How Reliable is Your Call? OPG Phased Array Ultrasonic Inspection Experience on Siemens- Parson Turbine Blade Roots 2001-2007.

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Abstract: This paper presents the practical aspects of phased array ultrasonic techniques (PAUT) as applied for inspecting Siemens-Parson turbine blades for nuclear and thermal generation stations. PAUT data from fatigue cracks and stress corrosion cracks are compared with magnetic particle, magnetic rubber replica and fracture mechanics. Examples of these comparisons are given and discussed. Limitations of PAUT method are also presented. It has been observed that PAUT has a tendency to undersize cracks. Comments regarding the blade root surface roughness and the influence of potential mechanical damages on PAUT calls are presented and illustrated. Human factor and practical aspects of technician training, field technical support for large-scale inspections are presented and illustrated.

Introduction:

Reliability of phased array ultrasonic technique calls on Parson blades depends on a group of factors, such as: crack size, orientation and location; blade surface roughness; probe size, frequency; detection technique; sizing technique; technician training and skills; blade location on rotor disk. In a previous paper[1] presented in Denver, at the EPRI 9-th Workshop on Steam Turbine and Generator, we described a generic topic regarding the PAUT applications on turbine components. During the last two years, OPG-IMS developed and improved the large-scale inspections for Siemens-Parson type low-pressure turbine for blade roots and for rotor steeples. We have also developed new types of targets, compared PAUT data with other methods (MP, rubber replica, fracture mechanics), assessed the probe performance [2-3] related to different machines and developed a comprehensive training and field technical support structure. This paper will provide an overview of the work to date related to Siemens-Parson low-pressure turbine blades. The specific topics presented and commented upon will be:

- Defect location and crack types
- PAUT techniques and their capabilities
- Technician training
- Field results
- PAUT comparison with other techniques

Defect Location and Crack Types

Finite element stress analysis (FESA), operating experience, magnetic particles and PAUT results confirm the major stressed locations, as presented in **Figure 1** and **Figure 2**. The cracks are, in general, grouped and could be classified as fatigue or stress corrosion cracks (SCC). Fatigue cracks have a length to height aspect ratio 5:1 to 8:1. Most SCCs have a length to height aspect ratio of 4:1. **Figure 3** illustrates examples of fatigue and SCC.

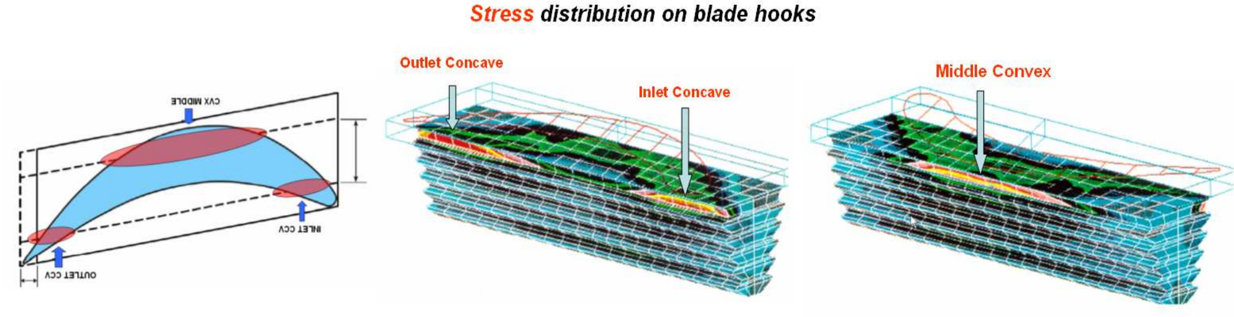

Figure 1: Major stressed locations evaluated by FESA.

Figure 2: Crack locations on concave side confirmed by fracture mechanics on two blades.

