A Contribution to Phased Array Ultrasonic Inspection of Welds Part 1: Data Plotting for S- and B-Scan Displays

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Abstract: Part 1 of the paper presents the detection and sizing capability based on image display of sectorial scan. Examples are given for different types of weld defects: toe cracks, internal porosity, side-wall lack of fusion, underbead crack, inner-surface breaking cracks, slag inclusions, incomplete root penetration and internal cracks. Based on combination of S-scan and B-scan plotted into 3-D isometric part, the defect features could be reconstructed and measured into a draft package. Comparison between plotted data and actual defect sizes are also presented.

Introduction

The powerful information of sectorial scan (S-scan) in combination with focus beams and probe movement are currently used for a broad domain of weld inspection applications [1-8]. Recent validation techniques or inspection qualification [9-10] lead to a faster pace phased array application for weld inspection. It is quite obvious the new technology will get a solid ground into the weld inspection, namely for the following reasons:

- Is a pulse-echo technique
- Has a direct link between S-scan and the welded component
- Increase productivity and reliability
- Could be applied for welded components with complex geometry, limited access or dissimilar metal welds
- Regulators and standardization organizations encourage the technology transfer and procedure qualification based on phased array ultrasonic technology
- Standardization process is well under way [12]
- Technician certificates for phased array are available through NDT Societies and specific centers

Part 1 of the present paper is presenting explanations regarding the weld defects S-scan display, trying to promote the idea of pattern recognition, similar to TOFD. A variety of weld defects will be presented in 2-D and 3-D images and an explanation is provided. Some comments on defect location, size and orientation are also included.

2-D Weld Defects Displays

Figure 1 represents a 2-D data plotting of S-scan in detecting and height sizing of a toe crack.

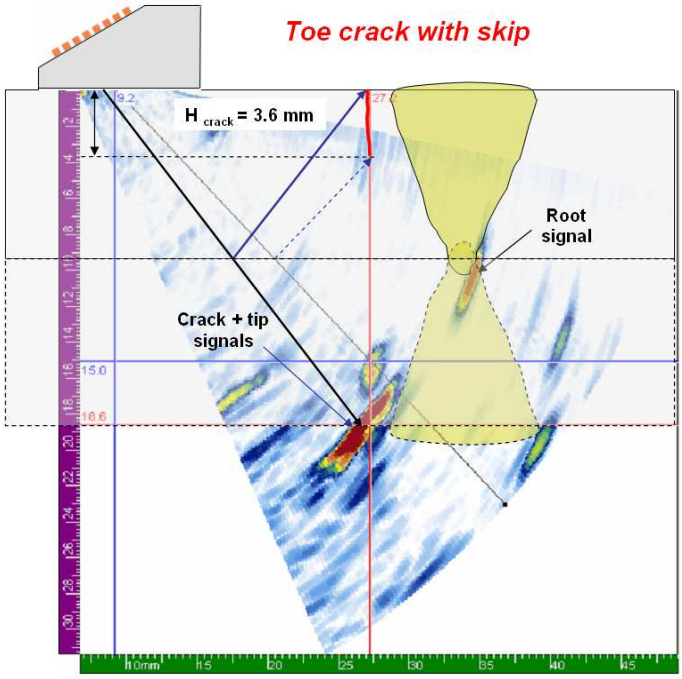

Figure 1: 2-D data plotting of a S-scan image in detecting and sizing a toe crack. Detection was performed with skip. The crack height is measured from corner trap to the last diffracted signal of crack tip. Actual crack height is 3.8 mm.

Figure 2 presents the detection, location and sizing of a side-wall lack of fusion located at 1.5 mm (almost at inner surface) versus the weld root. A combination of B- and S-scan is providing the LOF length, height and inner ligament. Note the root signal shadowed by LOF location.

