# A Contribution to Phased Array Ultrasonic Inspection of Welds
## Part 3: Sizing Capability

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**Abstract**

Part 3 of the series presents the sizing capability for length, height, outer and inner ligament for specific implanted weld defects in training samples and mock-ups with thickness between 6.4-52 mm. It is discussed the influence of beam angle on sizing the lack of fusion defect. More than 50 implanted weld defects with 50% crack population were sized using high-frequency (5-10 MHz) linear array probes. The correlation between the design/manufacturer flaw size and PAUT data for length, height and ligament is graphically presented. It was concluded the length is oversized by 2-6 mm, height and inner ligament are undersized by 0.2 to 0.5 mm, and outer ligament is oversized by 0.5 mm. The sizing results were based on non-amplitude techniques and pattern display of S- and B-scan. The sizing capability is far better than ASME XI tolerances for performance demonstration and comparable to TOFD ideal tolerances.

### Introduction

Weld defects, and namely linear ones ( length to height ratio > 3:1 ) produce a pattern in S-scan display. A combination of encoded B-scan with S-scan view will lead to defect parameters (nature, location, orientation, length, height and ligament). Some aspects of weld patterns in S-scan were presented in ref.1.

Sizing accuracy for the ouside ligament and of the crack closure was presented in ref.2-3.

This last part will be focused on weld defect sizing capability in different scenarios:

- Flaw located in the root area
- Flaw located near the outer surface – weld crown dressed
- Flaw located near the outer surface – as welded
- Flaw located on far-side weld preparation – single side examination

### Experimental program

The thickness of welded samples used in this program was between 6.4 – 52 mm. Four mock-ups were pipe-to-pipe butt welds. More than 50 implanted defects were detected and sized in 25 samples. Table 1 presents an example of the variety of samples and flaw type. Figure 1 and 2 illustrate examples of implanted defects in plate weld and mock-ups.

**Table 1:** Test pieces with implanted defects used for sizing capability study (examples).

| Test piece ID | Thickness [ mm ] | Defect type | Length x height [ mm ] | Ligament [ outer/inner- mm ] |
|---|---|---|---|---|
| UT-1311 | 9.5 | Porosity / slag | 13 x 2.4 | 1.5 |
| UT-1313 | 16 | LOF | 12 x 3.2 | 3.2 |
| UT-1315 | 9.5 | LOF | 8 x 3.8 | 2.2 |
| | | Toe crack | 13 x 3.8 | outer |
| UT-1316 | 16 | crack | 13 x 3.8 | inner |
| | | slag | 20 x 3.8 | 1.5 |
| TP 9 | 365 x 24 | flaw 3-crack | 35 x 8 | inner |
| | | flaw 4-LOF | 25 X 3 | 5.2 |
| | | flaw 5-LOF | 30 X 3 | 2.4 |
| | | flaw 6-crack center line | 45 x 12 | 2 |
| | | flaw 7-crack | 35 x 10 | inner |
| BLOCK 6 | 204 x 12.7 | flaw A-crack | 40 x 9.2 | inner |
| | | flaw E-crack | 15 x 2.5 | inner |
| OH 0010 | 25 | Crack-HAZ | 13 x 5 | inner |
| | | LOF | 23 x 2.5 | 3.2 |

