PRACTICAL APPLICATION OF TIP DIFFRACTION TO CRACK SIZING

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Abstract

Tip diffraction method is well known as a very exact sizing technique. Many researches for the technique have been done and several instruments have been developed. But almost all of the techniques require special instruments for it and so it is not easy to apply the techniques in field test where common ultrasonic flaw detector is used. It is true that common flaw detector is not suitable to perform the tip diffraction methods in many applications. But in some cases, especially in sizing linear cracks, the common flaw detector is enough to measure the size of crack by tip diffraction signal with less precision. We suggest a procedure to perform crack sizing by tip diffraction signal with a common flaw detector. It uses beam profile characteristic of ultrasonic transducer also. The crack sizing of this procedure needs quite less skill and can improve the accuracy of sizing in comparison with conventional crack sizing techniques. And we made a small accessory helpful to perform the procedure. It is useful to check beam direction and index of angled beam ultrasonic transducer and to predict the position where tip diffraction occurs. By combining this technique with conventional crack sizing techniques it is possible to improve preciseness of crack sizing.

1. Introduction

In field test, generally simple flaw detectors are used and several kinds of methods using such flaw detector are applied to crack sizing. 6 dB drop or 20 dB drop method is used conventionally and the methods refer to echo amplitude. But in general cases the echo amplitude does not show good stability and repeatability. So the methods require careful skill of inspector and the reliability of the methods is not good.

The Time Of Flight Diffraction (TOFD) is a NDT method developed in the 70's by AEA. This method differs from traditional pulse echo technique in that it monitors diffracted signals at the edges of defects which are directly related to the true position and size of the defect, as opposed to the reflection on defects according to a reference reflector.[1] But almost of the TOFD techniques require specific instruments and it is not easy to apply the methods to the field test where the conventional flaw detector is used.

Crack is a very important flaw to find by ultrasonic test and in many cases the shape of crack is planar. In that case, to measure the size of the crack height and length have to be estimated. But it is not easy by the conventional methods. So we tried to apply tip diffraction method to it and suggest a simple process. This process relies on the tip diffraction signal and is performed by the conventional flaw detector. A simple accessory was designed to help performing of this process.

2. Beam profile and beam center line

Figure 1 represents the beam profile of ultrasonic transducer. The upper image is produced by a simulation program and the lower drawing is a simplified beam profile which is called as beam directivity. In these figures it is possible to assume a beam center line which keeps peak ultrasonic energy. As seen in the lower drawing the peak of beam profile is a point and it means that the beam center line is not thick.

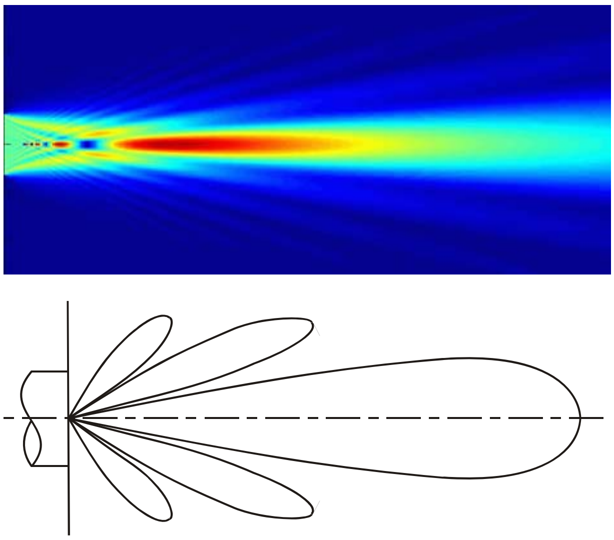


Figure 1*: Beam profile.*

A standard or reference block is used to set the display range of a flaw detector. When an angle beam transducer is used a block having rectangular edge is useful to set the display range. Corners of the block are used as reference points for the range setting. By moving the transducer forward and backward against the right angled edge, the positions of the corner echoes could be marked on the screen of flaw detector. At that time the criteria of the positioning is where the echo signal is highest. In other words, it means whether the beam center line reaches at the corners.

Figure 2 shows the positioning of corner echoes in the angle beam application. The screen was captured from EPOCH II of Panametrics and the signal was produced by 'PEAK MEM' function. One interesting thing of this screen is that the height of echo signal follows the beam profile at near the corners. And the peak points seem to be sufficiently short to assign the corner positions as lines on the screen. Another thing to be interested in is that the echoes produced by the side robs are not shown. Maybe the echoes are too small to show comparing to the main echo.

