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1.7 Full Field AUT Trials

In order to access current capabilities of both multi-probe and PA AUT systems, the two systems were evaluated in artic and tropical field inspection conditions. Later, some of the welds were also studied in a lab environment using PA AUT to determine its capabilities under nearly ideal conditions.

1.7.1 TransCanada Arctic Field Trial

With the cooperation of Trans Canada Pipeline and two AUT companies, a field trial was conducted in January 2004 in Alberta, Canada with an average temperature of approximately -20°C or -4°F. The purpose of the field trial was to compare inspection results between PA UT and multi-probe UT on the same welds under realistic conditions. AUT inspections were performed using both UT test systems on 250 girth welds on pipe having 610-mm (24-in.) diameter with a 7.8-mm (0.31-in.) wall thickness. The weld prep was a V-groove bevel having a 60-degree included angle. The welds were actual field welds and did not have any intentional flaws. Each system was operated independently by different AUT inspection teams.

Both AUT inspections used the zonal approach described in ASTM E1961 and were very similar regarding calibration procedures and beam angles used for each zone. In fact, the same beam angles were used for the various weld zones, and both inspections used P/E techniques for everything except the TOFD scans and the transverse flaw-detection scans. The test frequencies were slightly different, but all were in the range of 4.0 to 7.5 MHz. The only major differences were that one inspection used linear PA probes which allowed focusing in the active plane, and the other inspection used round unfocussed probes.

During the weld scans, data was fed to the computer in the truck and was viewed in real time. After the scan, a more detailed data evaluation could be performed if suspect areas were found. Software tools allowed the imaged indications to be measured to determine acceptance. The welds were inspected using a typical pipeline code which required that flaws exceeding 40% screen amplitude were reportable if the length exceeded a specified dimension. The acceptable flaw length requirements varied depending on whether the flaw was a surface-breaking flaw or an internal flaw.

A calibration standard was located on the truck and was checked frequently. The calibration standard included FBHs and notches for calibrating the various inspection zones. The calibration standard used was in accordance with the requirements of ASTM E1961 which describes the calibration procedure for zonal weld inspection. While initial calibration can take several hours, the periodic calibration checks were performed in less than a minute. The calibration scan was immediately checked by the operator in the truck to verify that the test setup was still valid.

The inspection cycle for each weld consists of:

- First step is attaching the band. This is a critical step because the position of the band determines the location of the probes. If the band is not located correctly within 1 mm or so, the sound beam generated by the probes could miss their target zones. Great care is taken to make sure the band is in the correct location around the entire pipe circumference. After adjustments are made, the band is secured.

- Then the scanner is attached to the band and manually positioned at the zero reference location on the top of the pipe.

- During the scan the scanner travels one full revolution plus an overlap distance. A pan is used to collect the couplant for environmental reasons and for reuse. The couplant used for cold weather applications usually consists of water and an additive to prevent freezing.

- After the scan is complete, the scanner and band are removed from the pipe and the crew moves on to the next weld. This inspection sequence is repeated for each weld.

The multi-probe technique shown here was performed in much the same manner as the PA technique. The one obvious difference is the physical size of the scanner needed to carry the increased number of probes.

As with the PA inspection, the band was attached, adjusted, and secured. The scanner was then mounted to the band and the scan was performed. The band was removed and the crew moved on to the next weld.

Data evaluation for the multi-probe technique was very similar to that used for the PA technique.

During the scans, one weld was found to have a crack indication and was removed. Both the PA and multi-probe AUT systems detected this flaw and correctly identified it as a crack.

Acceptance criteria for these welds were based solely on flaw length and are summarized in Table 1.7.1-1. The multi-probe inspection identified one weld, ML-0131, as rejectable due to a crack indication. The PA inspection identified eight welds as being rejectable, including weld ML-0131. The multi-probe data was later analyzed by a third party to look at the welds that contained rejectable indications found during the PA inspection. The data revealed that flaw lengths measured during the PA inspection were generally longer than those measured during the multi-probe inspection. This caused some flaws to fall into the rejectable category based on measurements greater than 12 mm (0.5 in.) for surface flaws. A comparison of the PA and multi-probe flaw measurements is shown in Table 1.7.1-2.

Table 1.7.1-1. Summary of Acceptance Criteria

Flaw	Length (mm)	
	Individual	Cumulative
Cracks	None allowed	
Root or Cap Bead Flaws	<=50mm	<=50mm in 300mm
Internal	12mm	25mm in 300mm

Table 1.7.1-2. Summary of UT Indications Found by Both AUT Inspections

Weld Number	Defect Type	Length (mm)		Height (mm)		Comments
		PA	Multi Probe*	PA	Multi Probe*	
ML-0076	IF Root Surface	14	4 + 12	1.2	0.2-1.0	Multi probe showed 2 flaws end to end
ML-0126	IF Root Surface	21	4	1.2	0.5-0.7	
ML-0131	IF Root Surface	47	65	3.2	2.0-2.5	Identified as crack by both inspections
ML-0133	IF	Accumulation	NR	Accumulation	NR	Multi probe showed amplitudes <40% FSH
ML-0135	IF Root Surface	16	5 + 6	1.2	1.2	Multi probe showed 2 flaws end to end
ML-0194	IF Root Surface	18	11	1.2	3.3	
ML-0200	IF Root Surface	24	23	4.0	0.7-1.0	
ML-0245	IF Root Surface	16	11	1.2	0.5-0.7	
ML-0245	IF Root Surface	13	10	1.2	0.5-0.7	

* Multi probe sizing information was not provided by AUT vendor.
Sizing was performed by third party using AUT data files.

