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3-D Data Plotting: A Useful Tool for PAUT

Peter Ciorau [1], Lou Pullia [1], Wence Daks [2], Howard Smith [2]
[1] Ontario Power Generation, Pickering, Canada, Email: peter.ciorau@opg.com, lou.pullia@opg.com
[2] CAD WIRE, Markham, Canada, Email: wence@cadwire.com, howard@cadwire.com

Abstract

The paper presents different aspects of data plotting (2-D bitmap images) into 3-D complex parts, such as turbine blades, rotor steeples, welds and steam chest valves. Extension to defect reconstruction, defect comparison to other methods (magnetic particles, optical, fracture mechanics and/or designed parameters) is also described. Applications to beam simulation, and to multiple frames plotting is also illustrated. Data plotting in combination with simulation and ray tracing helped optimizing the probe design, the inspection parameters and namely provides a valuable tool for technician training. Defect parameters are within the following tolerances: location : ± 1 mm, angle = ± 1°, length : ± 2 mm and height : ± 1 mm. Some aspects of real 3-D data acquisition and analysis are commented and suggested.

Keywords: S-scan, phased array, crack height, data plotting, beam simulation, welds, turbine blades, rotor steeples, data comparison, magnetic particles, optical, fracture mechanics, defect reconstruction.

Introduction

The application of phased array ultrasonic (PAUT) to turbine components triggered the development of additional tools needed for probe design, reverse engineering, 3-D complex EDM notches, inspection parameters and the data plotting [1-2]. Ontario Power Generation (OPG) tried to develop along a 12-year period a unified package to include: inspection simulation, probe design, mock-up/defect manufacturing, data acquisition and plotting into 3-D parts, defect parameters evaluation and PAUT optimization. The task was too complex and ahead of available PAUT-CAD capabilities; as a result it fell short of meeting our expectations. As a consequence, OPG employs a large variety of specific pieces of software needed to solve the PAUT issues:

- Beam simulation, focal laws: PASS , PA Calculator, SimulUS, CIVA
- Ray tracing: Imagine 3D, CIVA
- Reverse engineering: KeyCreator
- PAUT data acquisition/analysis: Tomoview/Ultravision
- PAUT data plotting, defect reconstruction: KeyCreator
- Reverse engineering of 3-D complex defects: KeyCreator

However, the new features added to KeyCreator [3] enhance the capability of complex presentation and plotting in a realistic way to represent 2-D bitmap frames overlaid within 3-D specimens, with an option to plot 3-D pixels into 3-D part. The present paper is an overview of the above mentioned capability related to PAUT applications.

Data plotting – turbine components

OPG developed a large variety of PAUT procedures for turbine components to inspect the blade roots (different OEMs: GEC Alstom, Siemens-Parson [4], Westinghouse), rotor steeples grooves (GEC Alstom, Siemens-Parson), disk bore and peg holes (GE, Siemens-Parson), disk-blade rim attachments (GE). Defects were detected and confirmed during a 10-year inspection period. Examples of defect locations based on B-and S-scan are presented in Figure 1 to Figure 4.

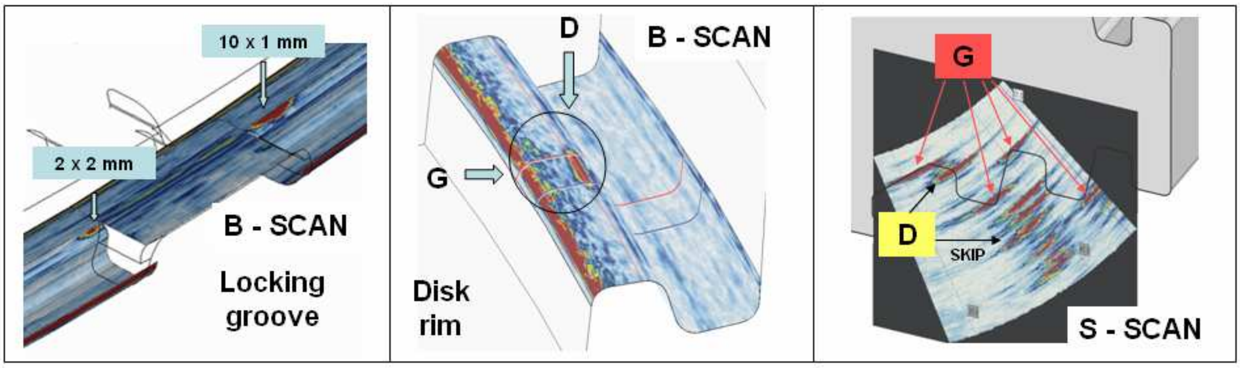


Figure 1: Examples of bent B-scan (left and middle) and S-scan data plotting for GE disk rim inspection.

Another example is presented in Figure 2 for L-0 blade of GEC Alstom. Detection is made by shear waves and sizing is performed by L-waves PAUT. Confirmation is performed by T-waves from convex side (same side as crack location).