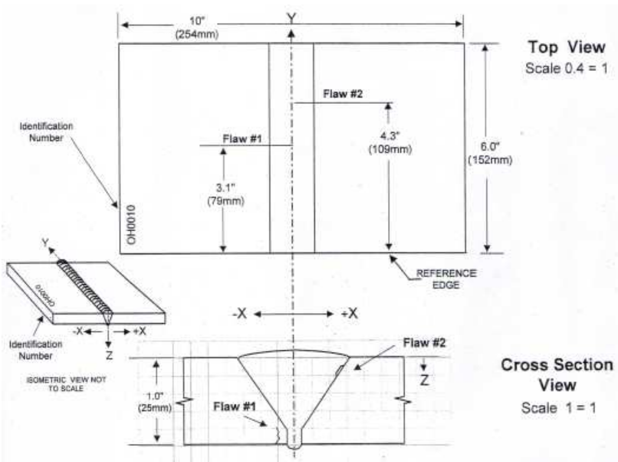


**Figure 1:** Example of implanted defects in a welded plate.

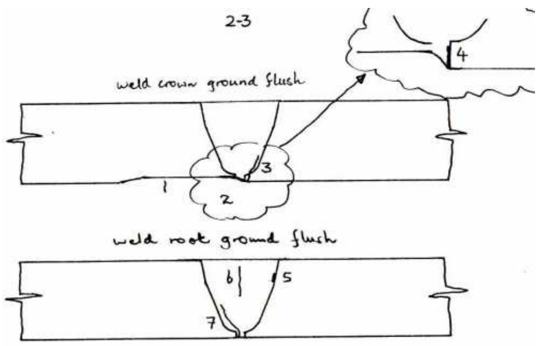


**Figure 2:** Example of implanted defects in mock-up TP 9 ( ∅365 mm x 24 mm).

The probes used in this experiment are presented in Table 2.

**Table 2:** 1-D linear array probes used for sizing

| Probe ID | F [ MHz ] | Nr. Elem. | Pitch [ mm ] | Remarks |
|---|---|---|---|---|
| 9+45T | 6 | 32 | 0.55 | Shear waves |
| 32+45T | 5 | 20 | 0.45 | Shear waves; CS-SS welds |
| 66+45T | 6 | 25 | 0.4 | Shear waves |
| 43+45T | 8 | 16 | 0.6 | Shear waves CS samples |
| 2 | 10 | 20 | 0.31 | L-waves CS |
| 9 | 6 | 32 | 0.55 | L-waves CS-SS |
| 22 | 7 | 32 | 0.44 | L-waves |
| 23 | 7 | 20 | 0.4 | L-waves |
| 38 | 8 | 25 | 0.4 | L-waves |
| 42 | 7 | 32 | 0.5 | L-waves |

OMNISCAN MX was used as a phased array machine in combination with pipe scanners and with X-Y lab scanners (see Figure 3). Data were collected at 0.5 mm encoder increment along the weld length.

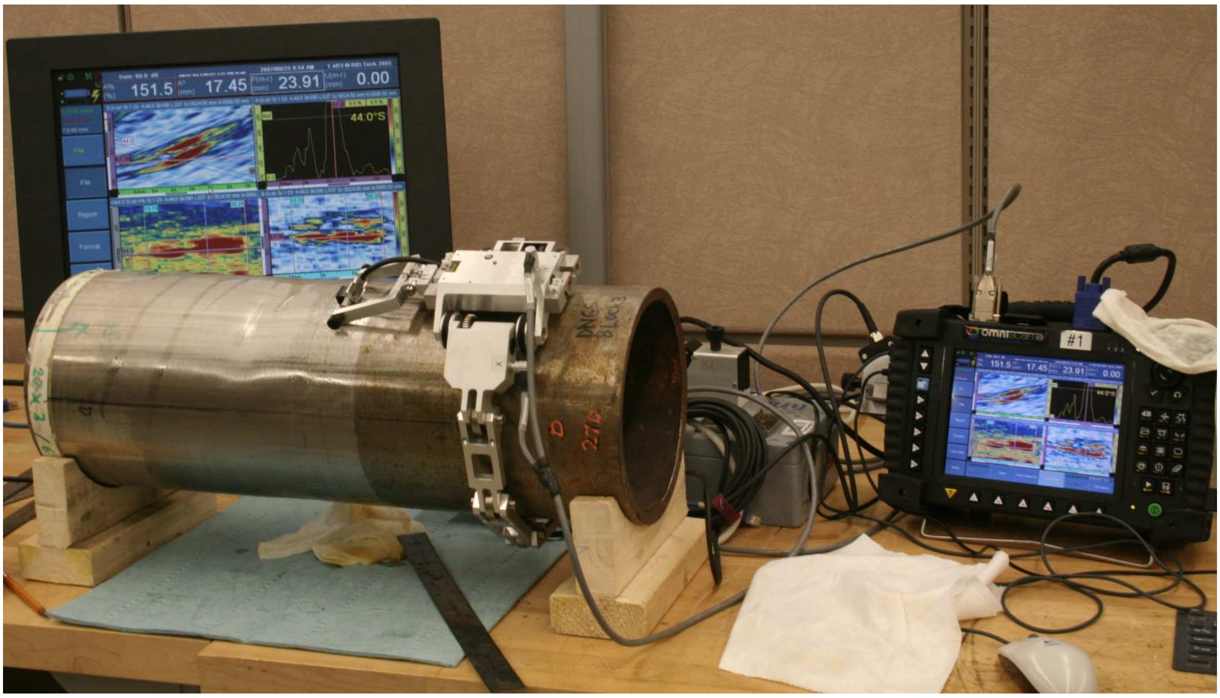


**Figure 3:** Example of experimental set-up for sizing capability on dissimilar piping weld mock-up DNGS BLOCK #3.

Three files were acquired for each probe/defect configuration. Files were analyzed either with OMNISCAN software and/or converted for analysis with Ultra vision and/ or Tom view software.

