# A novel checking technique for probe characterization and phased array system performance assessment

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***Abstract:*** The paper presents the principle of checking method of the PA system using the same set-up as used in the field. The method is based on S-scan display of the side-drilled holes (SDH) located in a large variety of blocks. The measurement of index, angle, SDH depth and signal-to-noise ratio (SNR) eliminates the need to perform hundreds of individual checking with set-ups irrelevant for actual inspection system. Examples are given for different blocks, types of waves, probe sizes and different machines. The method could easily detect the mistakes in programming the wedge angle, height of the first element, wedge velocity and/or probe pitch. Examples are given in detecting and sizing cracks with different programmed parameters. The method was used to characterize more than 120 linear array probes for two large-scale phased array inspections of low-pressure turbine components performed in spring 2007.

## Introduction

The S-scan view is used by phased array ultrasonic technique (PAUT) for defect characterization, as is presented in **Figure 1** and **Figure 2.**

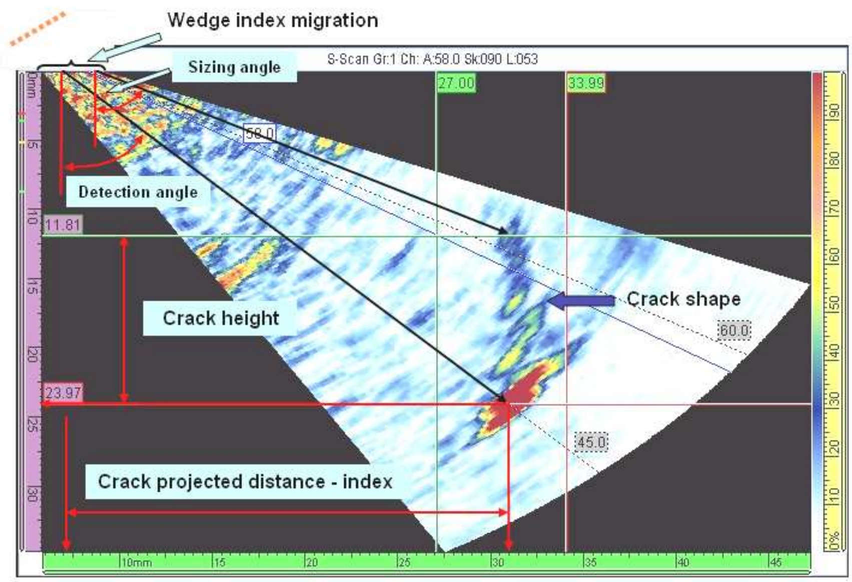


**Figure 1:** Example of crack parameters measurement using S-scan image-based display for shear waves probe.

It is well known the fact a sectorial scan (S-scan) employs a group of angles and the ultrasonic beam is focused at specific depth. Depending on application, the S-scan presentation could be changed to different inspection scenarios, such presented in **Figure 2**. Defect on the blade root is located at constant depth, while the crack on the steeple is along the hook, skewed at 20°.