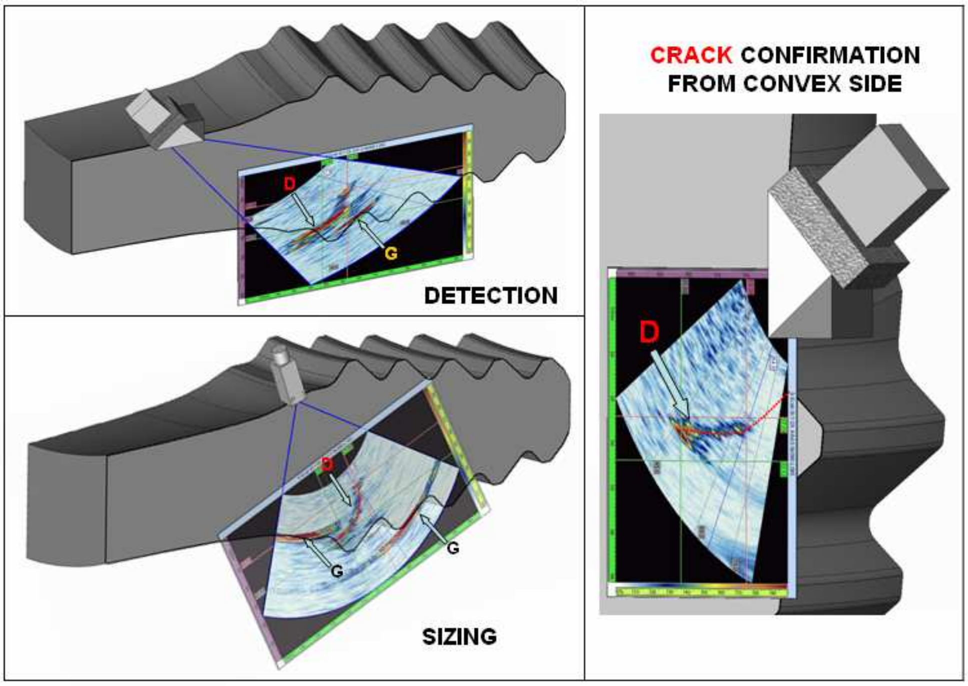


Figure 2: Example PAUT inspection features (probe, part, defect and S-scan) for crack detection and sizing in L-0 blade (GEC Alstom).

A very useful tool of 3-D plotting (probe-part-defect-PAUT relationship) is presented in Figure 3 for side technique applied to Siemens-Parson R9 rotor steeple.

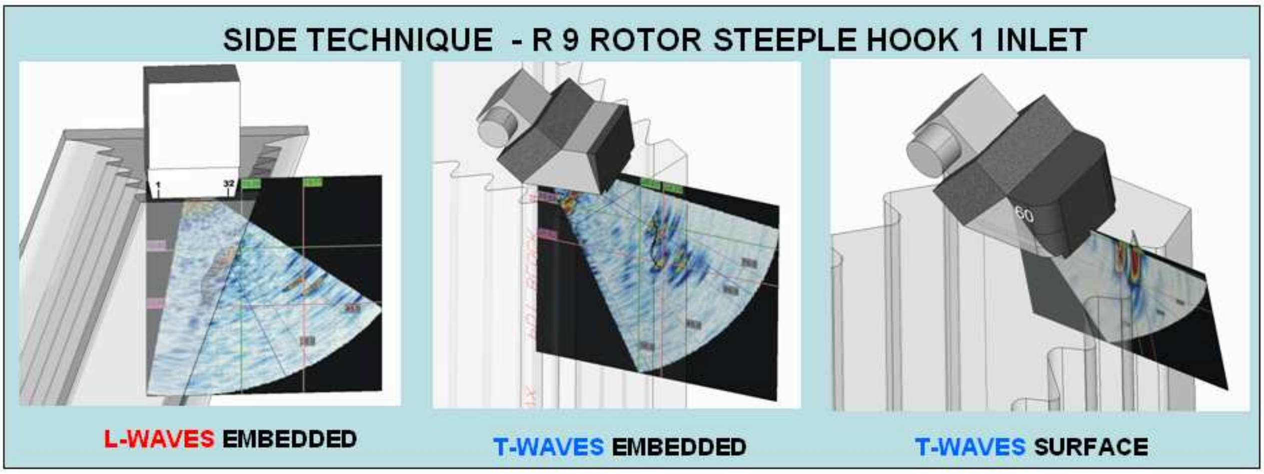
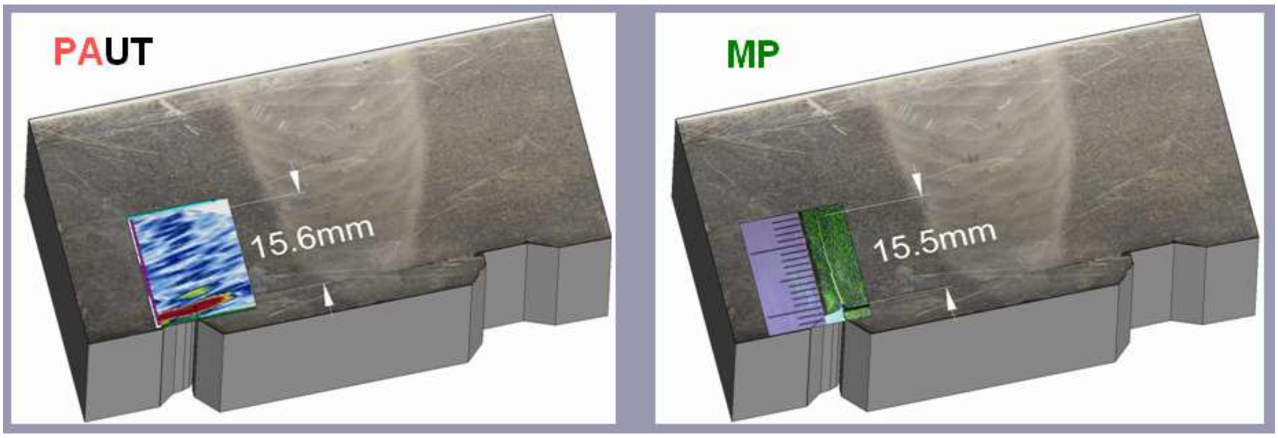


