCC**

Figure 9. Application results to cracks

6. Application to other structure

Although the one of the advantages of this technique is that arranging probes on both side of flaw is not necessary, when probes are set opposite each one, it is possible to estimate width of root penetration of T joint as shown in figure 10. The figure shows comparison between TOFD and this technique. The measurement of root penetration is easier using this technique as shown in figure 10.

This arrangement can be also used to estimate the nugget diameter in the spot weld is measured.



TOFD method **Twin Diffraction Waves Technique**

Figure 10. Application results to T joint

7. Conclusions

Estimation of flaw length using Twin Diffraction Waves Technique is inherently very accurate because the technique is based on the transit time of echoes whereas traditional techniques that utilize signal amplitude are subject to a great deal of variability due to coupling conditions etc. The measurement result is not influenced by the ability of the inspection engineer.

References

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[2] Kim Young-Gil et al, Practical Application of Tip Diffraction to Crack Sizing, 12th Asia-Pacific Conference on Non-Destructive Testing, Auckland, New Zealand, CD-ROM, (2006)