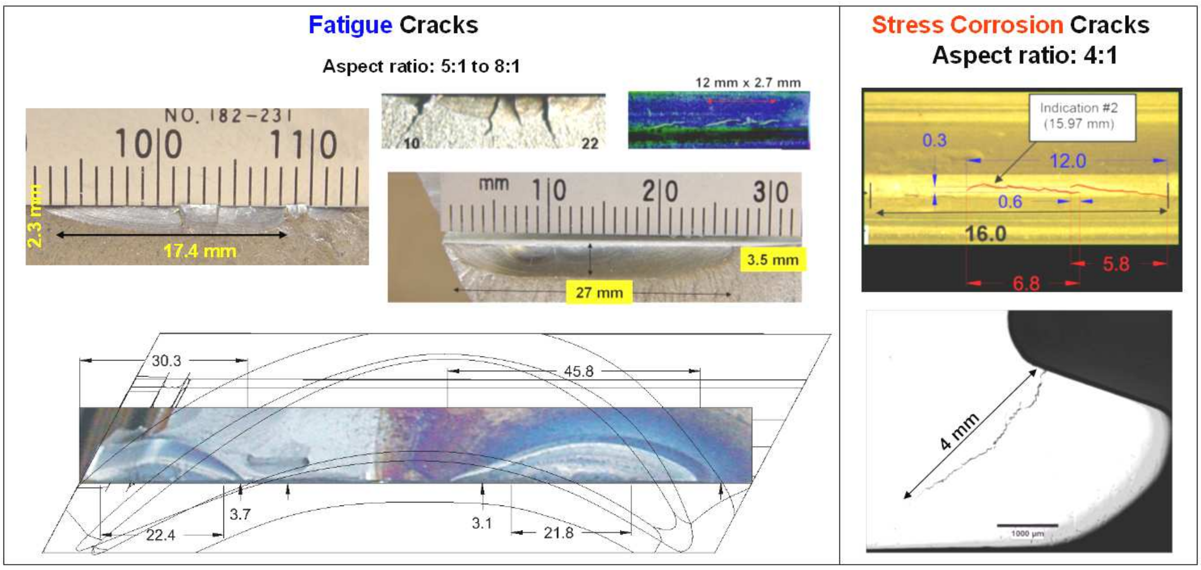

Figure 3: Confirmation of fatigue and SCC by fracture mechanics, MP and rubber replica.

Some blades are manufactured with a locking strip on the outlet side. Cracks may be developed in this region, on hook 2-locking strip, with a length to height aspect ratio = 3:2 (quarter ellipse) - see **Figure 4**.

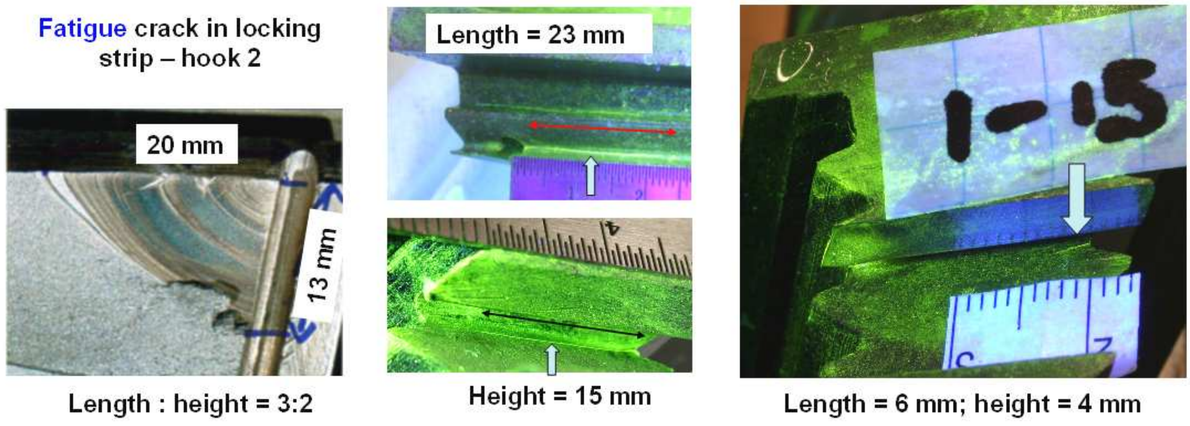

Figure 4: Examples of fatigue cracks located in the locking strip area confirmed by MP and fracture mechanics.