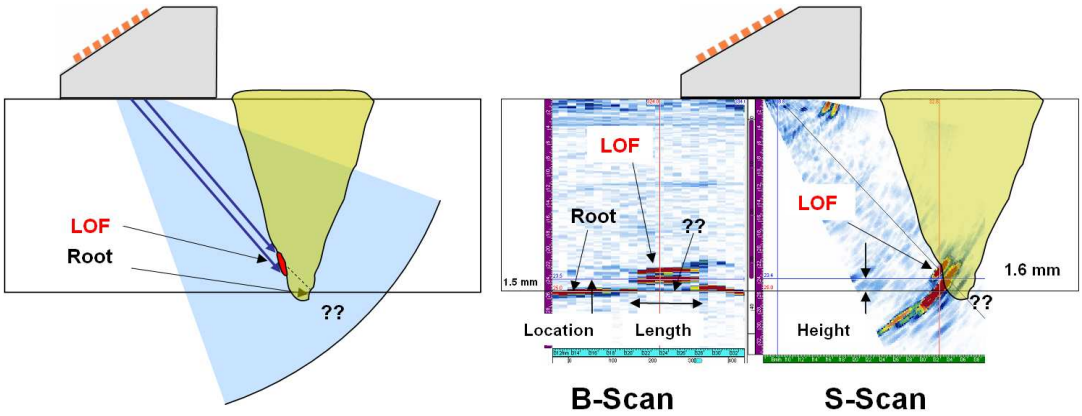

Figure 2: 2-D data plotting for a LOF located near the inner surface. A combination of B-and S-views provide the LOF parameters (location, length, height, orientation). *Left:* detection principle and shadowing effect of the root signal; *right*: 2-D data plotting for S-scan; B-scan was added for length and inner ligament measurements.

Figure 3 represents 2-D data plotting for a side-wall LOF detected with skip.

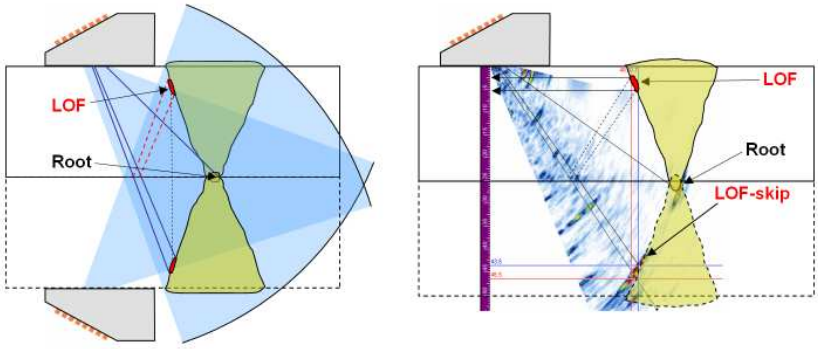

Figure 3: *Left:* Detection principle and data plotting in S-scan for a side-wall LOF detecting with skip; *Right:* S-scan data plotted over weld overlay.

Figure 4 presents a group of pores located at 1.5 mm from the outer surface detected in ½ skip. Porosity nest dimensions are: 1.5 mm x 3 mm x 10 mm (length-evaluated in B-scan).

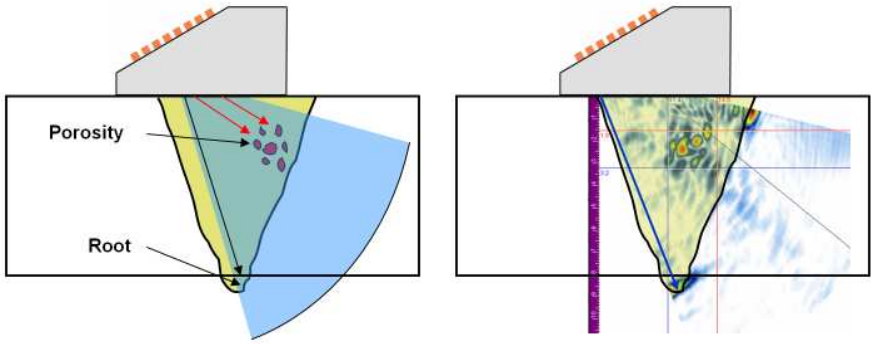

Figure 4: S-scan data plotting for porosity detected in ½ skip. *Left:* principle; *right:* S-scan data over 2-D weld overlay.