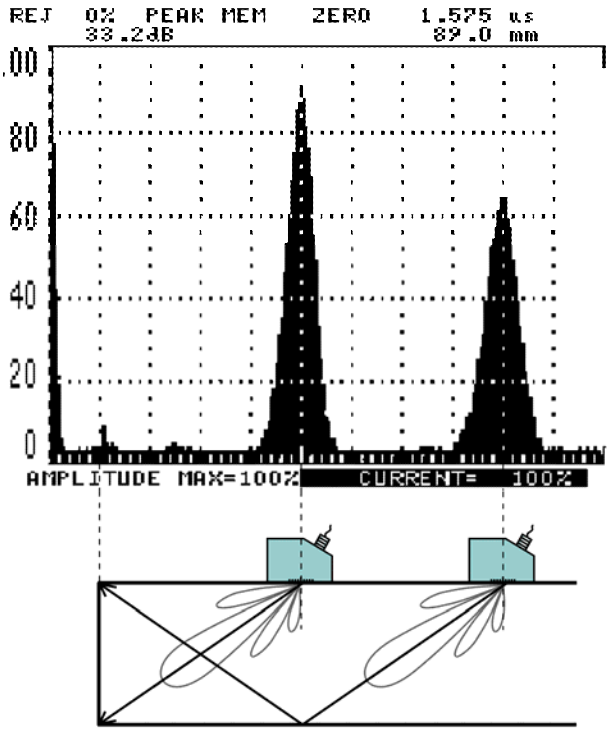


Figure 2*: Beam profile effect at corners.*

As seen at corner echoes, if the peak point of an echo is taken it is possible to assume that the reflection place of the echo would be a point as like as the corners and it exists on the beam center line. This idea can be expanded into that the beam profile may be simplified as a line if the tracking of echo peaks is kept.

In many cases of the angle beam applications it is possible to expect the beam center line. In that case, if an echo is detected and the peak of the echo is searched then it is possible to respect where the echo is reflected. Figure 3 shows the relationship between the position of echo on the screen and the position of the reflection on the test object. Thus the position of echo on the screen provides some information of the reflector including the depth and the distance from the transducer.

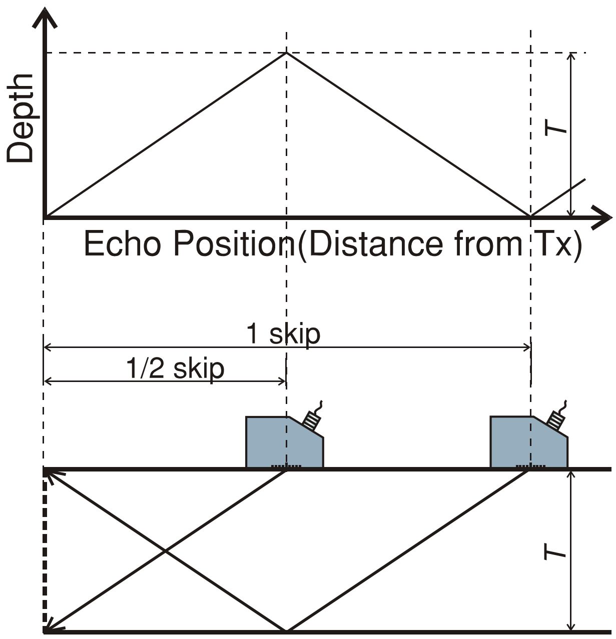


Figure 3*: Depth according to echo position.*

To use the beam center line as beam path, it is important to get the peak of echo. For it, scan has to be done. There are several scans for UT. Among them the depth scan and the swivel scan are very useful to get the peak of echo. Figure 4 shows the depth scan (upper) and the swivel (lower) scan. Using both or one of them the peak of echo can be checked. The performance of these scans is easier than other scans and especially checking the peak of echo by these scans is very easy and reliable.