Figure 3: Example of data plotting for side technique applied to Siemens-Parson R9 rotor steeple.

Data plotting –welds

OPG extended PAUT from turbine to welds inspection in different phases and for different configurations [5-8] and with different evaluation purposes [detection, sizing, ligament measurement, ECA, feasibility study, defect reconstruction, bench measurements]. Examples of data plotting for welds are presented in Figure 4 to Figure 8. The data plotting is using advanced editing features, such: overlaying multiple data planes, isometric plotting, and bent B-scans. Data comparison, defect reconstruction and measurement tools were also used for reporting and performance demonstration purposes.



(*courtesy OlympusNDT – Waltham –USA*)

Figure 4: Data comparison between PAUT and MP for a fatigue crack located in the counterbore of an economizer weld.

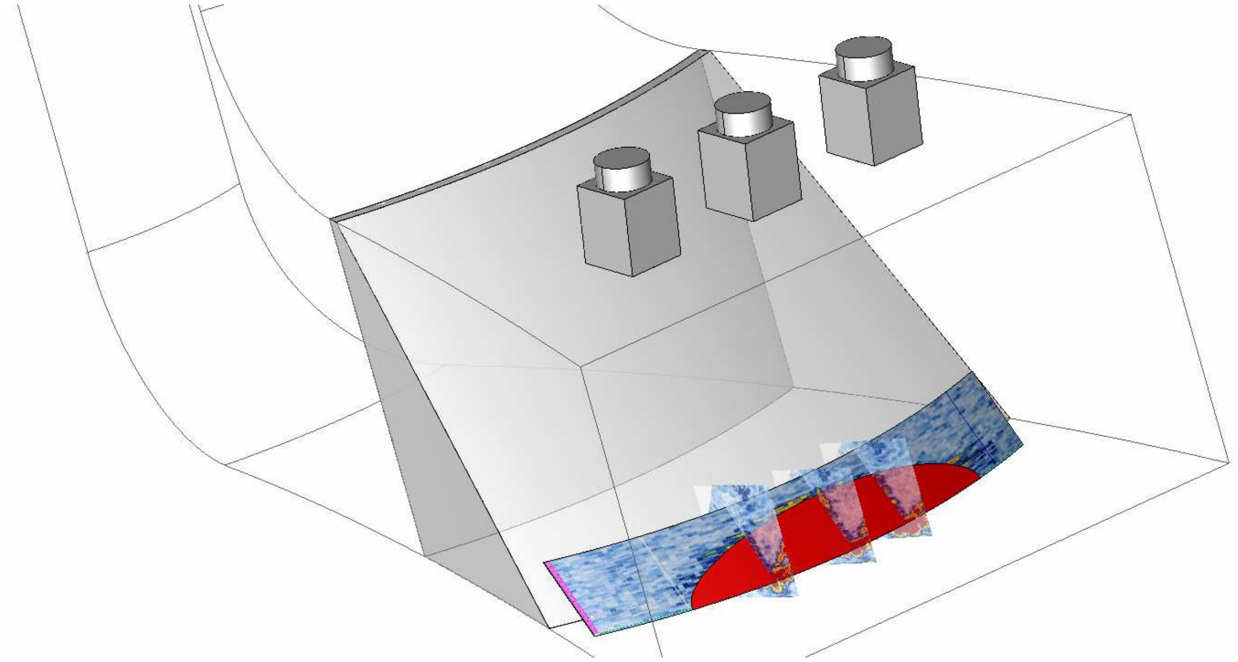


Figure 5: Example of data plotting, probe position, and defect reconstruction for a crack located in HAZ of a nozzle.