PAUT techniques and their capabilities

The major detection and sizing techniques are: top and wing (see **Figure 5**).

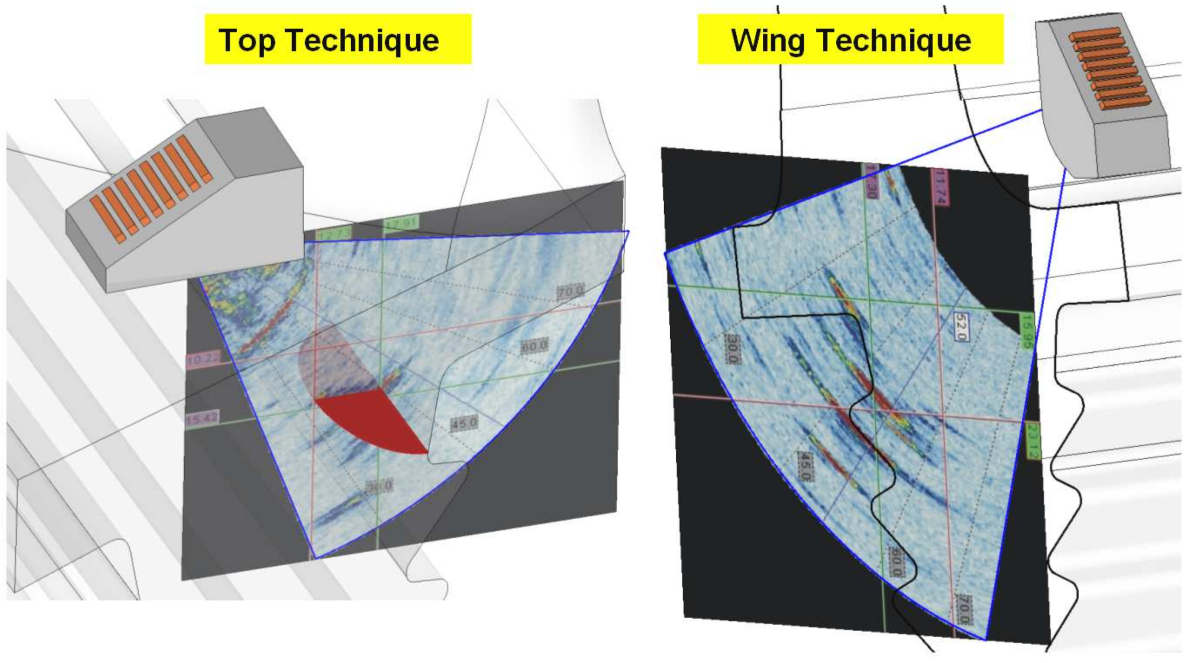

Figure 5: Top (*left*) and wing (*right*) techniques used for detection of cracks in Siemens-Parson blades.

Side technique is applied as a confirmation technique and as a detection technique for cracks located in the locking strip-hook 2 (see **Figure 6)**. The height evaluation is based on diffracted amplitudes from the last significant tip for top and wing techniques (see **Figure 7**) and on scattered signals from multiple SCC branches, when side technique is used (see **Figure 6**).

