SHAPE RECOGNITION AND SIZING OF PLANAR CRACK FROM TIP DIFFRACTION ECHOES BY USING PHASED ARRAY ULTRASONIC TEST INSTRUMENT

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ABSTRACT

PA UT (Phased Array Ultrasonic Test) instrument produces B-scan image. Generally the B-scan image represents the surface contours of volumetric reflectors in target area. But in the case of crack the B-scan image does not show crack contour. Instead the bottom and tip of the crack produce two distinguishable spots on the B-scan image. From the spots the location and height of the crack can be estimated. However it is not possible to figure out the shape of the crack from the B-scan image and additional mechanical scanner is needed to figure out the shape of the crack. In this paper a simple practical method is introduced to figure out the shape of a crack without a mechanical scanner and to estimate the size of the crack. This method is based on the transverse scanning to the crack instead of the usual vertical scanning. In this method the bottom and tip echoes can be captured at each scan line and these echoes compose the shape of the crack on a B-scan image. In addition to this, geometrical calculation is possible to estimate the size of the crack if the assumption is applied that the ultrasonic beam at each scan line has a plane wave front. The assumption is practical when PA UT probe has some large surface and the size of a target crack is comparable to the size of the probe. There are some limitations but this method has practical benefit. And the intuitive shape recognition and sizing of crack can be possible through this practical method.

Key words: PAUT, horizontal scanning, B-scan, shape recognition, crack height

1. Introduction

Basically PAUT (Phased Array Ultrasonic Test) instrument produces B-scan image. B-scan image is composed by accumulating compressed A-scans in a sequence and it shows the cross section of target material under inspection. At earlier days when single-element transducer was used, B-scan was implemented by using a linear scanner in industrial nondestructive testing and by using a swing scanner in medical imaging. But phased array ultrasonics uses electronic scanning technique instead of the mechanical scanning to get B-scan image. And the beam from a phased array probe can be focused and steered electronically without moving the probe. The beam is controllable because a phased array probe is made up of multiple small elements, each of which can be pulsed individually at a computer-calculated timing. The term phased refers to the timing, and the term array refers to the multiple elements. [1] Nowadays PAUT instrument replaces conventional ultrasonic flaw detector gradually because of its benefits. B-scan image of
phased array ultrasonics makes it easier to find defect and to interpret the defect. And there are many possibilities to develop new techniques for ultrasonic testing by using phased array ultrasonics.

Wave diffraction is a general phenomenon in ultrasonics. The sharp tip of a well defined internal defect like a crack will diffract an incident ultrasonic beam, creating a spherical wave front whose arrival at the probe can be used to locate the tip and measure the depth of the crack. Common angle beam transducers are used for this test. [2] In the case of a crack-like defect the incident ultrasonic beam produces splitted echoes by the root corner and the tip of the defect. And the depth of the crack can be calculated geometrically from the difference between the paths of the echoes. [3]

In general, B-scan image shows the contour of volumetric reflector. But in the case of crack-like defect common B-scan image shows only two spots instead of the contour of the crack. One of them is corner echo and the other is tip echo. It is the result of vertical sectorial scanning toward the crack by the phased array ultrasonic instrument. The vertical sectorial scanning has benefits to change incident angle intentionally and to cover wide scan area. In this case another scanning along the crack is needed to see the shape of a crack. But if transverse linear scanning to a crack by a PAUT instrument is applied, the B-scan image of the scanning may show the shape of the crack. And it is possible to estimate the approximate height of the crack geometrically.

2. Consideration [4]

If the source of ultrasonic sound is a point or the source is looked at far distance, the ultrasonic sound seems to propagate spherically. But if the source of ultrasonic sound has plane surface as like as an ultrasonic transducer and the field of the sound is looked within near distance, the wavefront of the sound has partially a plane area having same arrival time. The size of the plane area is approximately same as the size of the sound source as like as Fig. 1. Fig. 2 represents the beam directivity of an ultrasonic probe. The intensity of the beam is highest at center. So if the maximum intensity of the beam is pursued at each distance from the probe, the beam can be represented as a line. This means that the location of a reflector is on the center line if the maximum echo caused by the reflector is searched.

Fig. 1: Ultrasonic beam propagation. Fig. 2: Beam directivity of UT probe.

Fig. 3 shows how to scaling the screen of a flaw detector with the beam path using a rectangle block known the thickness of it. 1/2 skip and 1 skip positions can be fixed by finding the maximum echo at each around 1/2 skip and 1 skip position. From the positions the horizontal distance of 1/2 skip can be measured. The beam path of 1/2 skip and the incident angle can be calculated with the distance and the thickness. There is proportional relation between the horizontal distance, the beam path and the scale on the screen of the flaw detector. So the location of a reflector can be estimated from the echo position of the reflector on the screen if the maximum echo is searched.
Fig. 4 shows the geometry at 1/2 skip position. The horizontal distance from the front face of a probe to the edge of the block, $L_{FC}$, can be measured on 1/2 skips position. The horizontal distance from the reflector to the 1/2 skip point, $L_{TC}$, can be measure easily from the scaled screen. The horizontal distance from the probe front to the reflector, $L_{FT}$, is calculated by subtracting $L_{TC}$ from $L_{FC}$. The depth of the reflector is proportional to the beam path to the reflector also. So it is possible to get the depth of the reflector, $Z_{ST}$, from the screen of the flaw detector almost directly. If the interested echo is caused by the tip diffraction of a toe crack and the thickness of the target inspected is known, the crack height, $Z_{TC}$, can be estimated approximately too.