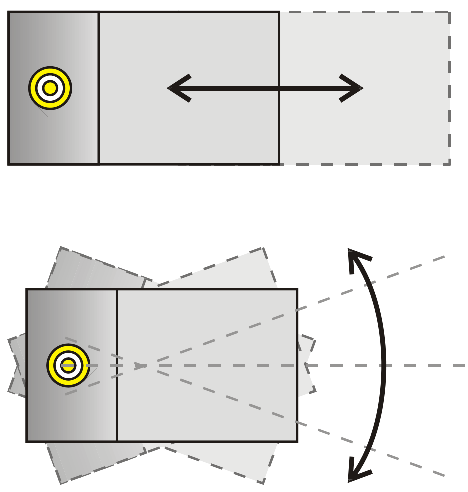


Figure 4*: Scanning to get echo peak.*

3. Sizing of linear crack by tip diffraction

To get the size of a linear crack the height and the length of the crack have to be measured. The 20 dB drop and the 6 dB drop methods are used in conventional UT and these methods rely on the echo amplitude of crack. But these methods are not easy because it is difficult to get reproducible and reliable echo amplitude. So tip diffraction is to be used for crack sizing.

Contrary to the amplitude methods, the methods using tip diffraction depend on time of flight. One of the methods is the satellite pulse technique. Figure 5 illustrates a principle involved in the satellite pulse technique. Both voids and linear defects can be sized quickly and relatively accurately using conventional UT equipment. The height of crack can be calculated by the following equation.[2]

$$h = \frac{c \cdot \Delta t}{2\cos\beta} \tag{1}$$

where, c is wave velocity in the material.

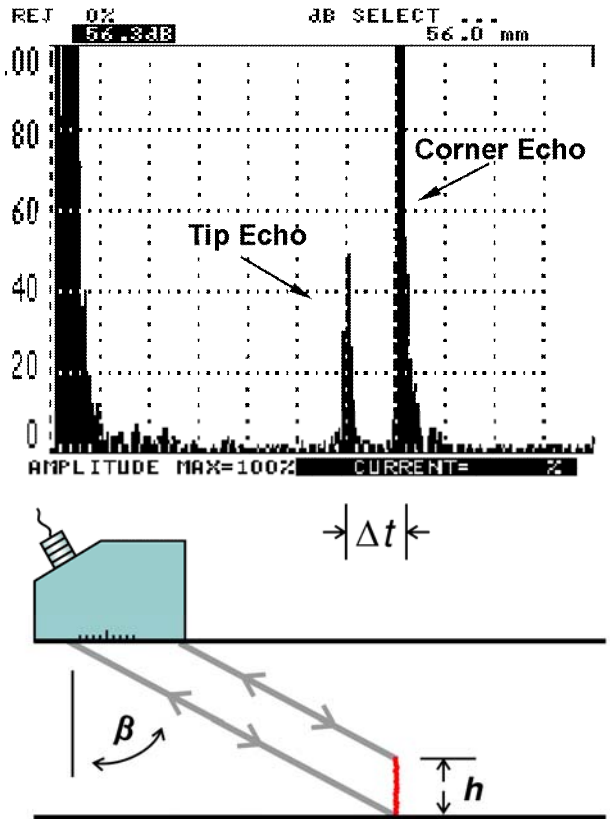


Figure 5: *Satellite pulse technique.*

The satellite pulse technique requires calculation. But if the relationship of Figure 3 is used the height of crack could be estimated directly from the screen. To do it, at first seek the tip diffraction echo, and next find the peak position of the echo. Then the distance to the crack tip can be read from the screen directly. The depth of the crack tip and the height of the crack can be derived from the distance as shown in Figure 6. This is a practical practice and has sufficient accuracy in the field test.

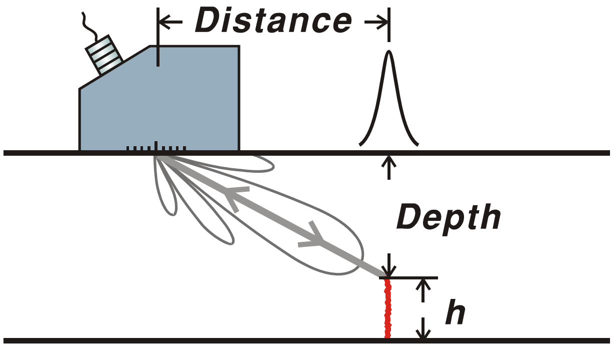


Figure 6: *Measurement of crack height.*

To estimate the length of a crack, both ends of the crack should be found. Tip diffraction may be used very usefully to decide the ends of a crack.