1.7.2 McDermott Tropical Field Trial and Round Robin

After completing the cold-weather trials, the next phase of the project was to perform warm weather trials on a pipe laying barge in Batam, Indonesia during the month of August 2004. An AUT round robin was conducted at the McDermott facility in Batam, Indonesia to evaluate multi- and PA probe techniques for inspection of pipe girth welds under actual field conditions. Again, both PA and multi-probe techniques were evaluated. During this trial additional data was gathered to evaluate the performance of AUT instrumentation in close proximity to welding torches.

In addition, to the electrical noise tests, the welds were also scanned before and after heating to determine the effects of temperature on the test results. The welds were heated to temperatures up to 90°C (194°F) prior to scanning. Overall, no adverse effects were noted from the noise level tests or the elevated temperature tests.

The welds were scanned using the zonal approach that was used for the Canadian trials. Attachment of the weld band and scanner as well as data acquisition and evaluation were similar. During these trials, the welds were scanned using two separate PA inspection systems and three multi-probe systems. The work was performed under the leadership of McDermott's QA/QC department. The pipe was 601-mm (24-in.) diameter with a 13.8-mm (0.54-in.) wall thickness. Four AUT inspection companies participated in the round robin. One company, using the same technicians, inspected the welds using both PA and multi-probe. Of the remaining three companies, one used PA and the other two used multi-probe. This resulted in a total of five unique AUT inspections being performed on each weld. While both PA and multi-probe techniques were used, all inspections were performed using the zonal AUT approach similar to what is described in ASTM E1961.

All AUT inspections used the same calibration reference standards for establishing test sensitivity and flaw position (distance) calibration. Here, the calibration sample is scanned similar to before except that calibration scans were performed with the scanner at the top, as well as, with the scanner on the bottom of the sample. This was done to check for scan variations due to gravity effects.

While the test sensitivity and distance calibration for each inspection was similar, no detection and rejection criteria were established for this round robin. AUT inspectors were asked to report and size all indications using detection levels and sizing techniques that they would typically use for detecting and sizing critical flaws in girth welds. This permitted each inspection to be unique and allowed the freedom to use detection and sizing techniques that were historically accurate based on the inspector's experience. A total of four welds were inspected by the five AUT inspections while full-scale welding operations were being performed nearby. Close proximity to welding operations was desirable in order to evaluate the susceptibility of the AUT systems to realistic field conditions such as electrical background noise, heat, and humidity (Figure 1.7.2-1).

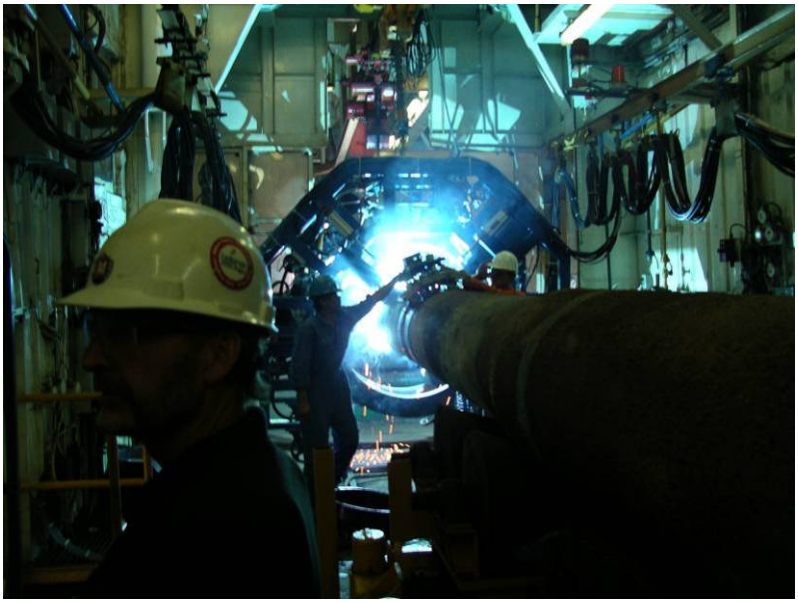

Figure 1.7.2-1. Batam Round-Robin AUT Field Trials

Of the four welds inspected two welds, Welds 3 and 4, were subjected to further evaluation. Weld 3 was cross sectioned at locations where flaws were identified by the different AUT inspections. Weld 4 was scanned by EWI using two different PA techniques and subsequently cross sectioned at selected locations.