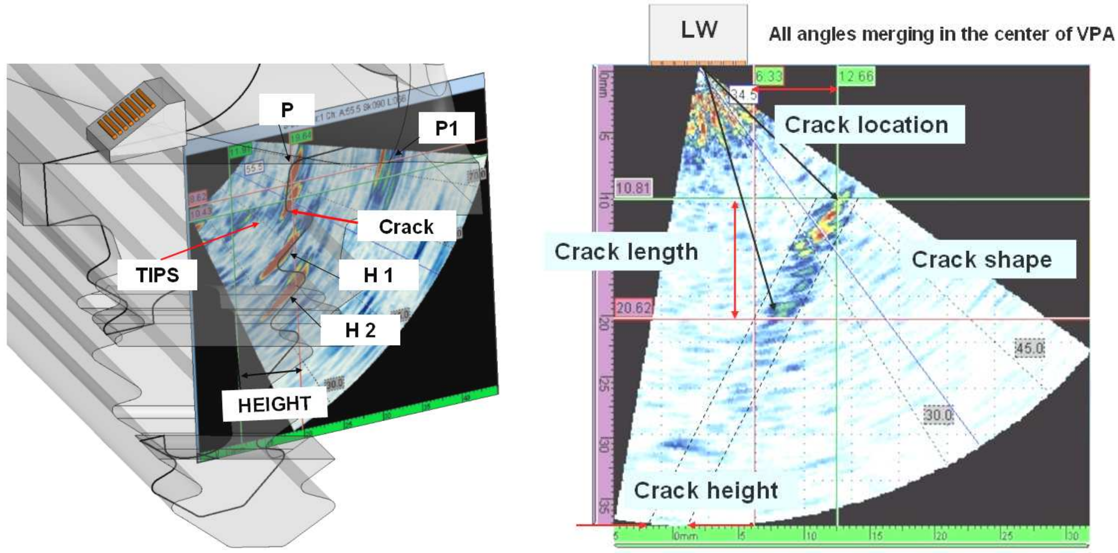


**Figure 2:** Examples of crack parameters measured in S-scan for shear waves probe on a blade platform (left) and a direct-contact longitudinal waves linear array probe on a steeple.

PAUT defect information is embedded in the S-scan. If the S-scan parameters are correctly linked with probe and known reflectors, the PAUT system could be certified as performing within specified tolerances. Similar approaches could be found in ref. 1-4.

The present paper is presenting the technique to certify the probe and system based on S-scan image and parameters measured in S-scan (depth, angle, index/projected, signal to noise ratio). The method is very sensitive to changes in actual or programmed parameters, such as pitch, wedge angle, wedge velocity and probe frequency. Examples are given for different parameter changes detecting by this method.

## Reference Blocks and PAUT Results

A variety of blocks were manufactured and some existing ones altered to suit the possible inspection scenario for a large number of set-ups, starting for near-surface detection and sizing and ending with large thickness (see **Figure 3** to **Figure 5**).