Detection and data plotting of porosity using the full skip are presented in **Figure 5.**

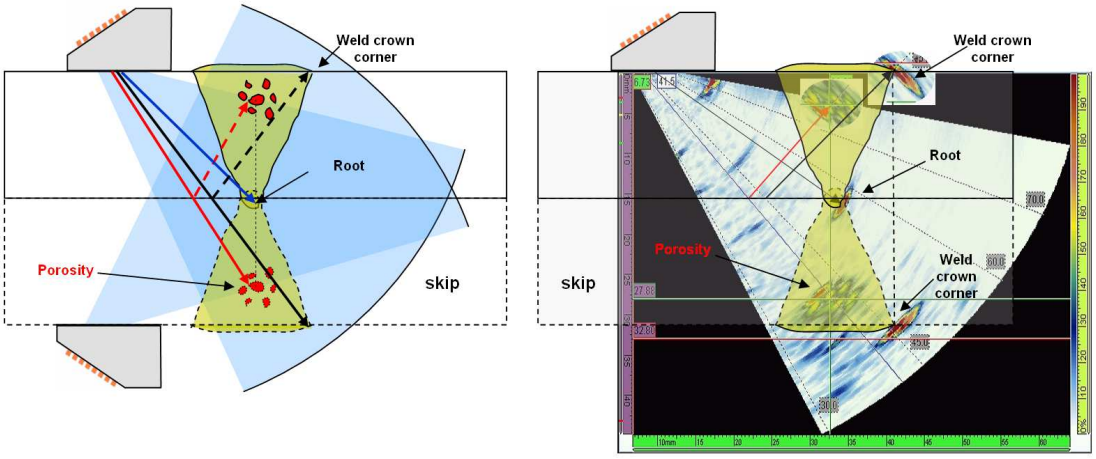

Figure 5: Principle of detection (*left*) and 2-D data plotting of Omniscan S-scan in detecting a nest of porosity with skip.

Figure 6 represents the data plotting of a incomplete root penetration and lack of fusions in a T-weld. A combination B- and S-scan provides a general view for a specific angle. Merging view is very useful for an overall B-scan defect location and sizing.

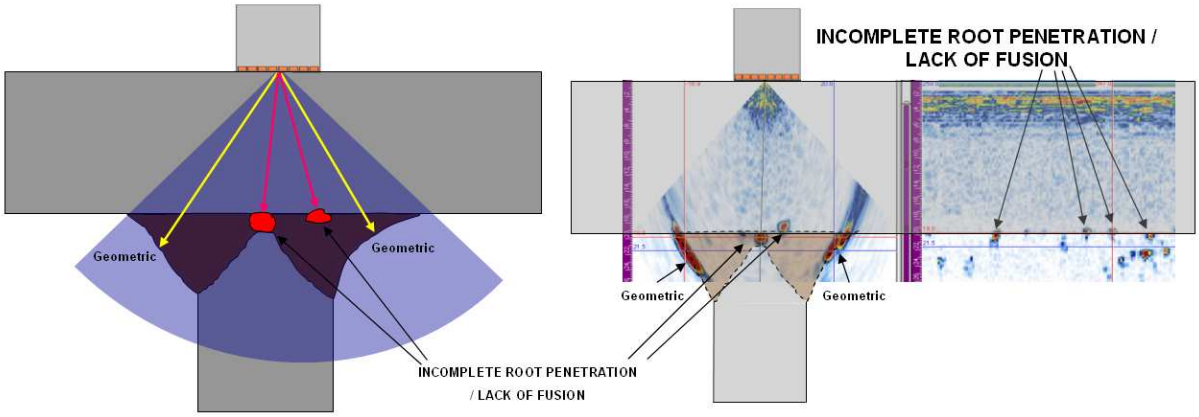

Figure 6: Data plotting for a T-weld S-scan display representing incomplete root penetration and lack of fusion detected by a direct-contact longitudinal waves probe.

Figure 7 illustrates the data plotting for an underbead crack in T-weld. Height is measured with index cursors and the inner ligament with ultrasonic (depth) cursors.