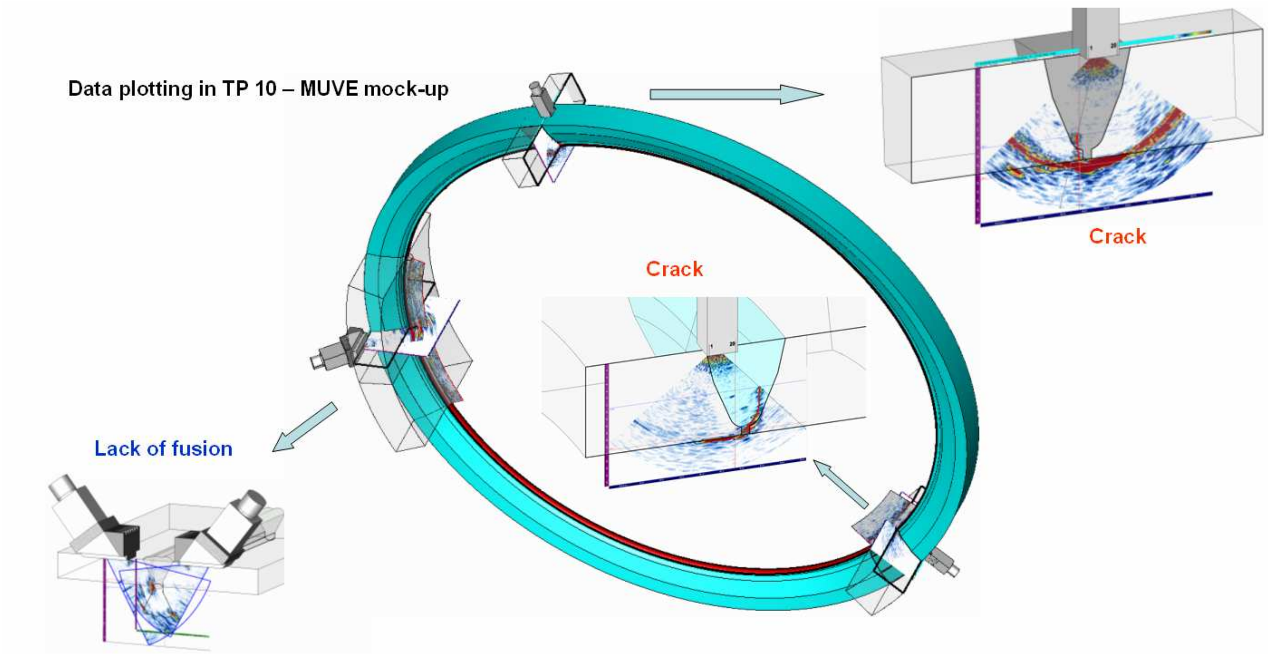


Figure 6: Example of data plotting for a piping weld mock-up with three implanted defects.

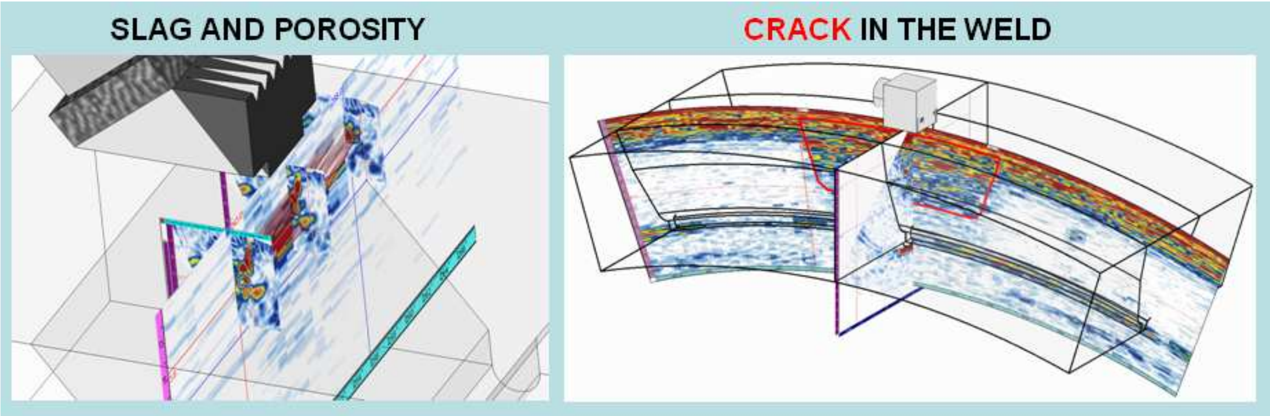


Figure 7: Examples of data plotting for slag and porosity (left) and weld crack (right) using superimposing B- and S-scans.