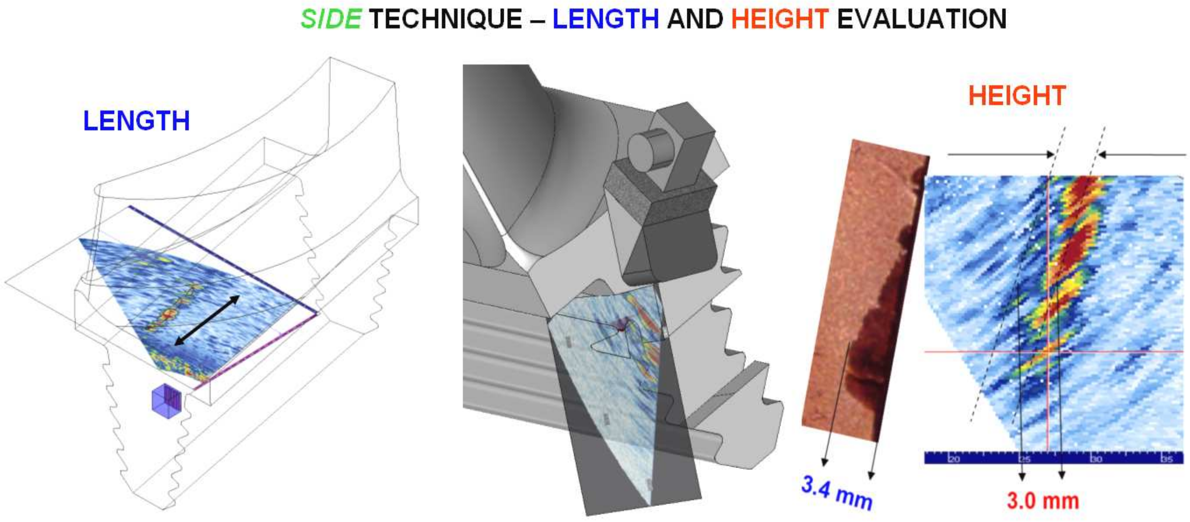

Figure 6: Side technique used for confirmation and sizing of SCC and fatigue cracks located in the locking strip-hook 2.

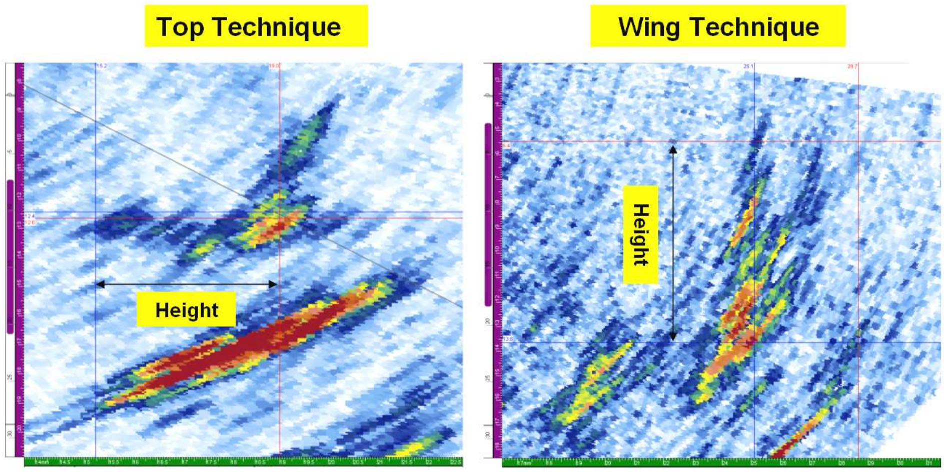

Figure 7: Crack sizing method for top and wing techniques.

Technician Training

Large-scale inspections could be performed in multiple scenarios:

- last two rows in-situ
- last two rows on stands
- last four rows on stands
- L-1 (row 9) on stands
- last row in situ

The number of inspection points is 1,200 to 9,000. The inspection window is very limited, so multiple teams working 24/7 are required. Technician training is one of the major activities of PAUT reliability chain. The training is performed on specific techniques with 14 to 20 lab exercises, including detection and sizing cracks in the retired-for-cause blades. Procedures, technique sheets, confirmation and sizing techniques are presented and exercised in depth. Examples of training activities are illustrated in Figure 8.

Figure 8: Examples of training activities using retired-for-cause blades with cracks and actual PAUT techniques.

Where possible, refresher training is performed prior to commencing inspection, and on-the-job technical support is provided for the duration of inspection window. Observation and coaching is also in place. Another factor which contributes to reduce the human error is the peer verification before and after the inspection is performed. A small technician note book titled Correct Component Verification, coupled with a very useful d-base are in place as human performance tools throughout the shift activities (see **Figure 9**).

Figure 9: Examples of peer verification and data entry on the general sheet and in the d-base.

Figure 10: Examples of in-situ and on the stands inspections.