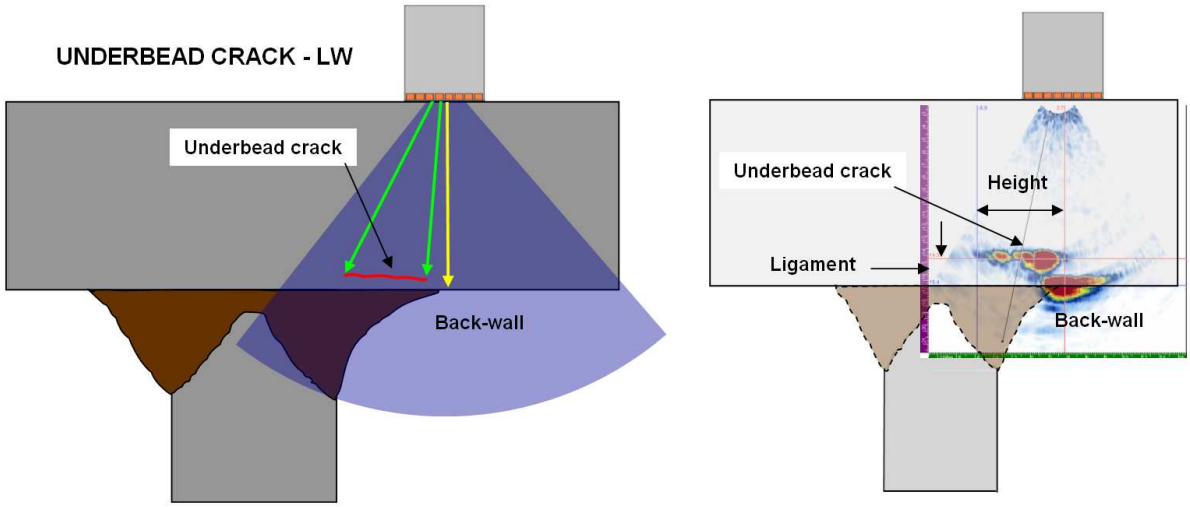

Figure 7: Principle of detection (*left*) and S-scan data plotting for an underbead crack located in a T-weld.

The same crack is detected by T-waves with a skip. Principle of detection and data plotting are presented in **Figure 8**.

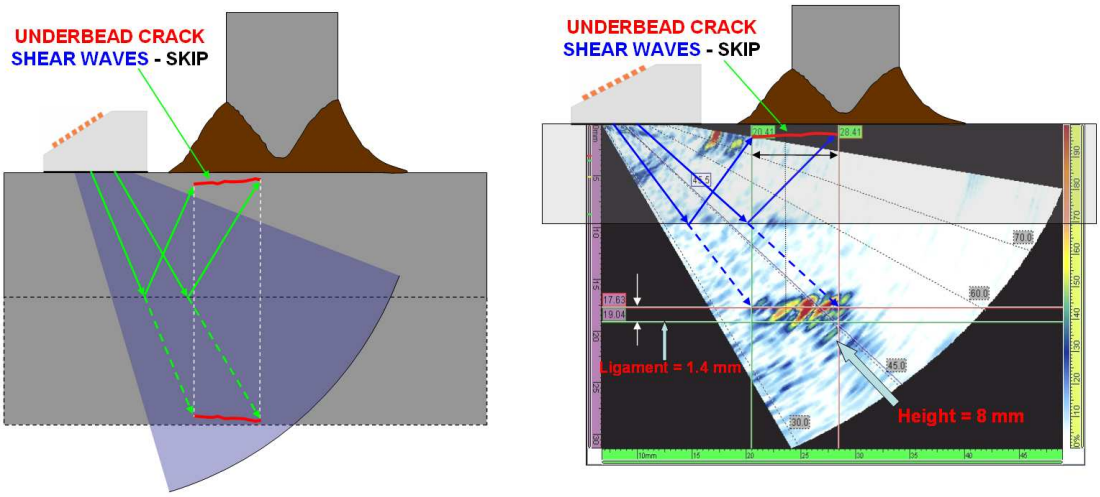

Figure 8: Example of S-scan data plotting for Omniscan –shear waves - in detecting the underbead crack from Figure OPG-7. *Left:* principle; *right*: data plotting.