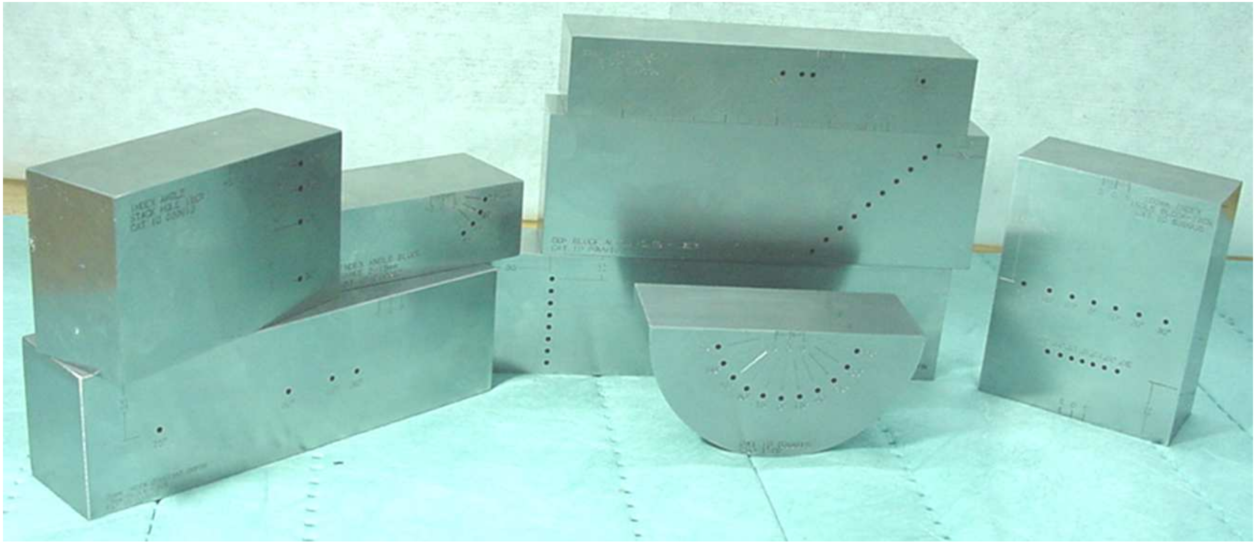

**Figure 3:** Examples of reference blocks to cover the range 0-60 mm in both S-waves and L-waves set-ups.

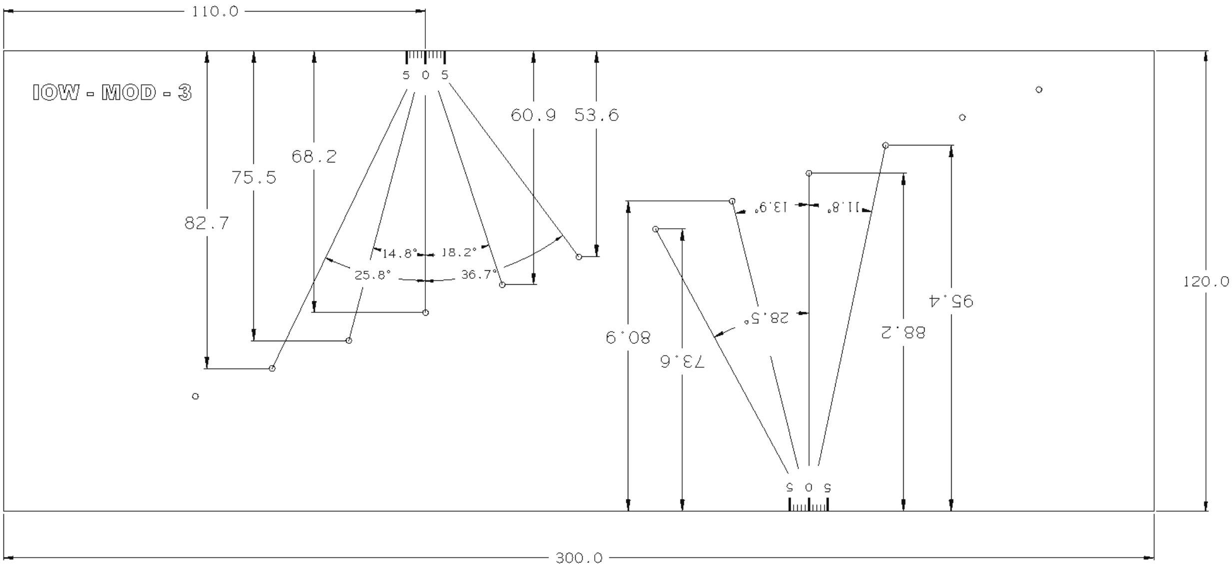


**Figure 4:** Block IOW-MOD-3 used for L-waves at deeper range (50-100 mm) and sweep range from –40 to +40 degrees.

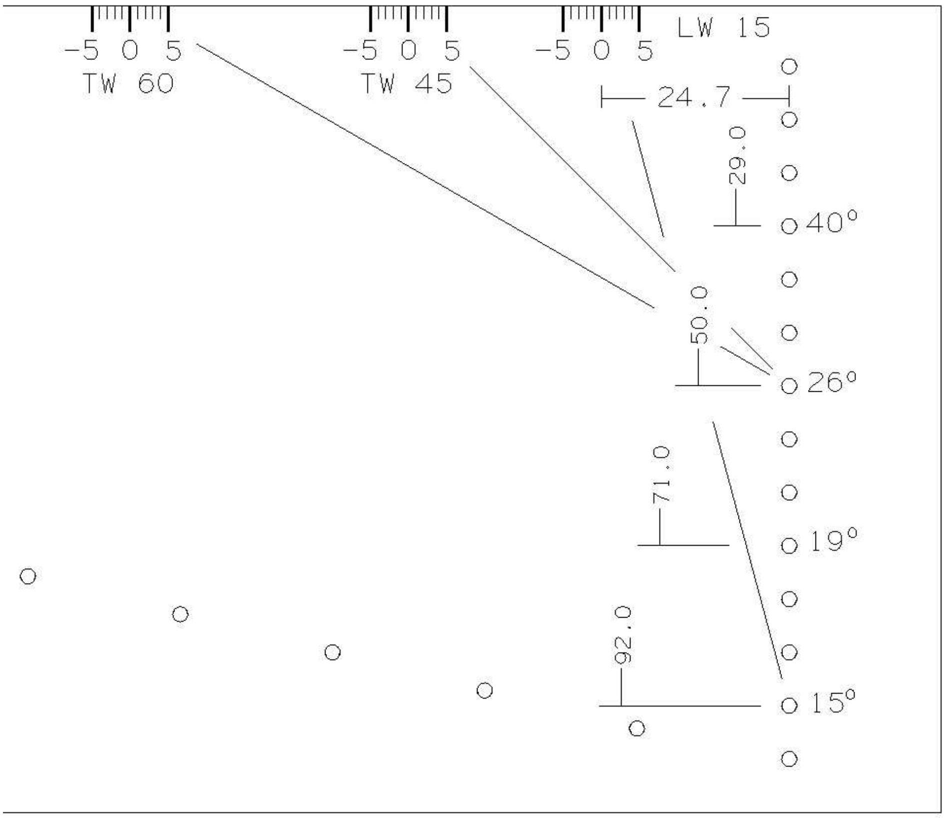


**Figure 5**: Example of TOFD-8-MOD block used for deeper range for both L-, and T-waves.

High accuracy measurements of the actual position of SDH and refracted angles to detect them from a specific position assure a direct link between probe, part and target. Plotting data into 2-D or/and 3-D isometric will provide an accurate measurement of ***actual*** PAUT parameters employed by the inspection set-up.