Fig. 3 shows that a PAUT probe is attached horizontally at an angle beam wedge. In this case the incident angle is fixed by the angle of the wedge and angle beam wedges have to be changed to cover several incident angles as like as the case of a single element UT probe. In the case of single probe a mechanical scanner is needed to produce B-scan image. But in this case B-scan image can be produced by the electronic scanning function of PAUT instrument.

Fig. 6 shows a B-scan line which is produced by an angle beam UT probe or by a single element or one scan line of PAUT instrument. B-scan image is produced by mapping the B-scan line at each scan position in a sequence. As a result B-scan image may shows the envelope of the crack by accumulating each tip echo. And if the crack size is similar as the size of the probe or smaller, it is possible to see roughly the shape of the crack on the B-scan image. Especially in the case of PAUT the shape of a crack can be recognized more easily by moving PAUT probe around a crack because similar pattern caused by the crack is moving too as PAUT probe is moving.

As shown in Fig. 6, the flight time difference, $T_{DF}$, between the tip echo and the corner echo of a vertical crack is proportional only to the height of the crack because the flight time in wedge, $T_{DW}$, is equal to the flight time in refracted material, $T_{DR}$. The flight time difference can be read from the scaled screen as the beam path difference. So the height of the crack can be calculated geometrically. But if the crack inclines towards the probe the crack seems to be bigger and if inclines outwards the crack seems to be smaller.
Fig. 7 is the drawing of the specimen which was used for practice. It has 4 thermal fatigue cracks around the dissimilar metal weld zone. The thickness at the end of the pipe is about 30.5 mm. The end of the specimen is right-angled so it is possible to get 1/2 skip and 1 skip positions. Fig. 8 is the 1/2 skip echo and Fig. 9 is the 1 skip echo. The 1/2 skip beam path on the screen is 93 mm (228 mm – 135 mm) in accordance with these echoes. The 1/2 skip distance on the specimen was measured as 39.5 mm. From the thickness and the 1/2 skip distance the 1/2 skip beam path in the specimen is calculated as about 50 mm and the incident angle is calculated as about 52 degrees. The cosine of the incident angle is about 0.61 (30.5 mm / 50 mm). The ratio of the beam path in the specimen to the beam path on the screen is about 0.53 (50 mm / 93 mm). And the ratio of the height to the beam path difference between the tip and the corner echoes in the screen scale is about 0.87 (0.53 / 0.61).

Fig. 7: Specimen used for practice.
As described in the ‘Consider’ chapter, if the crack is relatively small in comparison with the probe size it is possible to recognize the shape of the crack by moving the probe around the crack. Fig. 10 to Fig. 13 show the recognized shapes of the flaws in the specimen. In the case of Flaw 3 the size of the crack is larger than the size of the probe. So it was not possible to get the full shape of the crack. The size of the Flaw 3 was estimated after the maximum echoes from the tip and the root corner of the crack were searched and the positions of the echoes were measured. But the result was too different than the specification unfortunately. Other cracks were sized by using the recognized shapes of them. Table 1 is the results of the estimations. As shown in the Table the results were moderately satisfied except Flaw 3. But the sizing of the crack width showed the tendency of over-estimated.
Table 1: Measurement results in comparison with specification.

<table>
<thead>
<tr>
<th>Flaw 1</th>
<th>Flaw 2</th>
<th>Flaw 3</th>
<th>Flaw 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flaw length (in)</td>
<td>0.903”</td>
<td>1.136”</td>
<td>1.808”</td>
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<tr>
<td>Flaw depth (in)</td>
<td>0.302”</td>
<td>0.568”</td>
<td>0.904”</td>
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<tr>
<td>Flaw length (mm)</td>
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<td>28.9 mm</td>
<td>45.9 mm</td>
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<tr>
<td>Flaw depth (mm)</td>
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<td>14.4 mm</td>
<td>23.0 mm</td>
</tr>
<tr>
<td>Flaw tilt (degree)</td>
<td>0</td>
<td>19</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>[Measured]</th>
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<tbody>
<tr>
<td>Flaw length (mm)</td>
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<tr>
<td>Flaw depth (mm)</td>
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</tbody>
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5. Conclusion

When angle beam method is used in ultrasonic testing, several angle beam probes are needed not to miss defects which cannot be detected by a particular angle probe. So PAUT is very useful to cover wide angle beam direction by vertical sectorial scanning. But in this case B-scan image of PAUT cannot show the shape of a crack. Instead it shows only two spots caused by the tip and the root corner of the crack. In this paper horizontal scanning of PAUT in angle beam method is considered to display the shape of a crack in a B-scan image. This idea was applied to a specimen which has 4 fatigue cracks and it was possible to get the tip shapes of the cracks. Also the heights of the cracks were estimated from the shapes and the results were not bad. This method sacrifices the benefit of the sectorial scan of PAUT which can cover wide angle beam direction. But it may be useful to check the shape and the size of a crack quickly.

6. References

[4] Young-Gil KIM, Nam Sik JO, Dong-Jin YOON, Bongyoung AHN: Determination of Crack Tip Location by using Tip Diffraction and Geometric Calculation, 19th World Conference on Non-Destructive Testing (WCNDT 2016), 13-17 June 2016 in Munich, Germany

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