A toe crack and a lack of fusion in T-weld detected by skip are presented in **Figure 9.**

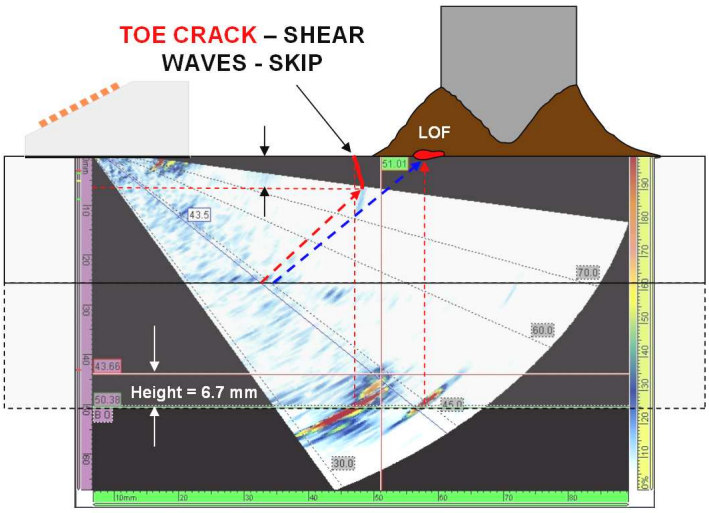

Figure 9: Example of toe crack and LOF detection and plotting using the skip. Omniscan data crack height is 6.7 mm vs. 6.8 mm actual height.

3-D Data Plotting

While 2-D plotting is a very useful tool to understand the relationship between the probe S-scan data for a specific probe position and the defect located into a cross section of the weld, the 3-D data plotting is linking the part, probe, beam and the defect characteristics in a global view. The 3-D simplified geometry is using only the S-scan with probe location at the correct beam intersections. In the early approach, the probe is just a schematic box with few linear array crystals placed on the isometric part. This approach was useful for training and reporting namely for the crack height. **Figure 10** presents an example of data plotting into a 3-D part for the

counterbore crack sizing using three techniques: L-waves, S-scan azimuthal, T-waves S-scan azimuthal and L-waves S-scan lateral.

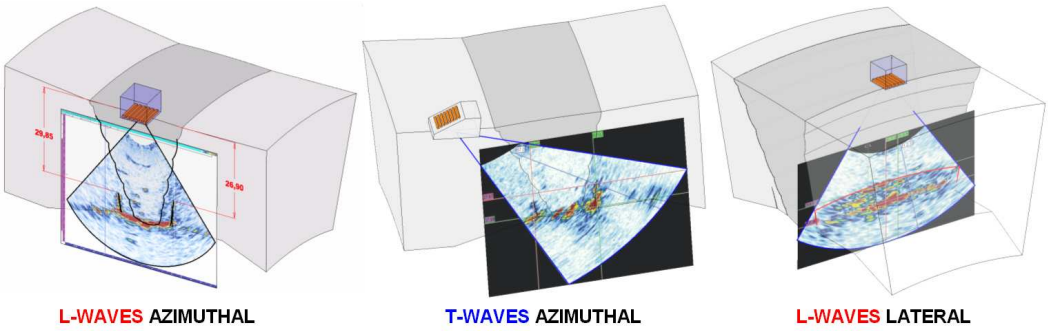

Figure 10: Examples of 3-D data plotting of S-scan display into isometric part.

Figure 11 illustrates a toe crack S-scan detection overlaid over the isometric drawing of the weld. A weld texture was also plotted along the selected piping weld section.