Probe/system characterization was based on the following inspection scenarios (see **Table 1** and **Figure 6** and **Figure 7**)

**Table 1:** Defect-block S-scan characterization scenarios.

| **Defect location** | **Block to be used** | **Remarks** |
|---|---|---|
| Constant depth | Aligned SDH | Don't use angle corrected gain |
| Variable depth with constant projected distance | Stacked SDH | Don't use TCG |
| 2-D orientation | Sloped or circular distributed SDH | Don't use TCG and ACG |

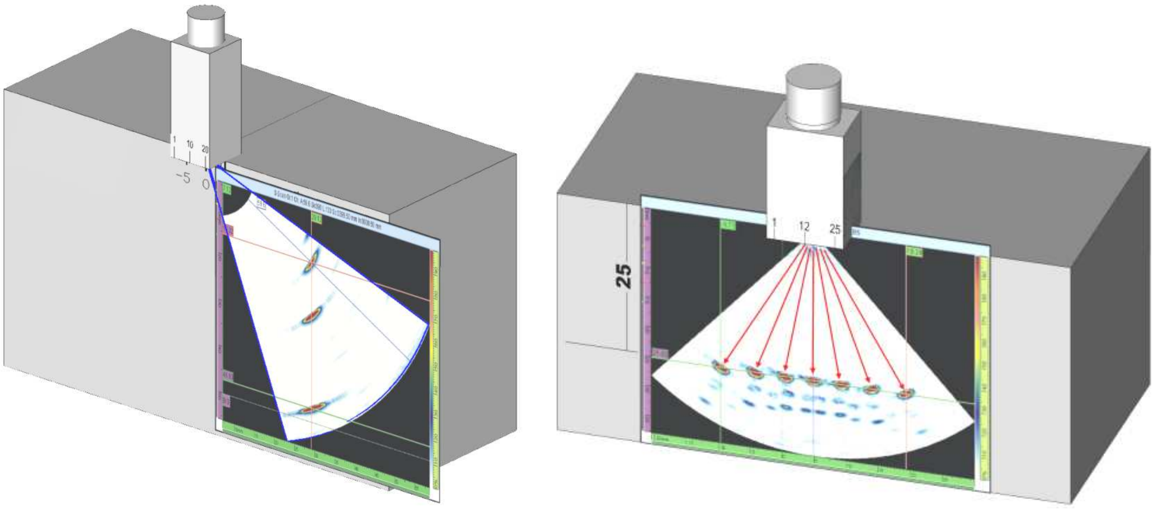


**Figure 6:** Examples of system characterization for stacked (left) and aligned (right) SDH-direct-contact L-waves probe.

