The Influence of PAUT Parameters on
Crack Location, Pattern and Height Sizing

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Abstract: The paper presents an internal study to assess the tolerances on PAUT parameters on crack display, location, pattern and height sizing for 3 (three) scenarios:

- Fatigue crack of 9.5 mm located at depth of 10 mm/45 mm/145 mm
- Stress corrosion crack of 10.5 mm located at transition depth 14 to 12 mm in a pipe weld – retired from service
- Crack-like EDM notches of 12 x 3 mm located at depth of 35 mm along the hook 1 of L-1 steeple

A large variety of 1-D linear phased array probes with frequency ranging between 3.5 MHz to 10 MHz and pitch between 0.3 mm to 0.6 mm were used in different variables assessment:

- Pitch, focal depth, angular resolution
- Wedge angle, velocity, location of 1st element height
- Test piece velocity

Based on experimental values, the following tolerances were set for PAUT parameters:

- Pitch = ± 0.1 mm for \( F_c = 3.5 – 6 \) MHz; ± 0.05 mm for \( F_c = 6.5 – 10 \) MHz
- Wedge velocity: ± 50 m / s; wedge angle: ± 1.0°; height of 1st element: ± 1 mm
- Angular resolution: depending on crack depth : 0.1° – 0.5°
- Test piece velocity: ± 80 m/s

Examples and graphs with single and combined variables are presented and commented. The effect of index value, focal depth and receiver filters are illustrated on sizing a SCC in a pipe weld.

Keywords: fatigue crack, stress-corrosion crack, crack-like EDM notch, 1-D linear array probe, pitch, wedge angle, wedge velocity, height of 1st element, test piece velocity, angular resolution, focal depth, receiver filters, crack height, crack tip sizing angle, PAUT (phased array ultrasonic technology)

Problem Statement

The application of PAUT to large-scale inspection of turbine components is in current practice within OPG for about 10 years (ref.1-5). During this decade, the following aspects regarding the reliability of PAUT results were identified and monitored:

- probe repeatability within a large family (same design)
- repeatability of PAUT results within a large family of machine (7 FOCUS LT 32/128, 15 OMNISCAN MX 32/128)
- repeatability of PAUT system (random combination machine+probe) (ref.6-10)

Other technical aspects were identified during training of 20-30 technicians:

- same set-up was used for detection and sizing probes with similar characteristics
- old set-up was used when a new wedge was used to replace an older one
- “dressing” the image by using high-resolution filters or/and changing the focal depth around the flaw depth contributed to a better sizing and pattern display
In-situ inspections were performed in different seasons, when the ambient temperature varied from 5° C to 35° C. All set-ups were built in lab conditions, at 20-23° C. Turbine components (blades, rotors, studs, valves) were manufactured 30-40 years ago. The forging structure of original component is different from the reference blocks made by Patriot Forge-Canada. Velocities were found to varied by 70 to 110 m/s. During the inspections on convex and concave sides of the blade wings, the wedge angle and the height of the 1st element were altered by 1-2 mm or 1-2 degrees.

Our previous experimental results published in OlympusNDT PAUT book (ref.11) demonstrated the quantitative effect of specific parameters on crack height and location. The experiment was limited to shear wave inspection. The present paper is addressing a multitude of technical aspects for L- and T-waves examination, as well as the influence of focal depth, filters and index (access) on crack sizing.

The following technical aspects will be presented:
- The influence of pitch size
- The influence of wedge velocity, wedge angle and height of the 1st element
- The test piece velocity variation
- The influence of index, focal depth and receiver filters on sizing SCC
- The combined effect of different factors on crack detection and sizing.

Based on experimental data, practical tolerances were set to limit the errors within the acceptable values.

**Experimental Program**

Experimental program was based on presumptions the following tolerances must be met:

- ± 1 mm for crack height
- ± 1 mm for crack location (depth)
- ± 2 mm for crack location – index (projected distance)
- ± 2° for crack tip angle (sizing)

These tight tolerances were set based on PAUT performances and comparison with MP and fracture mechanics of fatigue and SCC cracks (see Figure 1, as an example).

![Figure 1: Example of MP and PAUT comparison on three SCC located on blade hook.](image-url)
The experimental program was set for the following tasks presented in **Table 1**.

**Table 1:** The list of tests and features for experimental program.

<table>
<thead>
<tr>
<th>TEST #</th>
<th>BLOCK ID</th>
<th>PROBE ID</th>
<th>FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OHR 20 # 18</td>
<td>TW : P66-45T (PLEXIGLASS)</td>
<td>CRACK HEIGHT (D), LOCATION</td>
</tr>
<tr>
<td>2</td>
<td>AB 259</td>
<td>TW : P9-30REX (REXOLITE)</td>
<td>CRACK HEIGHT (D) LOCATION, PATTERN</td>
</tr>
<tr>
<td>3</td>
<td>AB 163B</td>
<td>LW : 78, 80, 84</td>
<td>CRACK HEIGHT (S) LOCATION, ANGLE</td>
</tr>
<tr>
<td>4</td>
<td>L-1 ST, AS BUILT</td>
<td>LW : P21, P25</td>
<td>CRACK LENGTH (D) LOCATION, ANGLE</td>
</tr>
<tr>
<td>5</td>
<td>OHR 20 ACUREN-SCC</td>
<td>TW : P74-45T</td>
<td>CRACK HEIGHT, PATTERN</td>
</tr>
</tbody>
</table>

The probe characteristics related to specific projects are presented in **Table 2**.