**Data analysis**

Sizing capability was performed for height, length and ligament (inner and outer).

The flaw ***length*** is oversized by 2 mm (see Figure 4). Some flaws were oversized by 3 to 6 mm. Implanted defects presented satellites defects, which may affect the designed flaw length and height. The length accuracy provided by PAUT is on order of magnitude less than AMSE XI acceptance tolerance for performance demonstration ($RMS_{Length\ ASME\ XI}$ = ± 19 mm) (ref.4).

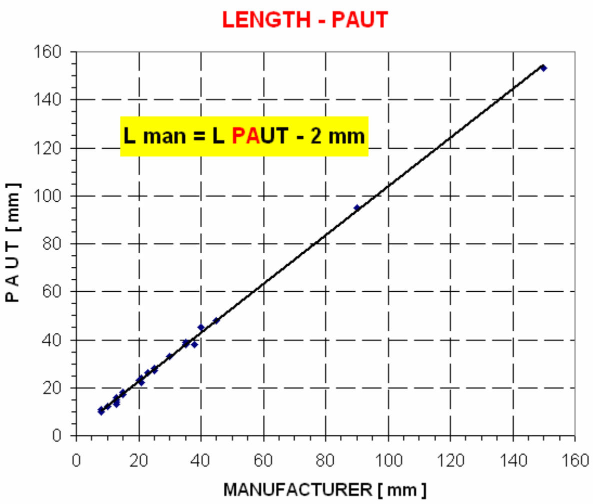


**Figure 4:** Correlation between manufacturer and PAUT for flaw length.

The flaw ***height*** measured by PAUT has an under-sizing trend of 0.2 to 0.5 mm (see Figure 5).

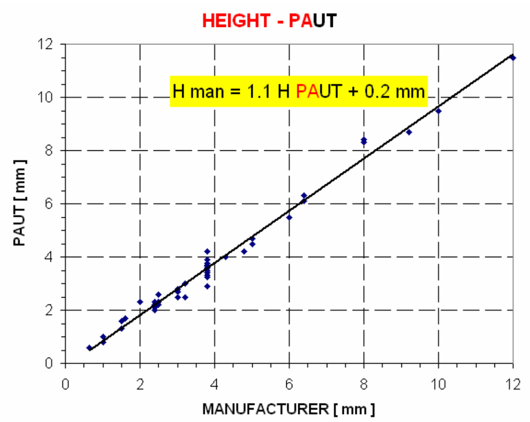


**Figure 5**: Correlation between manufacturer and PAUT for flaw height.

The height error evaluated by PAUT is an order of magnitude less than the ASME XI tolerances for performance demonstration (RMS $_{\text{height ASME XI}}$ = ± 3.2 mm).

Height measurement for side-wall lack of fusion depends on probe index (angle). Sizing is unreliable when the beam is reaching secular reflection (angles > 52°-see Figure 6).

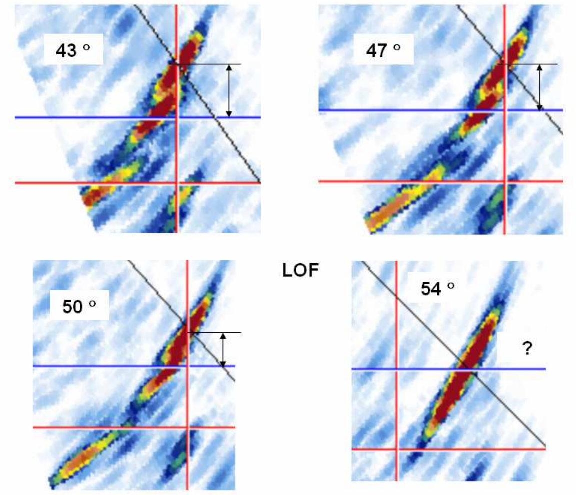


**Figure 6:** Example of the influence of detection angle on LOF sizing capability (one-side examination).

The flaw ***ligament*** was evaluated for different probe index positions, depending on weld crown status (as welded, flush, overlaid). Figure 7 presents some examples of ligament measurement for different weld flaws (cracks, LOF, slag/porosity).