When a crack is detected, it is possible to know the approximate location of the crack and in or out of the crack. An easy way to decide the end of a crack is performed at out of the crack. At first move to out of the crack, it is not difficult. Next do swivel scan toward the expected end of the crack. Then the tip diffraction echo should be appeared. Lastly find the peak of the echo. In this case the depth is not important so careful depth scan does not need. But proper depth scan affects the amplitude of the tip diffraction echo. From the position of the echo on the screen the distance to the end of the crack can be estimated. The end of the crack locates on the beam direction axis so the end of the crack can be determined also. Figure 7 shows this method.

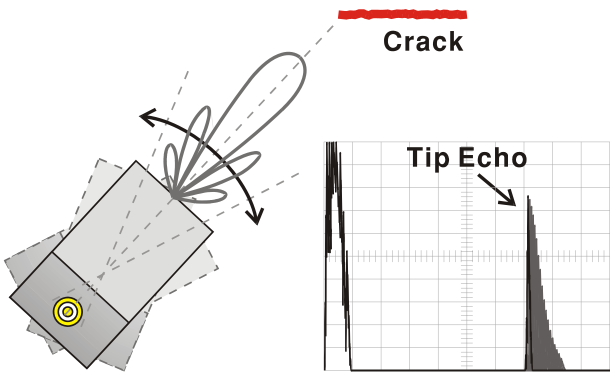


Figure 7: *Swivel scan at out of crack.*

In case that the probe is in the crack, the process is similar. Figure 8 shows such case. Different thing is that an echo from the corner of the crack appears during swivel scanning. And sometimes extra echoes appear. Although such echoes may disturb this processing, it is not so difficult to distinguish the tip diffraction echo from the other echoes. The tip diffraction echo appears lastly when swivel scan is done from in to out of the crack. After finding the tip diffraction echo, others are same.

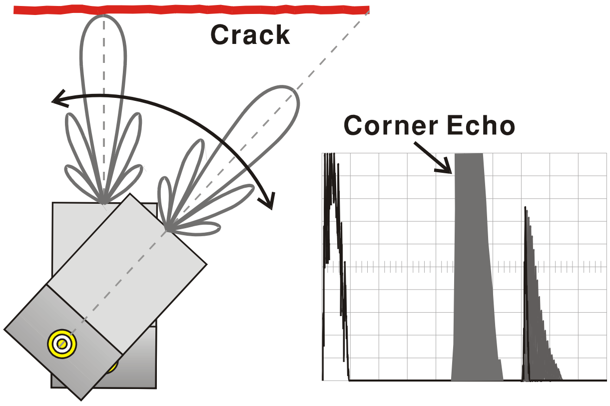


Figure 8*: Swivel scan at in of crack.*

Another attractive way to find ends of crack is illustrated in Figure 9. This practice is performed at any points more than two near the end of a crack. In this case only beam direction is important. At each time when the peak echo of tip diffraction is checked, draw the beam direction line on the test object. Then the cross point would be the end of the crack.

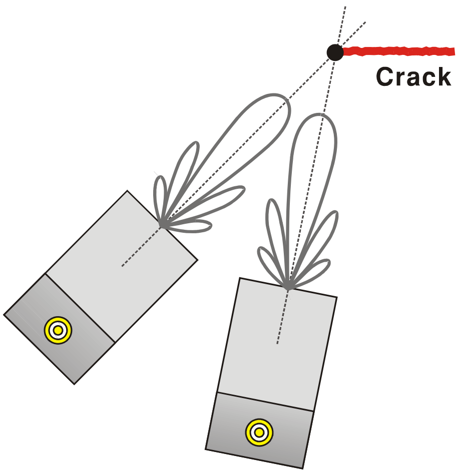


Figure 9*: End of crack detected by line crossing.*

4. Beam indicating needle

To help crack sizing by tip diffraction we made a small accessory and call it as a beam indicating needle. It has a small block able to slide and a needle able to rotate as shown in Figure 10. The main function of this is to set the beam direction and the beam index of transducer. When the angle beam examination is applied the beam direction and the beam index of transducer are very important factors. It is same in the case of the crack sizing by tip diffraction. So at first the setting for beam direction and index must be done.