Weld 3 was cross sectioned by a vendor chosen by McDermott. A total of eight locations, containing flaws detected by AUT during the round-robin inspection, were selected for destructive evaluation. The eight flaw locations were identified as Sections 1 through 8. After a section was extracted from the pipe, it was further cross sectioned, typically at 1- to 2-mm (0.04- to 0.08-in.) intervals, in a “salami-slicing” fashion to reveal the extent of the weld flaw(s). The maximum flaw height was measured by EWI for each section using metallographic images. These metallographic measurements were then compared to flaw heights reported during the different AUT inspections. For flaws extending through multiple zones, this required that the flaw height in adjacent flaw zones be summed together in order to determine the total UT measured flaw height. This assumed that it was the same flaw extending from one zone to the next.

The UT measured flaw height for each AUT inspection was compared to the flaw height measured from metallographic cross sectioning and is shown in Table 1.7.2-1 and Figure 1.7.2-2. The comparisons in Table 1.7.2-1 show that no particular inspection was definitively better than another; or that any UT technique was better than another. For example, all AUT Inspections greatly undersized the flaw at Location 238, however. PA Inspection 1 performed

the worst on this particular flaw while PA Inspection 2 performed the best. Likewise, Multi-Probe Inspection 1 was very accurate on Location 380, while Multi-Probe Inspection 3 oversized the same flaw. When comparing different techniques, Multi-Probe Inspection 1 was very precise at Location 764, but PA Inspection 3 oversized the flaw height by nearly 2 mm.

Table 1.7.2-1. Batam Weld 3; Comparison of AUT Data and Destructive Data

Section No.	Location (mm)	Metallography Flaw Hgt. (mm)	Field AUT #1		Field AUT #2	Field AUT #3	Field AUT #4	Comments
			PA	Multi-Probe	PA	Multi-Probe	Multi-Probe	
1	238	7.5	1.7	1.8	5.5	2.7	NR	LOF; lack of penetration
2	380	1.9	1.2	1.9	3.3	3.7	---	slag inclusion
3	426	2.1	2.7	0.5	1.5	1.5	---	lack of penetration
4	764	4.5	2.7	4.5	6.3	5.5	---	slag, porosity, LOF
5	1045	1.0	0.9	0.6	1.1	1.5	---	lack of penetration
6	1355	0.5	1.0	0.8	2.6	NR	NR	slag inclusion
7	1675	1.9	Geometry	Geometry	NR	NR	---	mismatch (hi/lo)
8	1895-1905	8.8	7.3	6.9	5.4	8.6	---	side wall LOF; lack of penetration

NOTES: 1. NR = not recorded
2. Inspection #2 reported total height of all flaws combined
3. Inspection #4 did not report flaw height
4. Metallography flaw hgt. for Section No.8 determined by combining results from Location 1895 and 1905

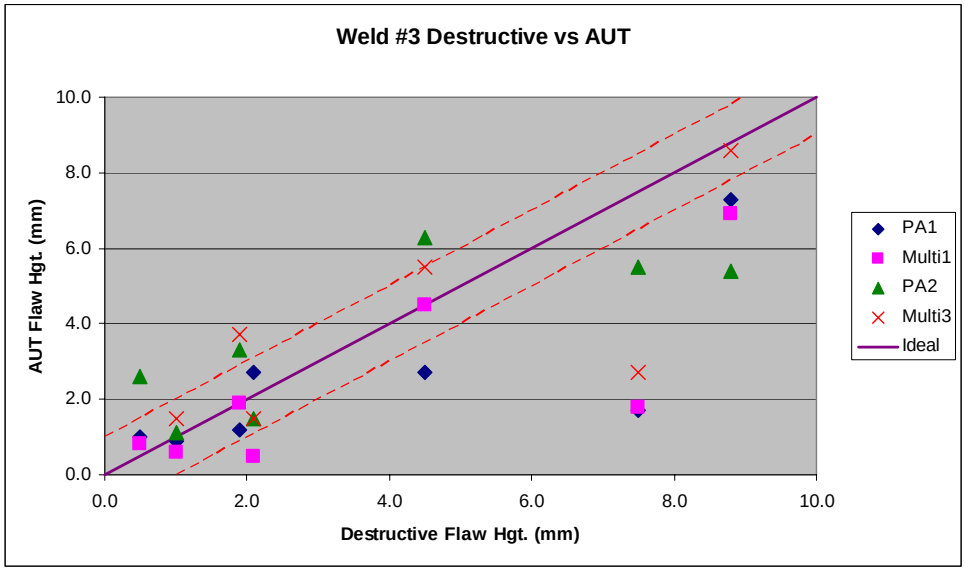

Figure 1.7.2-2. Weld 3, AUT Flaw Height versus Destructive Flaw Height

Other comparisons and conclusions can be made from the data, but overall, none of the AUT Inspections were significantly better or worse than another. All AUT Inspections oversized and undersized flaws to about the same degree. The major difference was that Multi-Probe Inspection 4 did not report flaws at Locations 238 and 1355, and Multi-Probe Inspection 3 did not report a flaw at Location 1355. Another observation was that the 1.9 mm high/low condition at Location 1675 was reported as geometry by PA 1 and Multi-Probe 1 and was not reported by PA 2 and Multi-Probe 3.

Overall, results from Weld 3 showed that flaws having large through-wall heights were generally undersized by both multi probe and PA when using the zonal approach.