**Table 2:** Probes and their characteristics related to specific projects.

<table>
<thead>
<tr>
<th>Probe ID</th>
<th>Fc [MHz]</th>
<th>Nr. el</th>
<th>Pitch [mm]</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>66+37°P</td>
<td>6</td>
<td>25</td>
<td>0.4</td>
<td>DNGS, PNGS, IQ</td>
</tr>
<tr>
<td>9+30°R</td>
<td>6</td>
<td>32</td>
<td>0.55</td>
<td>DNGS, IQ, Nanticoke</td>
</tr>
<tr>
<td>78</td>
<td>7</td>
<td>64</td>
<td>0.6</td>
<td>DNGS, Nanticoke</td>
</tr>
<tr>
<td>80</td>
<td>7</td>
<td>64</td>
<td>0.4</td>
<td>DNGS, Nanticoke</td>
</tr>
<tr>
<td>84</td>
<td>7</td>
<td>64</td>
<td>0.5</td>
<td>DNGS, Nanticoke</td>
</tr>
<tr>
<td>21</td>
<td>10</td>
<td>28</td>
<td>0.5</td>
<td>DNGS</td>
</tr>
<tr>
<td>25</td>
<td>3.5</td>
<td>32</td>
<td>0.6</td>
<td>PNGS, DNGS, IQ</td>
</tr>
<tr>
<td>74+37°P</td>
<td>10</td>
<td>16</td>
<td>0.31</td>
<td>DNGS, PNGS</td>
</tr>
</tbody>
</table>

P = Plexiglas ; R = Rexolite

The variables were determined either by artificial altering the probe/wedge/piece characteristics or by simple connecting similar probes or /and probes with different wedge characteristics in a pre-defined set-up.

**Results**

The effects of wedge parameters (angle, velocity and height of 1<sup>st</sup> element) are presented on Figure 2 to Figure 5.

The height of 1<sup>st</sup> element has little effect on crack height, but affects the location (depth) and the index. An acceptable tolerance is: ± 1.5 mm. The wedge velocity has a more significant effect on location, than on sizing. An acceptable tolerance value is: ± 100 m/s. Wedge angle variation is acceptable within ±2°.
Figure 2: Wedge velocity effect for Plexiglass.  
Figure 3: Wedge velocity effect for Rexolite.

**Figure 4:** Example of wedge angle influence on crack height, tilt and location.

**Figure 5:** The influence of the 1st element height on crack parameters.
However, the combined effect of the three independent factors may lead to either a missing detection or to an unacceptable sizing pattern (see Figure 6).

**Figure 6:** Example of combined effects of wedge parameters on crack detection and location.

A more realistic value for wedge parameters is listed below:
- wedge velocity = ± 50 m/s
- wedge angle = ± 1°
- height of 1st element = ±1 mm

Probe pitch is an essential parameter. The effect of probe pitch on crack and EDM notch features is illustrated in **Figure 7** to **Figure 12**.

**Figure 7:** The effect of probe pitch for 6 MHz probe on Plexiglass wedge.

**Figure 8:** The general effect of probe pitch on T-waves (Rexolite wedge)-top and L-waves (bottom).
Figure 9: The effect of probe pitch on location, length sizing and detection angle for L-waves of 10 and 3.5 MHz. Screen shots displays below.

Figure 10: Examples of S-scan screen shots (top) and 3-D data plotting (bottom) for probe #25 on L-1 steeple block with complex EDM notches.
**Figure 11:** Examples of pitch influence on crack sizing parameters for specular set-up and 7-MHz L-waves probes.

An acceptable value for pitch size variation is 60 microns for frequency > 6 MHz and 100-150 microns for L-waves of 3.5-5 MHz.

Video display, filters, angular resolution and focal depth may affect the analysis results, as presented in **Figure 12** to **Figure 14**.

**Figure 12:** Examples of video display (smoothing) on crack height evaluation.

**Figure 13:** Examples of angular resolution on crack height pattern.
Test piece velocity affects the crack characteristics, as presented in Figure 15. An acceptable tolerance is ±100 m/s.

Conclusions

The experimental data of five tests concluded about the tolerances on specific PAUT parameters in sizing, location and crack pattern. The tolerance range depends on application scope. Some tolerances may be too tight, but in turbine components cases they are crucial for a reliable large-scale inspection. The conservative values are:

- Wedge velocity: ± 50 m/s
- Wedge angle: ± 1.0°
- Height of 1st element: ± 1 mm
- Probe pitch: ± 50 microns for $F_c \geq 6.5$ MHz
• Probe pitch: ± 100 microns for \( F_c = 3.5 \) MHz – 6 MHz
• Test piece velocity: ± 80 m/s
• Angular resolution: < 1°

Imasonic manufacturing tolerances for probes with encapsulated wedge fulfill the OPG requirements.

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References

10. Ciorau, P.: “Phased Array Equipment Substitution-Practitioner Approach for Large-Scale Turbine Inspection”- ndt.net- vol. 12, no.6 (June 2007)