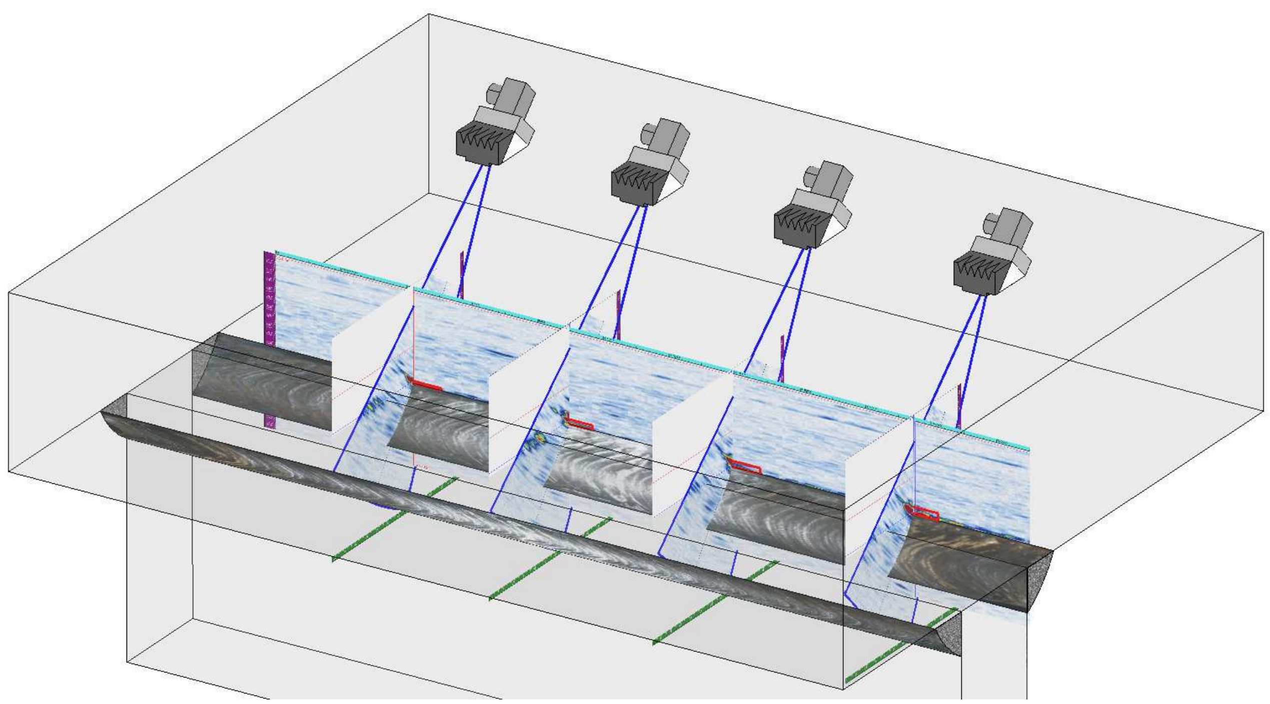
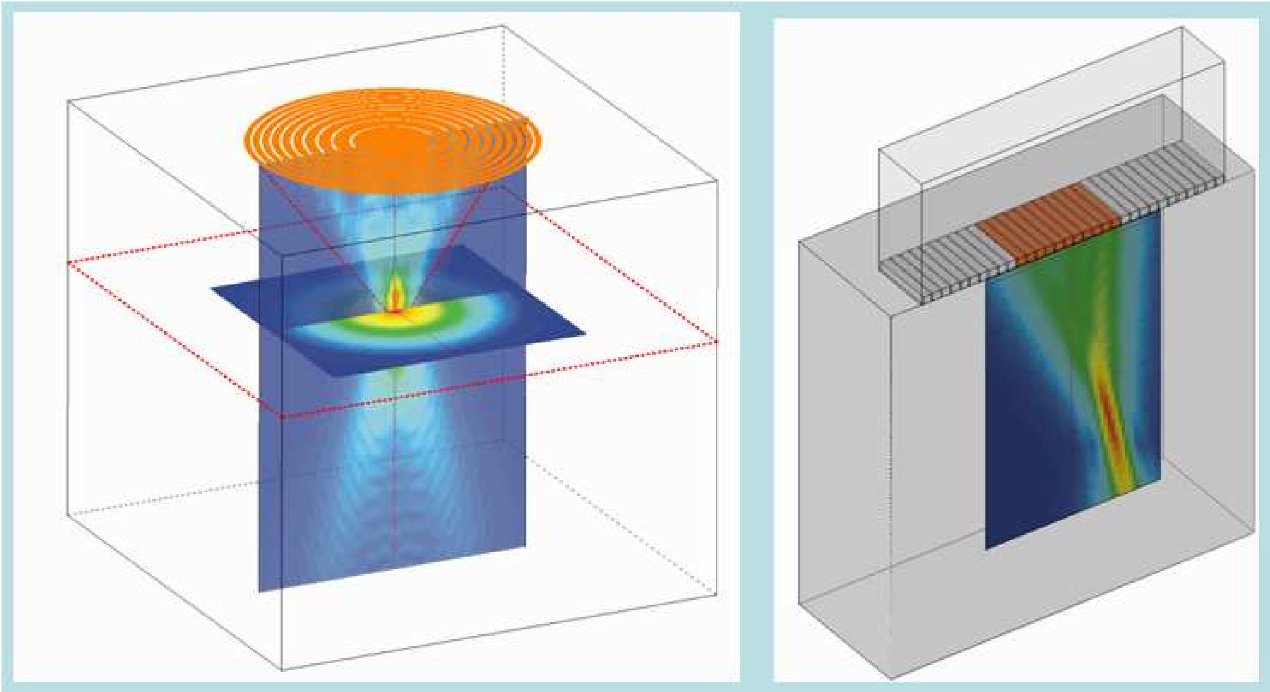


Figure 8: Data plotting and probe-defect-part relationship for steam generator lug welds. Implanted defect: four toe cracks of different height-same length.