EWI Lab Evaluation of Batam Weld 4

Following the round-robin field inspections in Indonesia, Weld 4 was cut from the pipe and shipped to EWI for further AUT evaluation in the lab, followed by metallographic cross sectioning. During the lab AUT, EWI concentrated on non-zonal PA inspection techniques nearly identical to those used during the field testing but using electronic steering, focusing and scanning features of PA. It should be noted that the techniques were very similar to those used in field tests; however, they were not identical due to variations in equipment and proprietary restrictions. The purpose of the evaluation was to gather additional PA AUT information from the flaws in Weld 4 and to determine what could be done to improve PA detection and sizing capabilities for fabrication flaws.

Upon receipt of the weld, EWI scanned Weld 4 from both the US and DS sides using PA 4- and PA 7.5-MHz PA probes. Scan data labeled US means that the probe was located on the US side of the weld, while DS means the probe was located on the DS side of the weld. This data file naming convention was used by EWI throughout the project. Technique parameters for both PA techniques were as follows:

	Lab PA 4-MHz Probe	**Lab PA 7.5-MHz Probe**
Wedge Angle (degrees)	34	33.7
Total No. of Elements	64	60
Aperture (mm)	17.9	16.0
No. of Active Elements	21	16
Starting Element No.	44	45
Focal Depth (mm)	20	20
Sector Sweep (degrees)	45 to 70	45 to 70
Sweep Angle Increment (degrees)	1	1
Calibration Gain (dB)	30	36
Scanning Gain (dB)	36	46

The reference calibration gain for both probes was established using a 25.4-mm-deep SDH having a 1.2-mm diameter Using a refracted shear wave angle of 53 degrees the gain was adjusted to produce an amplitude of 80% of FSH from the calibration hole. Scanning gain for the PA 4-MHz probe was 6 dB above the calibration gain. Scanning gain for the PA 7.5-MHz probe was 10 dB above the calibration gain. Wedge noise in the PA 4-MHz probe prevented the use of a higher scanning gain.

Lab scans for Weld 4 were accomplished using a raster scan. Scan data was collected at 2.0-mm (0.08-in.) intervals in the scan direction and 4.0-mm (0.16-in.) intervals in the index direction. For all scans the scan direction was parallel to the pipe axis and the index direction was parallel to the weld. There were three important differences between the field scans and the lab scans:

- The use of electronic beam steering from 45 to 70 degrees
- The use of the P/E technique for all zones, including weld bevels
- The use of raster scanning for the lab scans instead of line scanning on needed base.

Data analysis was performed on each scan and the results were compared to data gathered during the field AUT inspections. In general, the EWI evaluation was independent of signal amplitude or flaw dimensions as is typically done for girth weld inspections. The purpose of the EWI evaluation was to detect all significant flaws regardless of whether the flaws were acceptable or rejectable. If an indication was detected, the signal response was observed on a combination of A-, B-, C-, D-, and S-scans to determine if the indication appeared to be a flaw. Indications that appeared to be flaws were sized using the combination of scan displays previously mentioned, with special reliance on the S-scan display which showed the electronic beam steering data.

Following data analysis, locations along the weld were selected for metallographic cross sectioning to determine the extent of AUT flaw indications. Cross-section locations for Weld 4 were selected by one of the AUT inspection companies and by EWI. The AUT inspection company selected eight locations and EWI selected an additional five locations. Cross-section locations included locations where flaws were detected by all inspections, by only a few inspections, and those detected only during the lab AUT. Figure 1.7.2-3 shows a combined D-scan view from the US and DS scans of Weld 4 with metallographic cross-section locations identified. Just prior to metallographic cross sectioning, manual TOFD scans were also performed at three weld areas where cross sections were to be removed. TOFD scan results are shown in Figures 1.7.2-4 through 1.7.2-6. Table 1.7.2-2 and Figure 1.7.2-7 show the results of the AUT inspections and the metallographic measurements.

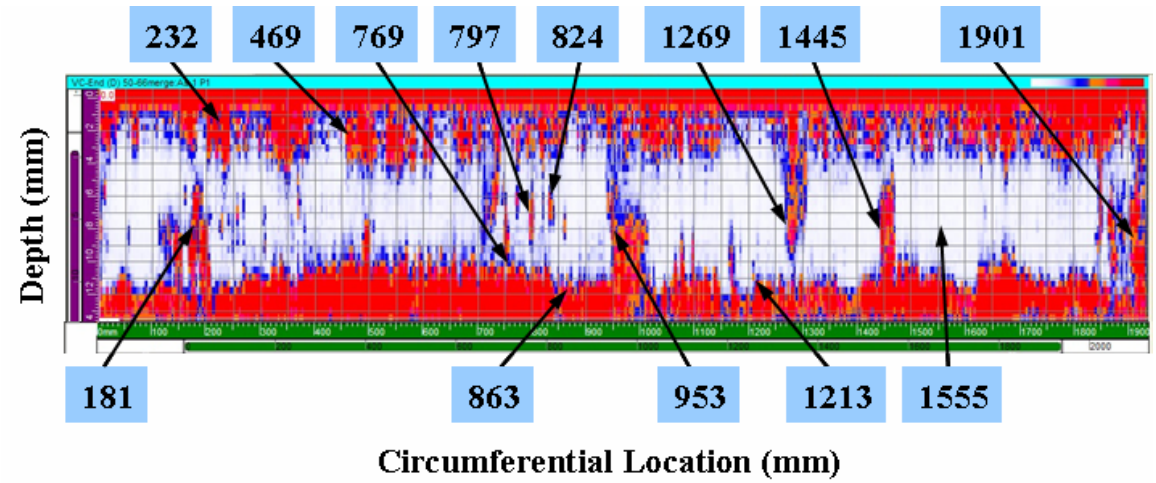

Figure 1.7.2-3. **Weld 4; Combined US and DS D-Scan View from Lab AUT Results Showing Metallographic Cross-Section Locations**