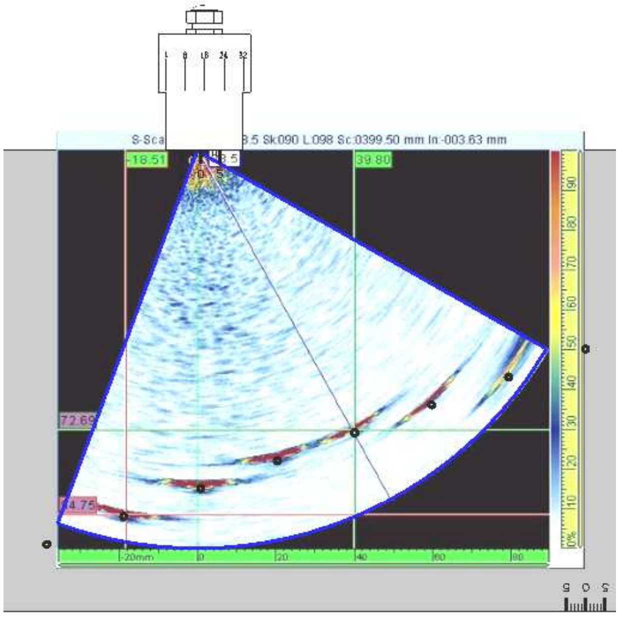


**Figure 7:** Example of probe characterization and data plotting for 2-D defects located at the depth range 60-95 mm. L-waves probe was used for angular sweep –20 to +50 degrees.

The probe / system is acceptable to be used in the field if the following parameters are fulfilled:

- Minimum angle: ± 2°
- Maximum angle: ± 2°
- Target depth: ± 2 mm
- Horizontal distance (index) between the specific SDH: ± 2 mm
- Vertical distance (depth) between two specific SDH: ± 2 mm
- Signal to Noise Ratio (SNR) for the lowest amplitude of SDH displayed within the S-scan > 30 dB.

More than 120 linear array probes were characterized in combination with Omniscan 16:16, Omniscan 32:32, Focus 32-32, Focus LT 32-32, Tomo III PA within one week by a single technician. This operation for probe characterization took OPG-IMS a 5-week period with three technicians. In spite of a significant manpower saving, the new procedure employs the **same** set-up to be used in the field. Some ultrasonic range, sweep angles and gain adjustments were needed to optimize the measurements. During this process probes, wedges and some set-ups were rejected. Actual wedge angle, height and velocity were corrected in such a way the SDH display was within minimum tolerances. After this calibration, the inspection set-up was corrected for the actual parameters and the system performance was checked on reference blocks and on performance demonstration blocks with crack-like EDM or known cracks.

**Figure 8** represents a comparison between three set-ups for probe 25 used to detect SCC in L-1 blade [4]. It may notice the SDH display presents a concave or convex arc for programmed pitch different from actual value.