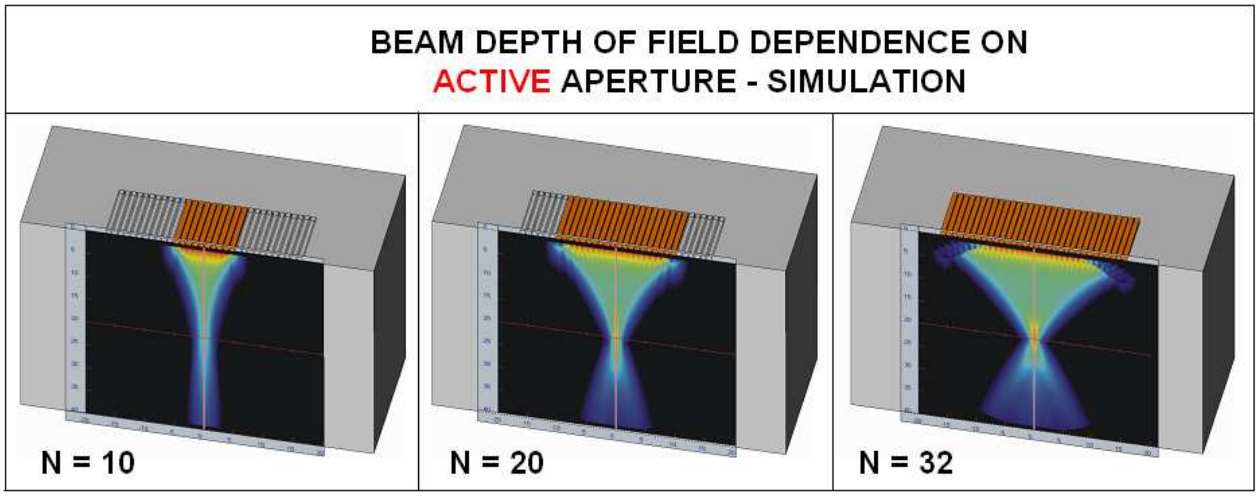
Data plotting – other applications

3-D data plotting can be extended to beam simulation (PASS and SimulUS) [9] - see Figure 9-10, to probe characterization [10] – see Figure 11-12, and to other complex parts, such MIC attack in piping [11] - see Figure 13-14 - or emergency stop valve [12] - see Figure 15. The data plotting used for probe characterization and defect reconstruction led to a general accuracy of ± 1 mm for defect location, ± 1º for refracted angle, length = ± 2 mm. More 2-D / 3-D data plotting examples may be found in OlympusNDT book [9].



(courtesy OlympusNDT – Waltham –USA)

Figure 9: Examples of PASS data plotting for annular array (left) and linear array (right) probe



(courtesy OlympusNDT – Waltham –USA)

Figure 10: Examples of data plotting for SimulUS (Peak NDT-UK) simulation of beam depth of field dependence on active aperture.

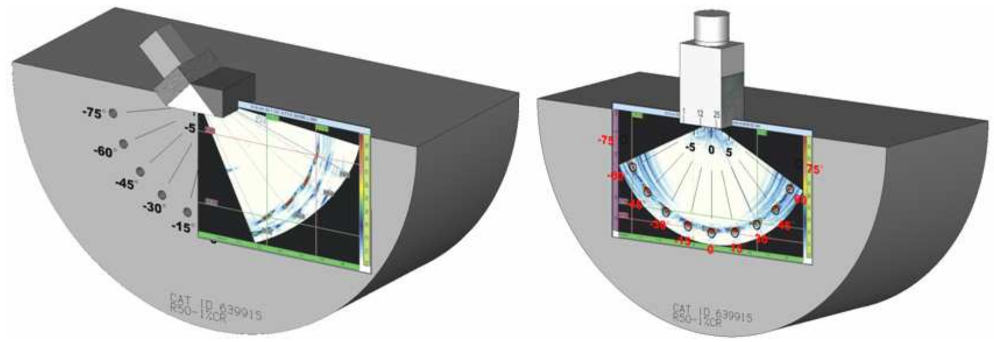


Figure 11: Example of data plotting for probe characterization - MIC attack set-up - on even-distributed side-drilled holes. ***Left: T-waves; right: L-waves.***