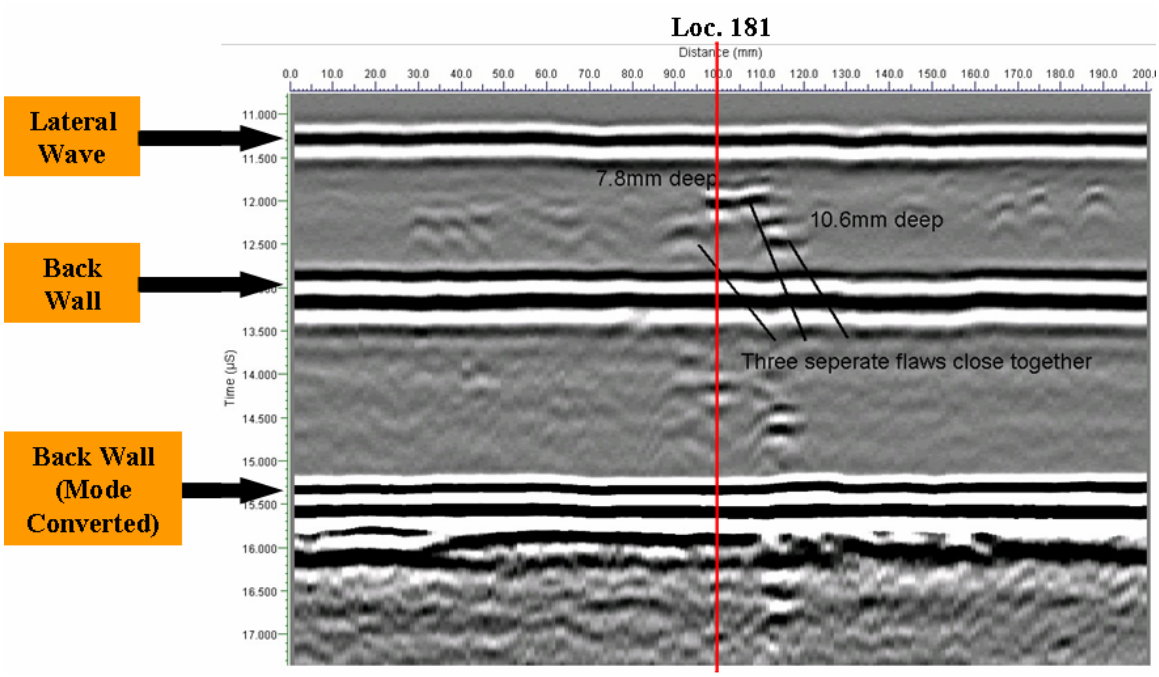

Figure 1.7.2-4. **TOFD Scan of Weld 4, Locations 81 to 281**

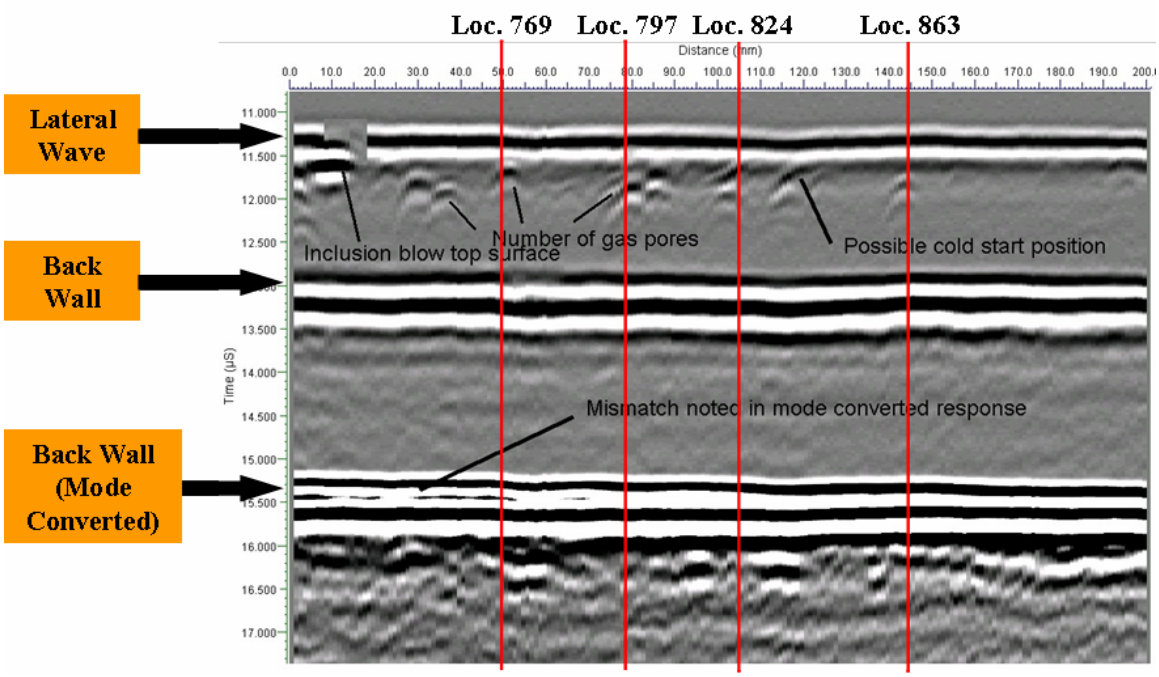

Figure 1.7.2-5. TOFD Scan of Weld 4, Locations 719 to 919

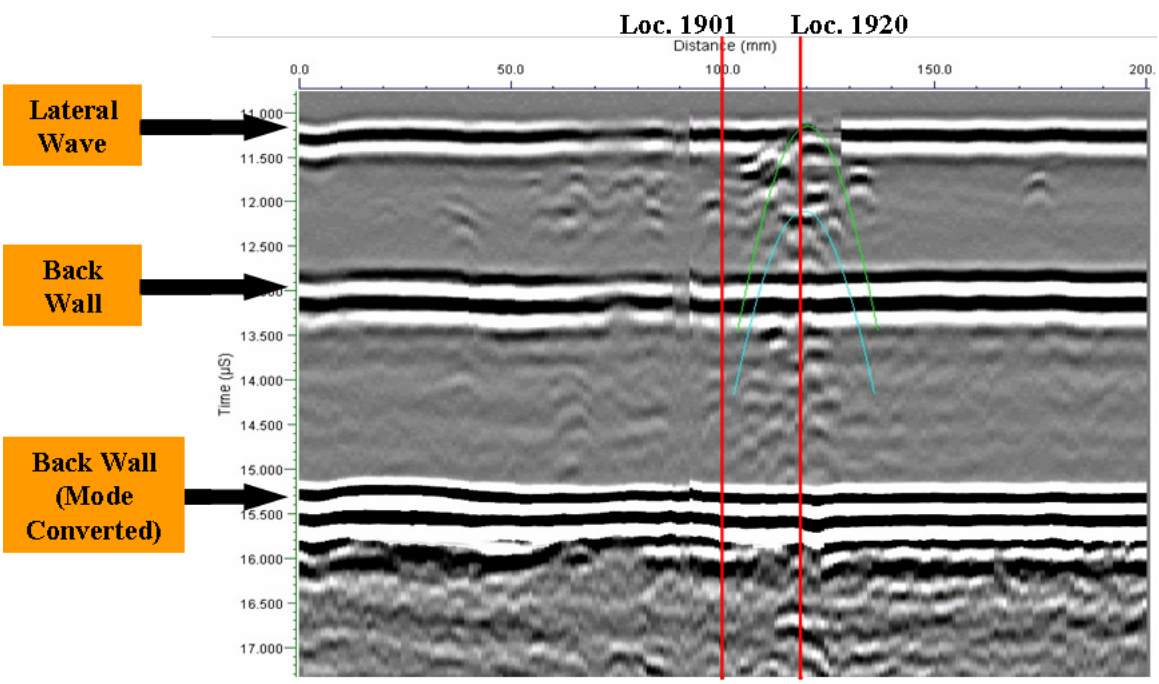

Figure 1.7.2-6. TOFD Scan of Weld 4, Locations 1801 to 85

Table 1.7.2-2. Batam Weld 4; Comparison of AUT Data and Destructive Data

Location (mm)	Metallography Flaw Hgt. (mm)	Lab AUT		Field AUT #1		Field AUT #2	Field AUT #3	Field AUT #4	Comments
		PA-4 MHz	PA-7 MHz	PA	Multi-Probe	PA	Multi-Probe	Multi-Probe	
181	0.5	1.8	2.9	2.1	X	3.7	2.8	X	LOF
232	Surface	3.2	2.9	X	X	X	X	X	Lap at cap
469	Surface	2.5	2.2	0.8	X	X	X	X	Lap at cap
769	1.2	2.2	1.7	2.6	X	X	X	NR	Root
797	1.0	1.8	2.5	X	X	X	X	X	LOF
824	1.0	1.3	1.7	X	X	X	X	X	LOF
863	1.0	1.7	1.0	X	X	X	X	NR	Root
953	2.6	3.4	3.7	3.4	2.3	2.5	4.3	X	LOF
1213	0.5	1.3	1.6	1.4	X	X	X	X	Root
1269	6.6	9.0	7.7	5.0	4.1	6.8	6.3	NR	Por. Cluster
1445	4.8	4.5	4.5	2.5	1.8	7.7	6	X	LOF/Crks
1555	---	No Flaw	No Flaw	No Flaw	No Flaw	No Flaw	No Flaw	No Flaw	No Flaw
1901		12.3	4.8	2.5	2.8	5.5	6.3	NR	LOF