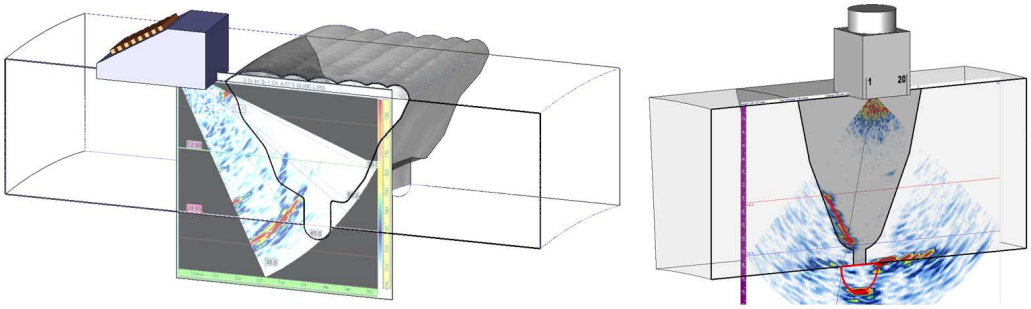

Figure 11: Example of 3-D data plotting of a toe crack (*left*) and of an embedded crack (*right*).

The next development was to include the 3-D drawing of the probe and to present data for sizing and evaluation. Ontario Power Generation – Inspection and Maintenance Services - Phased Array Group is using as design package the KeyCreator software.

Figure 12 and **Figure 13** illustrate the 3-D data plotting and actual probe size (including probe on the wedge) for different types of weld defects.

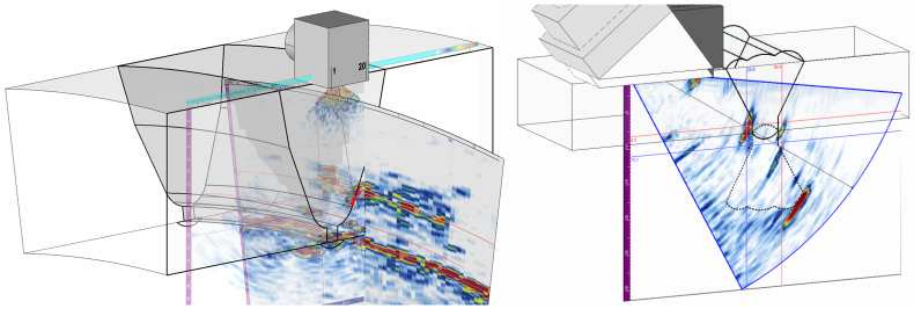

Figure 12: Example of data plotting for LOF using L-waves (*left*) and T-waves (*right*).

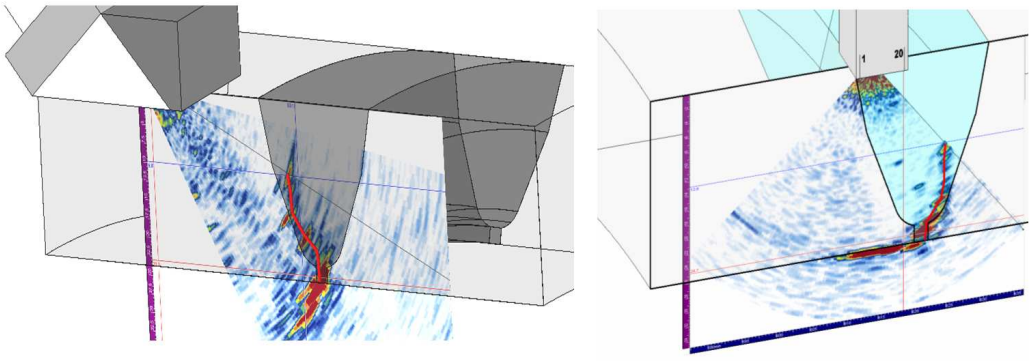

Figure 13: Example of data plotting for an inner-surface crack detected with shear-waves probe (*left*) and with an L-waves probe (*right*).

PAUT data could be used for defect reconstruction, as is presented in **Figure 14**.