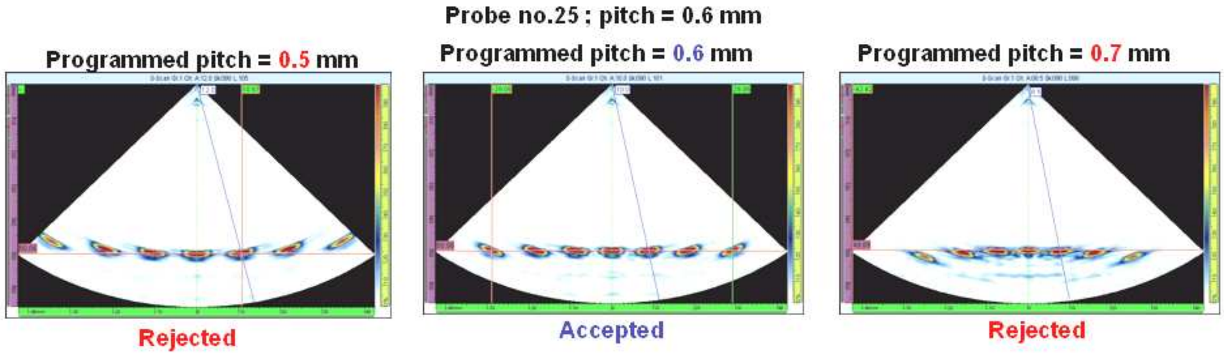


**Figure 8:** Example of probe characterization with three different pitch parameters.

The tolerances for the new characterization method could be set by the requirements on crack sizing and plotting.

**Figure 9** presents the principle of checking the probe features on aligned SDH. This probe is used for inspection of a blade, as per Figure 2-left.

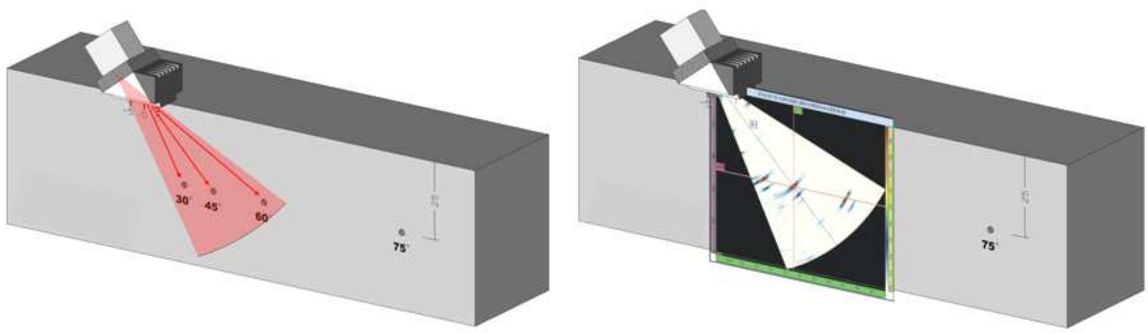


**Figure 9:** Example of probe checking on aligned SDH: left-principle; right-data plotting and comparison.

**Figure 10** illustrates the influence of wedge angle (programmed vs. actual) for three angle.
The new method easily detects the mismatch between programmed and actual angle, based on reading, such as index, SDH depth and SDH alignment pattern (downward means $\text{ß}_{actual} > \text{ß}_{programmed}$; straight means $\text{ß}_{actual} = \text{ß}_{programmed}$, and upward means $\text{ß}_{actual} < \text{ß}_{programmed}$ ).

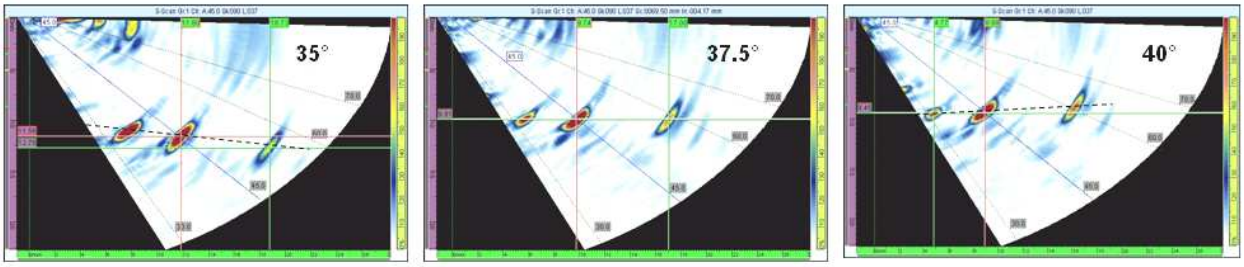


**Figure 10:** Example of probe characterization for three programmed wedge angles-shear waves.

**Figure 11** illustrates the influence of wedge angle on crack parameters. Crack pattern is affected by programmed wedge angle. The height of the crack (actual =8.4 mm) is smaller for lower angles and is larger for higher programmed angles. If the crack height tolerance is < ±0.5 mm, both patterns are rejected. This will lead to realistic tolerances on probe wedge parameters.