Sizing Capabilities and PAUT Reliability

PAUT sizing capability was compared with MP, rubber replica and fracture mechanics. It was found that generally, the length is oversized and the height is undersized. If the crack has a significant height (>12 mm) and length (>30 mm), the wing technique is limited in height sizing from CVX side. Other complimentary techniques, such as wing technique CVX-CVX and top technique L-waves are required to size the last significant tip. The over-all performance in sizing is presented in **Figure 11**.

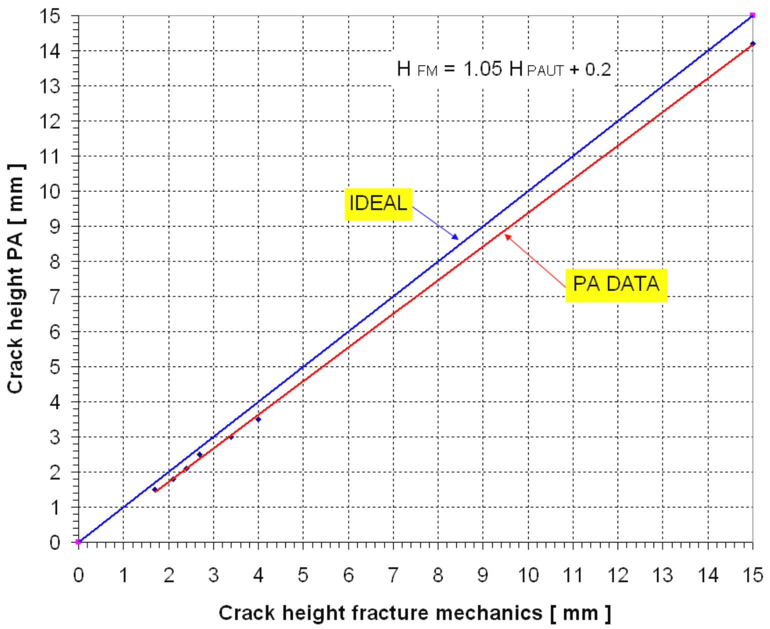

Figure 11: PAUT sizing capability compared to fracture mechanics. Crack height range: 1.6 mm – 15 mm. An under-sizing trend between 0.5 mm to 1.0 mm is noticed.

How reliable are PAUT calls? Examples presented in Table 1 conclude that PAUT reliability depends on redundancy and diversity. Cracks 10 mm long by 1.6 mm in height are reliably detected and sized. Cracks with height less than 1 mm could be sized only if the blade surface roughness is less than 12 microns.

Table 1: Examples of PAUT reliability demonstration [2001-2007].

Number of inspections	Findings	Confirmation by MP / fracture mechanics	Remarks
1296	12 cracks (2 SCC, 10 fatigue)	12 cracks	Two rotors de-bladed
648 + 648	0 cracks	0 cracks	Two inspections; one in 2002 and one in 2003
28	0 cracks	0 cracks	Hard blades
6	Group of SCC cracks on hook 5,6 CCV and CVX	7 SCCs ; 5 –hook 6; 1 hook 5 –CCV, one CVX	See **Figure 12**
108	0 cracks	0 cracks	Hard blades

