A Comparison of Ultrasonic Flaw Responses as Observed Through Austenitic Stainless Steel Piping Welds

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Outline

- Discuss far-side weld problem and UT techniques applied
- Describe laboratory work on flawed piping specimens using L- and S-waves and provide synopsis of results
- Discuss conclusions for capability of ultrasonic examination as applied to austenitic welds
- Discuss future work

Difficulties with Inspecting Austenitic Stainless Steel Welds

- Far-side austenitic weld inspection techniques continue to be of limited effectiveness due to coarse grain structures
- The large size and orientation of the anisotropic grains in the weld metal scatter and attenuate sound, complicating flaw detection and characterization
- Current U.S. performance demonstration qualifications through PDI are considered ‘best effort”
- This work is being conducted to determine the feasibility of using advanced UT methods to detect and size flaws on the far-side of austenitic welds
  - Outcome is expected to baseline capabilities to support performance qualification

Research Approach

- Evaluate UT techniques on uniformly-welded piping specimens (Part 1)
  - Examine welded specimens with L- and S-waves using multiple angles to detect and characterize flaws through consistent weld microstructures
- Apply best methods to non-uniform welds (Part 2)
  - Observe acoustic responses from far-side reflectors in piping having varied, field-simulated weld parameters
- Correlate acoustic responses as function of weld microstructures
  - Through-weld sound field mapping
  - Optical micrographs of weld cross-sections

Ultrasonic Techniques Applied

- Low-frequency/SAFT
  - 250-450 kHz
- Phased Array
  - 2.0 MHz
- Automated conventional UT
  - 1.5 MHz and 2.25 MHz

Low-frequency/SAFT

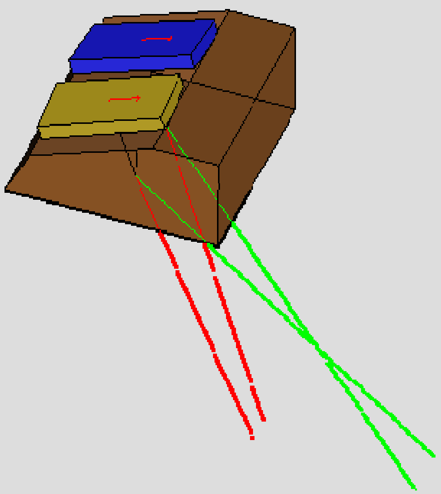
- Range of frequencies between 250-450 kHz
- Raster scanning, digital data storage
- Data post-processed using Synthetic Aperture Focusing Technique (SAFT)
  - Full-volume, 3D SAFT reconstructions at varied beam angles between 6° and 24°

Phased Array

- Tomoscan III®, 32/64 channel instrument
- Data acquired and viewed in Tomoview®, version 2.2R9
- Line scans performed parallel to weld at varied distances from weld centerline
- Steered angles from 30° to 70°, at 1° increments
  - No beam skewing performed

Transmit-Receive Phased Arrays Applied

- Longitudinal Wave Probe
  - 2 x 2 x 14 elements, aperture of 20mm (active) by 10mm (passive)
  - 2.0 MHz - 70% bandwidth
  - Wedge angle for a nominal 50° L-wave (SS)
  - Roof and squint angles to produce 20mm crossover depth (SS)
- Shear Wave Probe
  - 2 x 1 x 12 elements, aperture of 32mm (active) by 12mm (passive)
  - 2.0 MHz - 70% bandwidth
  - 55 nominal shear wave (SS)
  - Roof and squint angles to produce 36mm crossover depth (SS)



Conventional Technique

- Automated raster scanning and digital data storage
  - Allowed off-line analyses and imaging
- 1.5 and 2.25 MHz transducers
  - Both 9.5mm and 12.7mm diameter search units were applied for each frequency
  - Wedges to produce 60° and 70° shear waves
- Conventional transducers used as benchmark for comparing results
  - Probes match those used for manual austenitic piping weld qualifications

Initial Specimen

- Uniformly-welded pipe specimens with implanted thermal fatigue cracks and machined reflectors