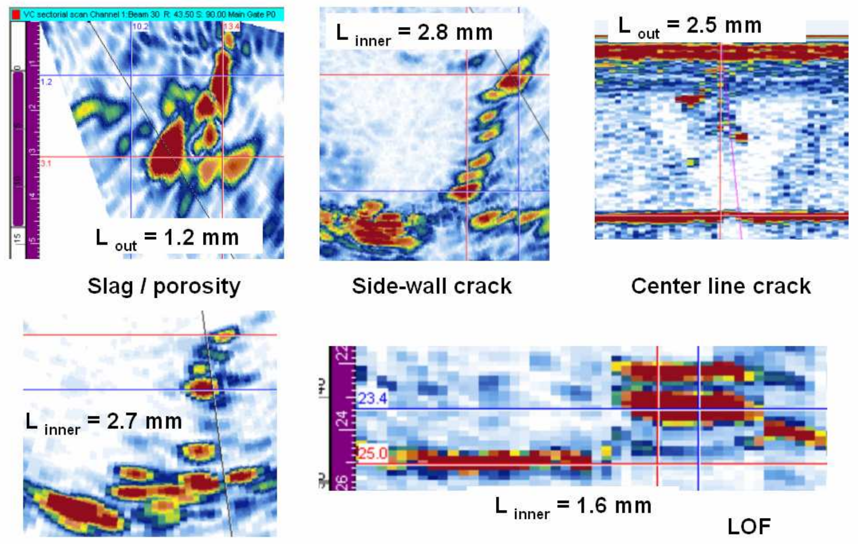


**Figure 7:** Examples of ligament measurement for different weld flaws.

The over-all PAUT performance for ligament evaluation is presented in Figure 8.

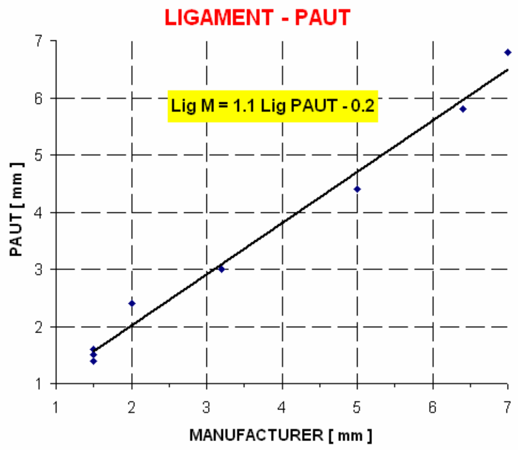


**Figure 8:** Correlation between manufacturer and PAUT for flaw ligament evaluation.

The PAUT capability on weld defects is consistent with our previous data published at the 16th WCNDT-Montreal (ref.5). Flaws located at 1.5 mm near the inner surface or /and below the outer surface could be correctly called as embedded, with an over-sizing trend of 0.3-0.5 mm for the ligament. The PAUT performance is better than ASME XI, when flaws with ligament > 3.2 mm must correctly called as embedded.

## Concluding Remarks

The sizing capability using PAUT concluded:

- Length is oversized by 2 to 6 mm;
- Height is undersized by 0.2 to 0.5 mm
- Ligament is oversized by 0.3-0.6 mm
- Flaws with ligament > 1.5 mm are correctly called as embedded.
- One-side examination LOF sizing is reliable for angles less than 54°.
- PAUT results are comparable to TOFD published results.
- PAUT sizing capability meets ASME XI requirements for performance demonstration.

## Reference:


1. Ciorau, P.: “A Contribution to Phased Array Ultrasonic Inspection of Welds Part 1: Data Plotting for S- and B-Scan Displays” in ndt.net, vol.12, no.6 (June 2007), *CINDE Journal*-vol.28, no 5 (Sep/Oct 2007), pp.7-10.
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4. ASME XI-Appendix VIII: Performance Demonstration for Ultrasonic Examination Systems-July 2007
5. Ciorau, P.:" Contribution to Detection and Sizing Linear Defects by Conventional and Phased Array Ultrasonic Techniques" – Proceedings of the 16th WCNDT-Montreal, Aug.30-Sep.03, 2004.

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