NOTES: 1. NR = not recorded
2. Inspection #2 reported total height of all flaws combined
3. Inspection #4 did not report flaw height

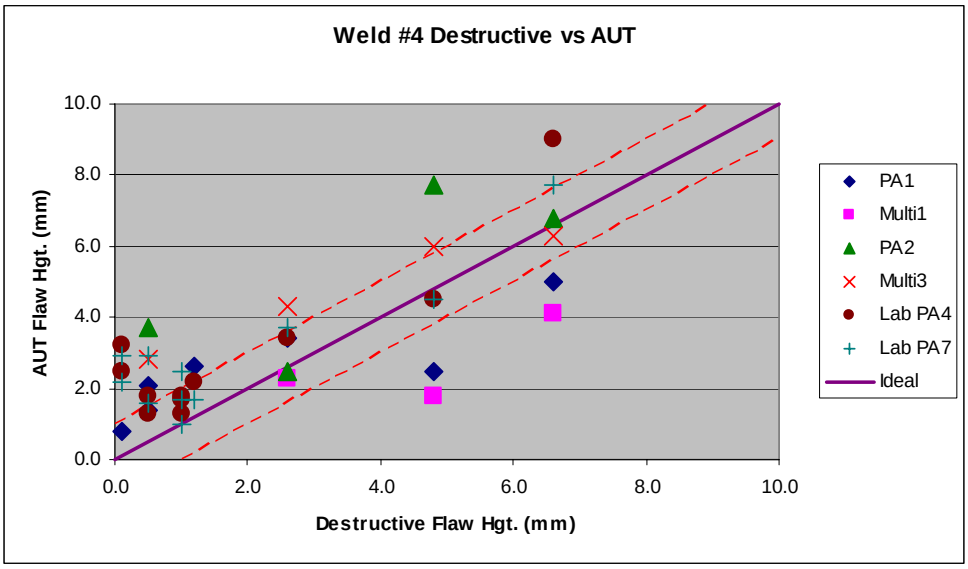

Figure 1.7.2-7. Weld 4, AUT Flaw Height versus Destructive Flaw Height

By reviewing the data in Table 1.7.5-2 it can be seen that there were several flaws marked with "x" that were not reported during the field inspections. Of the flaws that were detected, most were oversized, including those sized during the lab AUT inspection. Of the field inspections, PA 1 performed the best and Multi-Probe 4 performed the worst. Of particular interest was the flaw at Location 1445 shown in Figure 1.7.5-8 and the flaw from Weld 3, Location 238 shown in Figure 1.7.5-9. Both of these flaws are similar in size and shape and both were significantly undersized or completely missed by the majority of the field AUT inspections.