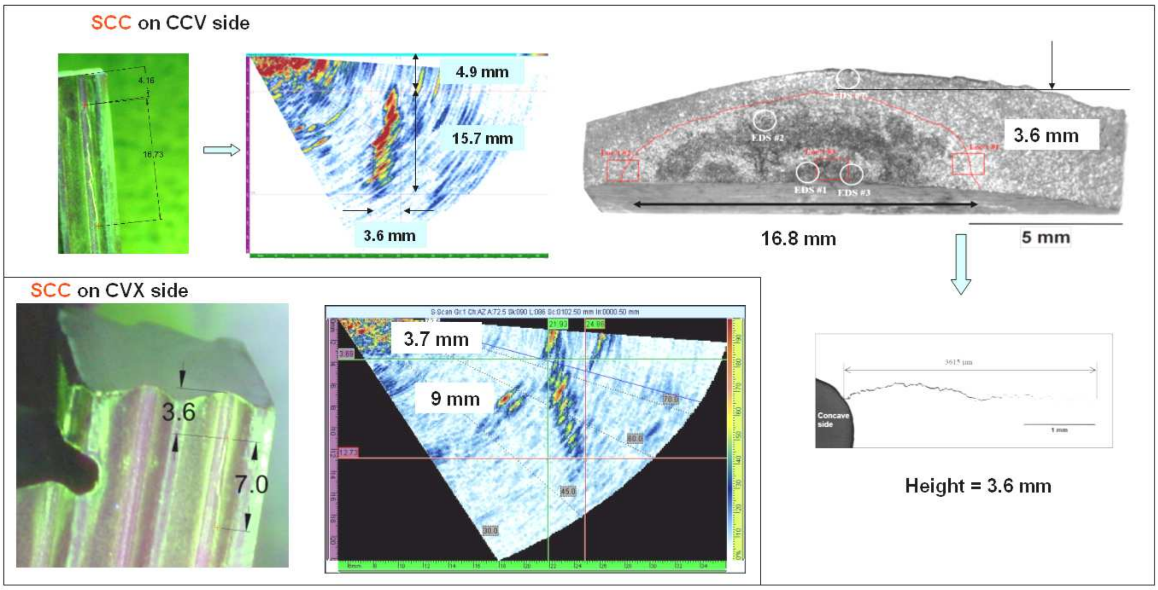

Figure 12: Examples of SCC sizing and confirmation by MP, PAUT and fracture mechanics.

Concluding Remarks

The reliability of PAUT presented in this paper is based on the following fundamentals:

Validation: procedure, probes, PA machines, blocks, techniques, technician training, QA, technical support, correct component verification, d-base for scans, d-base for indications

Redundancy: S-scan, probe movement, probe skewing, detection and sizing by 2-3 probes, different frequencies

Diversity: Confirmation independent of detection, 2-3 techniques for sizing, higher frequency probes, comparison with known / similar cracks.

- PAUT tends to under-size the cracks by 0.5 to 1.0 mm.
- Side technique is very reliable for SCC – length and height, with under-sizing trend of 0.5 mm for cracks and 1-3 mm for cracks with length > 15 mm.
- Cracks with height > 12 mm are undersized due to limited capability of probe movement. Complementary techniques are required, such as wing technique CVX to CVX and L-waves top technique.
- Some Siemens-Parson blades cannot be reliable inspected by wing technique for middle CVX, due to foil geometry. Detection and sizing is based on mode-converted signals (see **Figure 13**).
- Cracks with length > 10 mm and height > 1.6 mm are reliably detected and sized.
- Cracks with height between 0.4 – 1.0 mm could be sized with high-frequency probes with special design and only if the blade roughness is smaller than 12 microns.
- False calls could be avoided by a combination of 2-3 techniques and probes with different frequencies (3.5 MHz – 10 MHz).

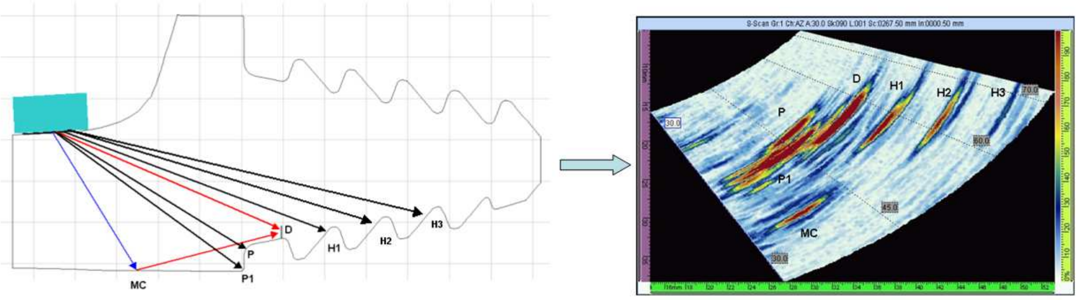

Figure 13: Example of crack detection using mode-converted signals.

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