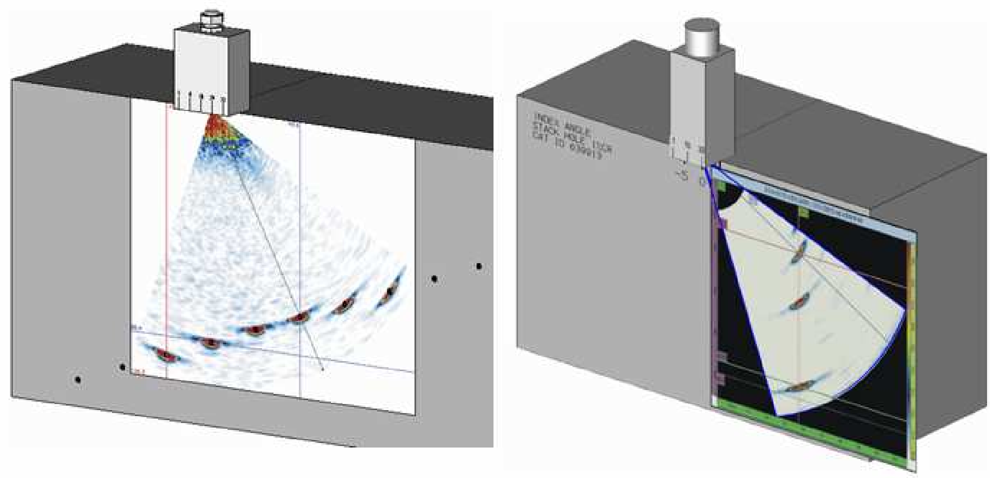


Figure 12: Examples of data plotting for probe characterization : deeper range [60-11- mm] (left) and shallow depth [10-40 mm] (right)

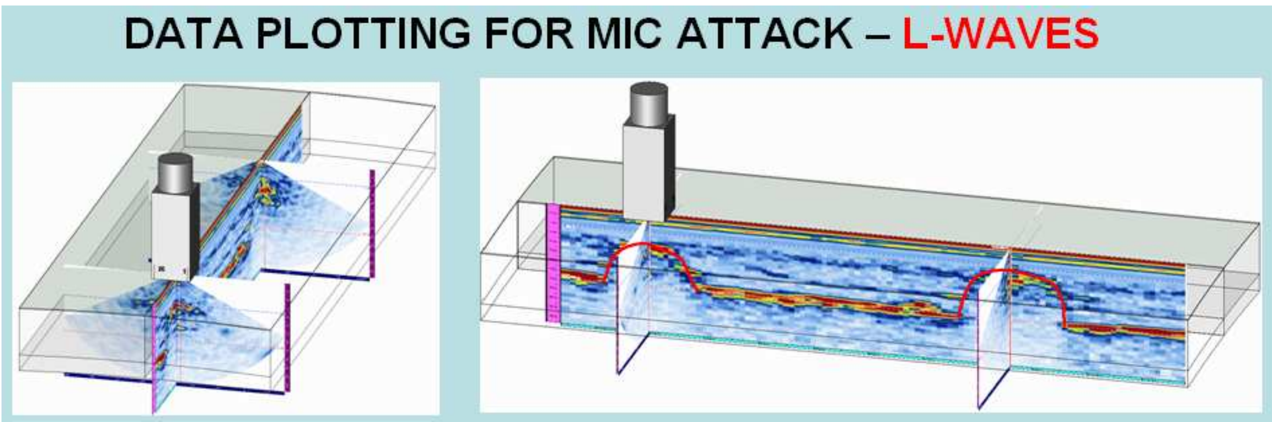


Figure 13: Examples of data plotting for MIC attack– L-waves on shut down cooler heat exchanger - HAZ of divider plate weld.