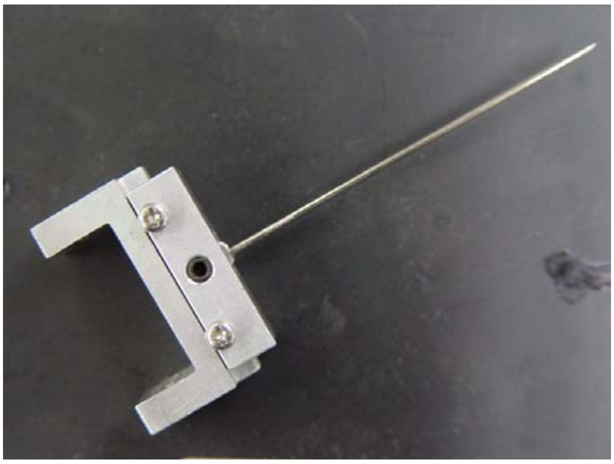


Figure 10*: Beam indicating needle.*

As described in many documents, to set the beam direction a block having right angled edge is used. To set it, do swivel scan against the edge at the distance of near half or one skip point and get maximum amplitude of the reflected echo. If so, the beam direction would be perpendicular to the edge. At that condition, rotate and set the needle to be perpendicular to the edge as like as Figure 11.

Figure 11*: Setting for beam direction.*

A through hole is used to set the beam index of transducer as shown in Figure 12. Because the beam direction has been set, the exact way to set the beam index is to do the transverse scan against the hole. But the transverse scan is not easy to perform. So instead of the transverse scan, the swivel scan against the hole is applied to get the peak of echo. The swivel scan is so easy to get the peak of echo reliably. After finding the peak of echo, slide the small block to align the needle with the hole. There may be some difference but the difference is not so significant. Then the beam indicating needle is ready to use.

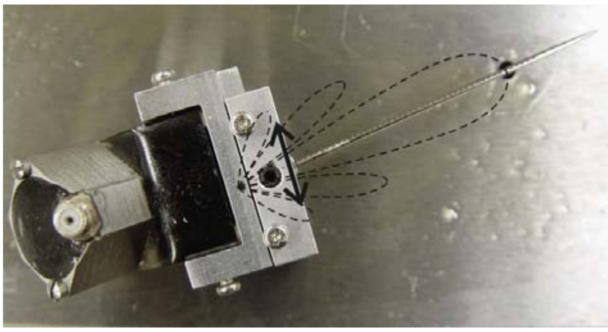


Figure 12: *Setting for beam index.*

There is one extra help with the beam indicating needle. As shown in Figure 13 by marking scale on the needle it helps locating the position of the reflection echo. For it, first find the half skip position and mark a tick on the needle aligned with the edge of the block. Next find the one skip position and mark that point also. From the half skip point and one skip point, the half skip distance can be known. And divide the half skip distance matching with the scale of the flaw detector screen and expand the scale to the rest of the needle. Hereby the echo position on the screen can be translated to the location on the test object directly.

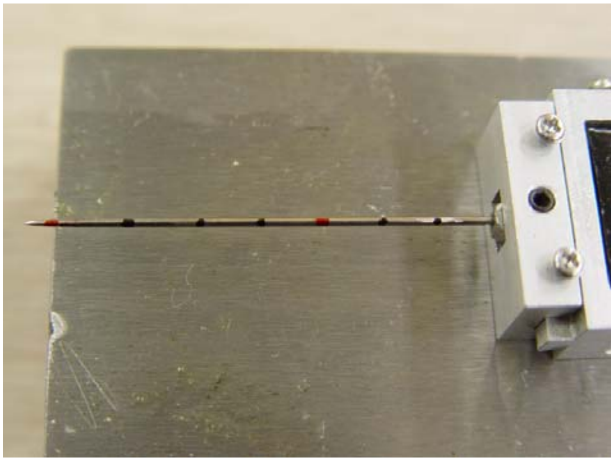
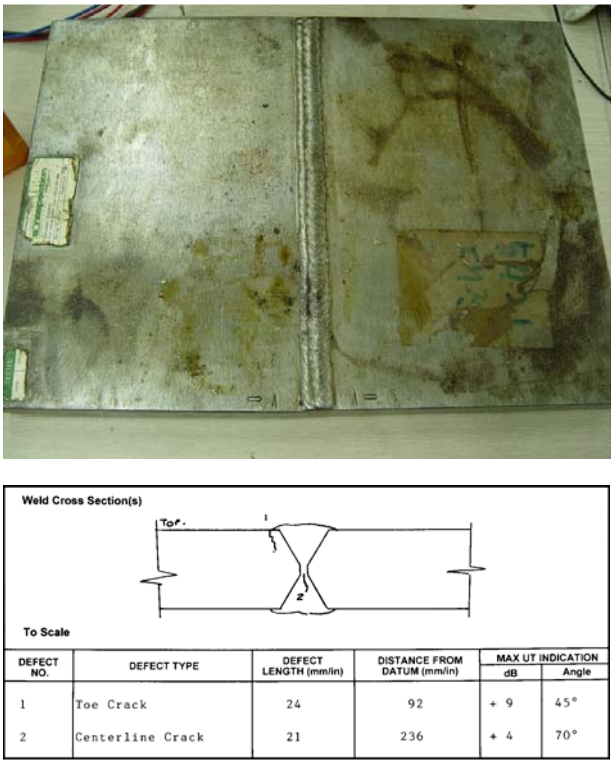