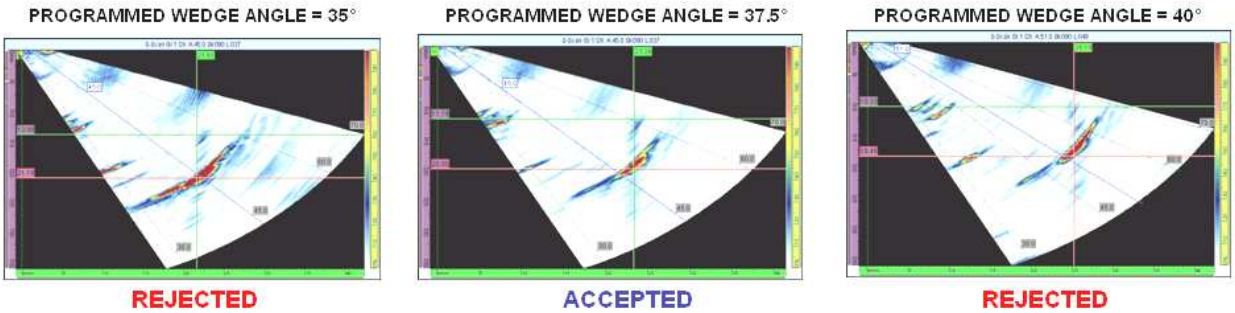


**Figure 11:** Example of crack detection and sizing by three set-ups with programmed wedge angle: 35°(left), 37.5°(actual-middle), and 40°(right).

**Figure 12** represents an example when probe #9 is used in both modes to confirm and size cracks in the counterbore. The tolerances for crack sizing were set to ± 1 mm. Both methods could be used in diversity mode, with L-waves method as primary detection and sizing and S-waves method as a confirmation [5].

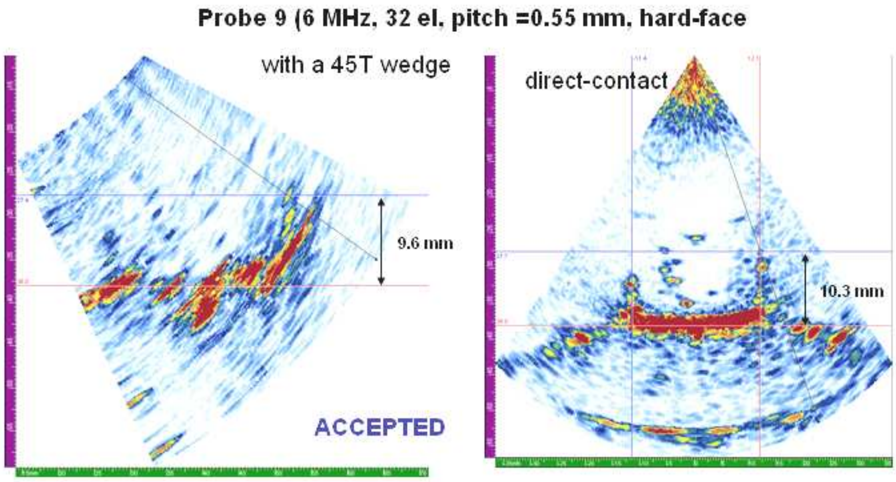


**Figure 12:** Example of crack sizing by shear waves (left) and L-waves (right).

## Conclusions

The new method for probe characterization in combination with the PA machine to be used for the field inspection offers conclusive advantages versus previous method or proposal [6-7]:

- employs solely S-scan display to measure the depth, index, and angle from specific SDH reflectors
- same inspection set-up is used for characterization
- anomalies and programmed mistakes could easily be detected and eliminated
- data plotting into 2-D or 3-D could be used for an easy assessment of errors
- tolerances could be linked to a specific inspection scope
- method is very productive
- method requires minimum mechanical measurements
- method could be used for a quick evaluation of overall performance when equipment substitution is required.

## References


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