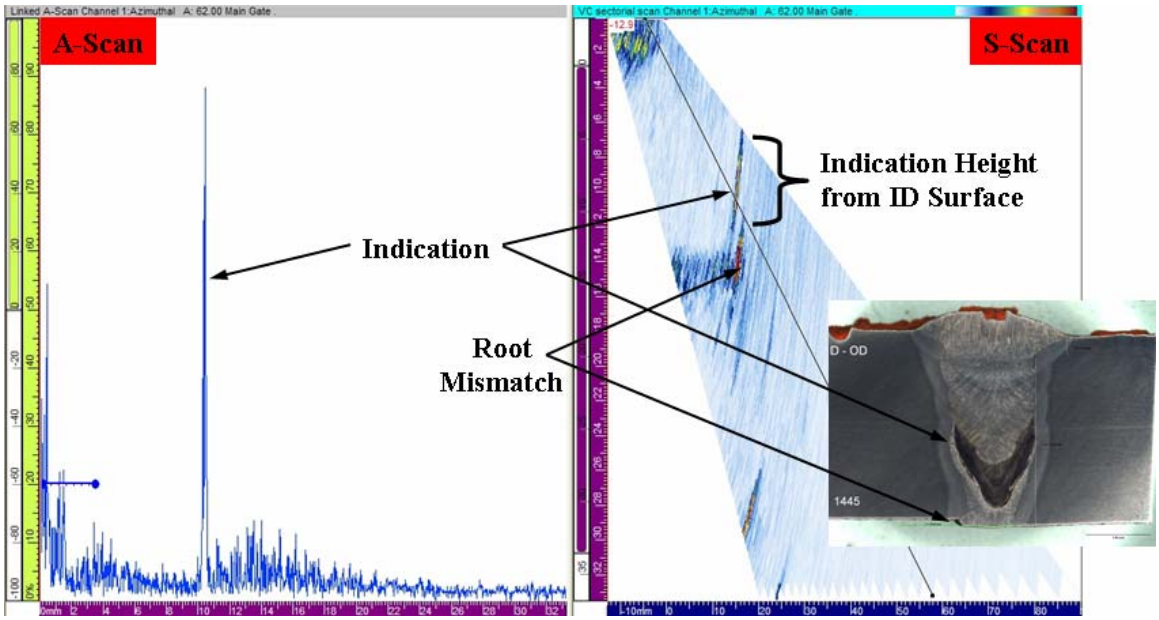

Figure 1.7.2-8. US PA 7-MHz Lab Data from Weld 4, Location 1445

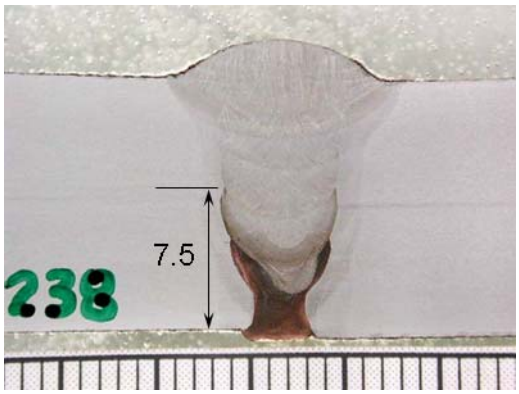

Figure 1.7.2-9. Flaw at Weld 3, Location 238

The data from Welds 3 and 4 show that in nearly all cases flaws greater than 1 mm (0.04 in.) in height were detected; however, the UT flaw height measurements were inconsistent. The data in Figures 1.7.2-2 and 1.7.2-7 shows that flaw height measurements appear more uncertain (more scatter) as flaw height increases. Much of the inconsistency appears to be related to the actual AUT test procedure used. For example, the PA lab scans were done using two different PA techniques, but the calibration target, scanning parameters, and flaw measurement routine were the same. Consequently, with the exception of Location 1901, all the flaw heights for the lab scans were similar even when using probes having different frequencies and element sizes. The field inspections were independent of each other which resulted in the use of slightly different AUT procedures and flaw detection/sizing algorithms.

Manual TOFD scans detected mid-wall flaws very well; however, the root flaw shown in Figure 1.7.2-10 was not detected by TOFD. Metallography showed this flaw to be 1.0 to 1.2 mm (0.039 to 0.047 in.) in height between Locations 769 to 863. The TOFD scan of these weld locations are shown in Figure 1.7.2-5.

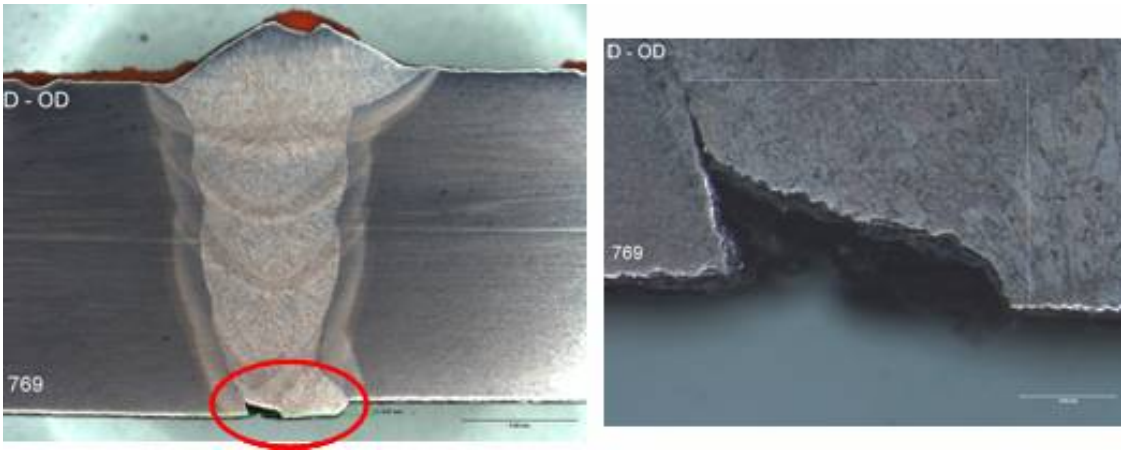

Figure 1.7.2-10. Weld 4 Root Flaw at Location 769

Results from Weld 4 showed that that flaws having large through-wall heights had greater scatter in the data and were both undersized and oversized when using the zonal approach. The lab scans using electronic beam steering and raster scanning detected several flaws that were missed in the field and sized the through-wall height with less scatter. However, flaws having through-wall dimensions less than the beam spot size of approximately 2 mm tended to be oversized.

It was found that the use of S-scans and data merging or data fusion techniques greatly enhanced the ability to interpret, detect and determine the location and size of flaws. For example, the use of a polar view helped to visualize the circumferential locations of flaws and the through-wall extent. It was also found that by merging data from the different beam angles collected, it was possible to get a composite view of the weld. By and large it was found that the detection and sizing performance of non-zonal PA technique using electronic steering, focusing and scanning features of PA linear probes is better compared to the zonal techniques (multi-probe or PA) using only focused beam at fixed angle for each zone. The better performance of non-zonal PA technique is attributed by factors like; the approach is less sensitive to base and weld material type, less sensitive to weld macrostructure, not sensitive to materials thickness, not sensitive to bevel angle and configuration and not sensitive to the tilt of the flaws.

Appendix A1.7.2 and Appendix B1.7.2 contains results of the PA AUT and metallographic results for all flaws detected by PA AUT and later sectioned.