Figure 13: *Beam profile.*

5. Test of crack sizing by tip diffraction

To test the practicality of the crack sizing by tip diffraction a specimen which has known flaws was provided. The test specimen is PL3640 produced by Sonaspection, UK shown in Figure 14. As seen in the datasheet it has a toe crack and a centerline crack. Commonly used specimen or reference block has artificial flaws of some ideal shape such as flat bottom hole, cylindrical through hole or linear notch. But this specimen has implanted flaws which are very similar to real flaws. So the test condition of this specimen is expected to be similar to the test condition of the real field test.



Weld Cross Section(s)

To Scale

DEFECT NO.	DEFECT TYPE	DEFECT LENGTH (mm/in)	DISTANCE FROM DATUM (mm/in)	MAX UT INDICATION dB	Angle
1	Toe Crack	24	92	+ 9	45°
2	Centerline Crack	21	236	+ 4	70°

Figure 14: *Test specimen and datasheet*

Figure 15 is the result of the crack sizing by tip diffraction. In this case the method using line cross was applied. The method is more intuitive and requests less attention. As seen in this figure the result is very good. According to the datasheet the crack starts at 92 mm from datum and the length of the crack is 24 mm. The result shows the crack start at about 92.5 mm from datum and the length of the crack is about 23.5 mm.

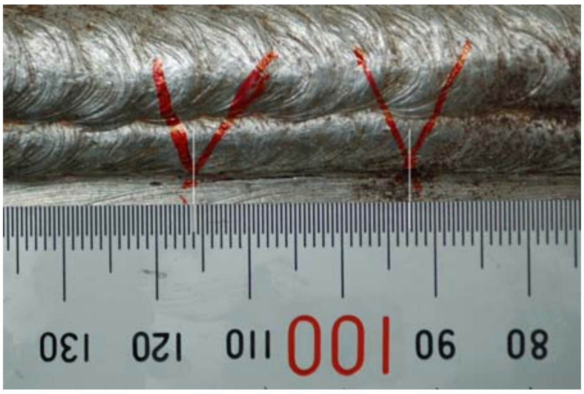


Figure 15: *Result of crack sizing*

6. Conclusions

Crack sizing by ultrasonic test is known as a difficult skill and many methods and techniques have been developed for it. Each method has advantages and drawbacks. The method relying on tip diffraction described in this paper is very simple, intuitive and reliable. And a great benefit of this method is that this method needs less attention in comparison with the other methods relying on amplitude. But this method has one critical drawback which is induced from the characteristic of the tip diffraction signal. The amplitude of the tip diffraction echo is much less than other reflected echoes and identification of tip diffraction signal among the other echoes is not easy. So some heavy training may be needed to operators.

In this paper the use of the beam indicating needle was focused at the crack sizing by tip diffraction. But the beam direction and the beam index are always important in the angle beam testing so it may be useful to other applications.

The concept, the peak of beam profile is virtually a point, makes the beam path a line. It means that if it is possible to find the peak of an echo it is possible to assume the reflection occurs at a point. The point must be upon the beam path line and so the distance and the depth of the reflection point can be easily estimated. Although it is not always possible to find the peak of an echo, the concept is very useful to some cases such as crack tip.

7. References

[1] N. Trimborn, "The Time-of-Flight-Diffraction-Technique ", *NDTnet - September 1997, Vol.2 No.09*.

[2] Ed Ginzel, "Sizing Techniques", *NDTnet, Nondestructive Testing Encyclopedia - Ultrasonic Testing –*

Acknowledgment

This work was supported financially by Korea Electric Power Research Institute (KEPRI).