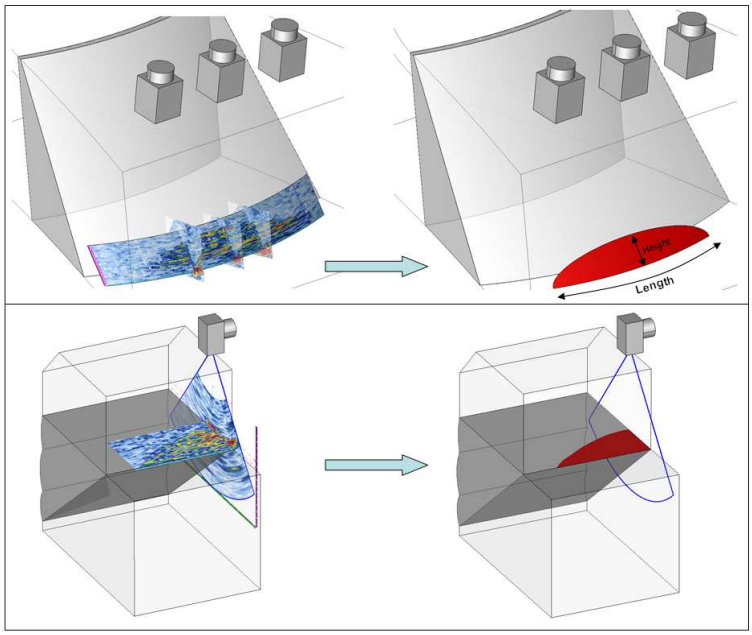

Figure 14: Example of defect reconstruction based on B-and S-data.

The advanced features include B- and S-scans, defect parameters, picture overlay and probe or multi-probe positions for the same defect or for different defects. Advanced features also include probe scanner movement, animation of probe trajectory and S-scan plotting at specific pitch, bent B-scan according to specimen curvature. **Figure 15** represents some examples of advanced 3-D data plotting for an embedded crack in a piping weld and for implanted to cracks in T-welds.

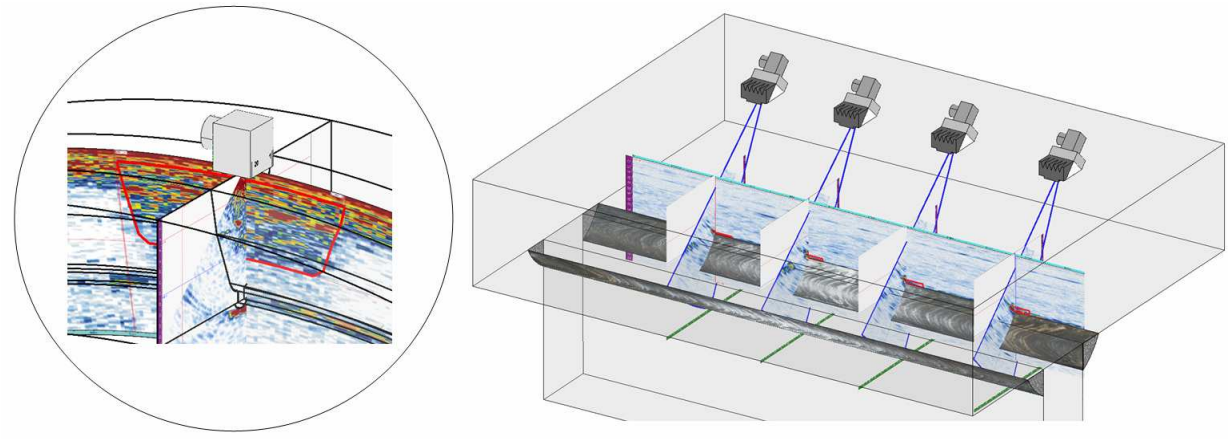

Figure 15: Example of data plotting of B-and S-scan into a piping weld for a crack detected with L-waves (*left*) and for four implanted toe cracks detected with shear waves (*right*).

Concluding Remarks

The results presented above concluded:

- S-scan must be used as an image-based tool, similar with radiographic / digital image in RT.
- Weld defect pattern is easy to be interpreted
- Height sizing and ligament evaluation is based on S-scan features
- A combination B- and S-scan increases the information regarding the defect parameters
- Plotting data into 3-D isometrics and using KeyCreator design package is a major step forward to understand phased array ultrasonic inspection data related to 3-D part and to defect.
- 3-D PAUT data could be used to reconstruct the defect into the inspected part.

Acknowledgements

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