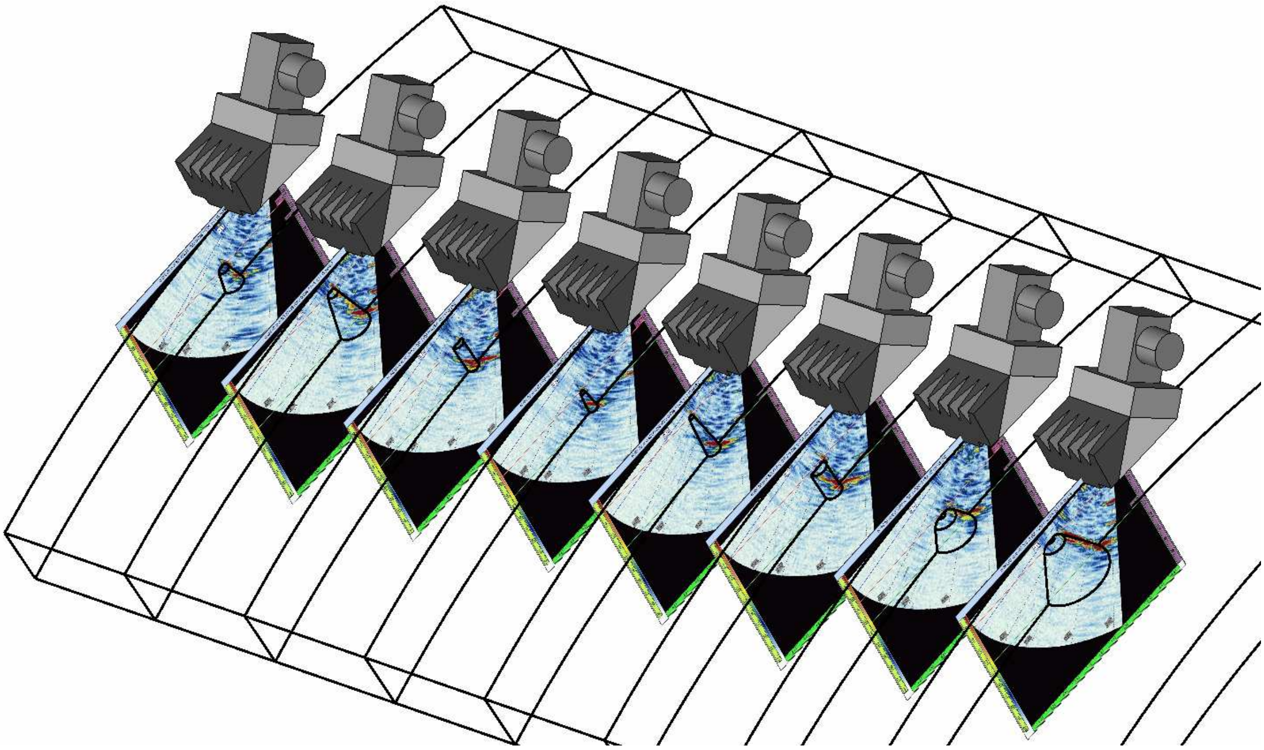


Figure 14: Data plotting for T-waves on NS-4-10 block with artificial localized MIC defects.

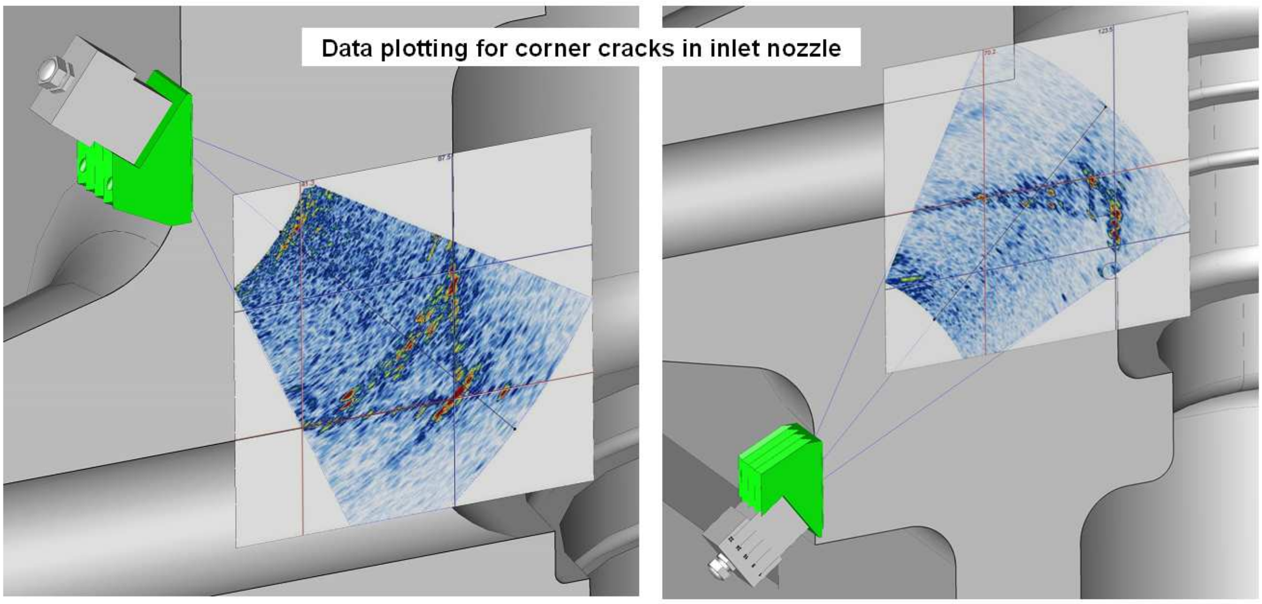


Figure 15: Example of data plotting for emergency stop valve; crack size and shape for priority 1 (*left*) and 2 (*right*) between inlet nozzle and upper chamber.

Concluding remarks and comments

PAUT data plotting presented in this paper is a very useful tool for the following reasons:

- Realistic link of 2-D B-, and S-scans with 3-D of complex part
- Realistic link between probe, beam, defect and part for understanding the inspection set-up
- Reliable defect reconstruction used for reverse engineering
- A very practical training tool for technicians
- A very useful tool for reporting and disposition
- A very good tool for defect comparison with PAUT data (capability and/or performance demonstration)
- A very useful tool for explaining to the customer the defect location, orientation, shape; very useful for life-assessment decision

Our comments and recommendations: PAUT is an emerging technology, and 3-D data acquisition and analysis will be available within 3 to10 years. It is very important to build the 3-D package around a friendly-to-use drafting package (Autocad, KeyCreator, Solid Works, Catia). The UT physics must be incorporated into developer kit of the drafting package. The interface must be simple, at level II entry, so the acquisition/analysis data should be displayed in near real-time. We hope the new trends of phased array manufacturers [13-16] to incorporate a 3-D acquisition/analysis package bundle with the new generation hardware will lead to a better understanding of PAUT and an increased reliability.

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