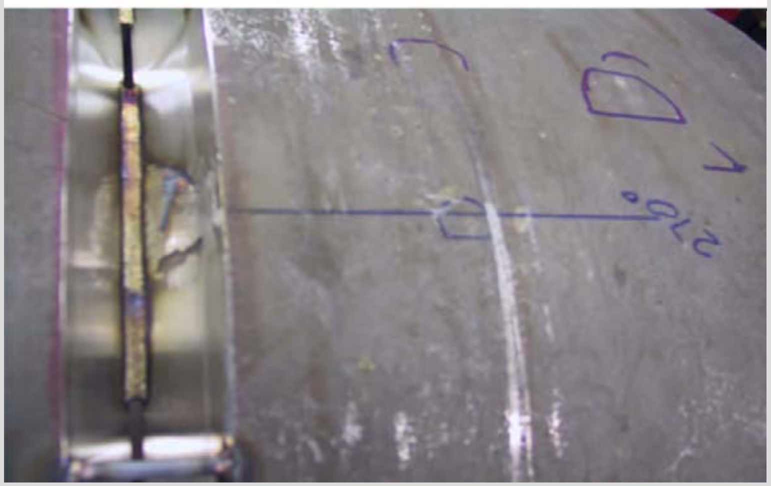
Vintage 304-L stainless, thermal fatigue flaws

Flaw Designation	A	B	C	D	E
Flaw Orientation	Circ.	Circ.	Circ.	Axial	Circ.
Flaw Length [±1.0-mm]	10.7 mm	30.5 mm	43.6 mm	13.3 mm	33.8 mm
Through-wall Depth [±1.0 mm]	5.0 mm	14.9 mm	21.5 mm	6.6 mm	16.5 mm
% Wall Thickness	15	43	64	19	48
Aspect Ratio	2.3	2.1	2.1	2.1	2.1
Circumferential Location (from 0°)	30°	65°	165°	270°	330°

Saw-cuts added for consistent UT reflectors

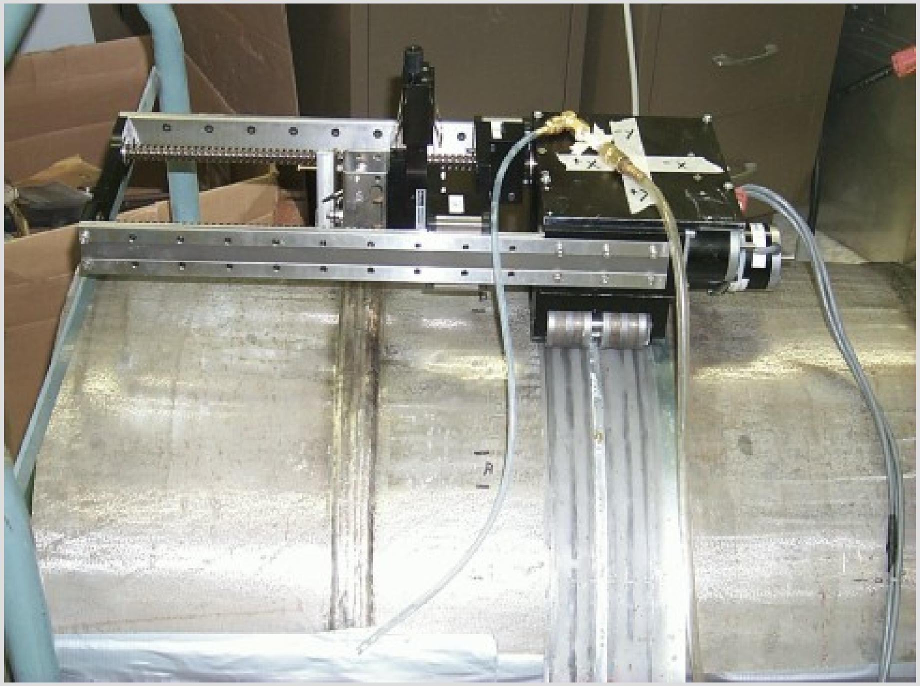
Designation	A	B	C	D	E	F	G	H
Angle to Surface	90°	90°	35°	90°	90°	35°	35°	35°
Length [±0.4mm]	32.8 mm	65.2 mm	36.2 mm	54.1 mm	43.7 mm	59.7 mm	57.3 mm	68.4 mm
Depth [±0.4mm]	2.7 mm	10.2 mm	2.5 mm	6.8 mm	4.3 mm	7.0 mm	6.3 mm	9.3 mm
% Wall	7.5	28.4	7.1	18.8	12	19	18	26
Aspect Ratio	12	6	15	8	10.2	8.5	9.1	7.4
Location	22.5°	45°	85°	150°	185°	210°	285°	310°

Initial Specimen (Cont'd.)



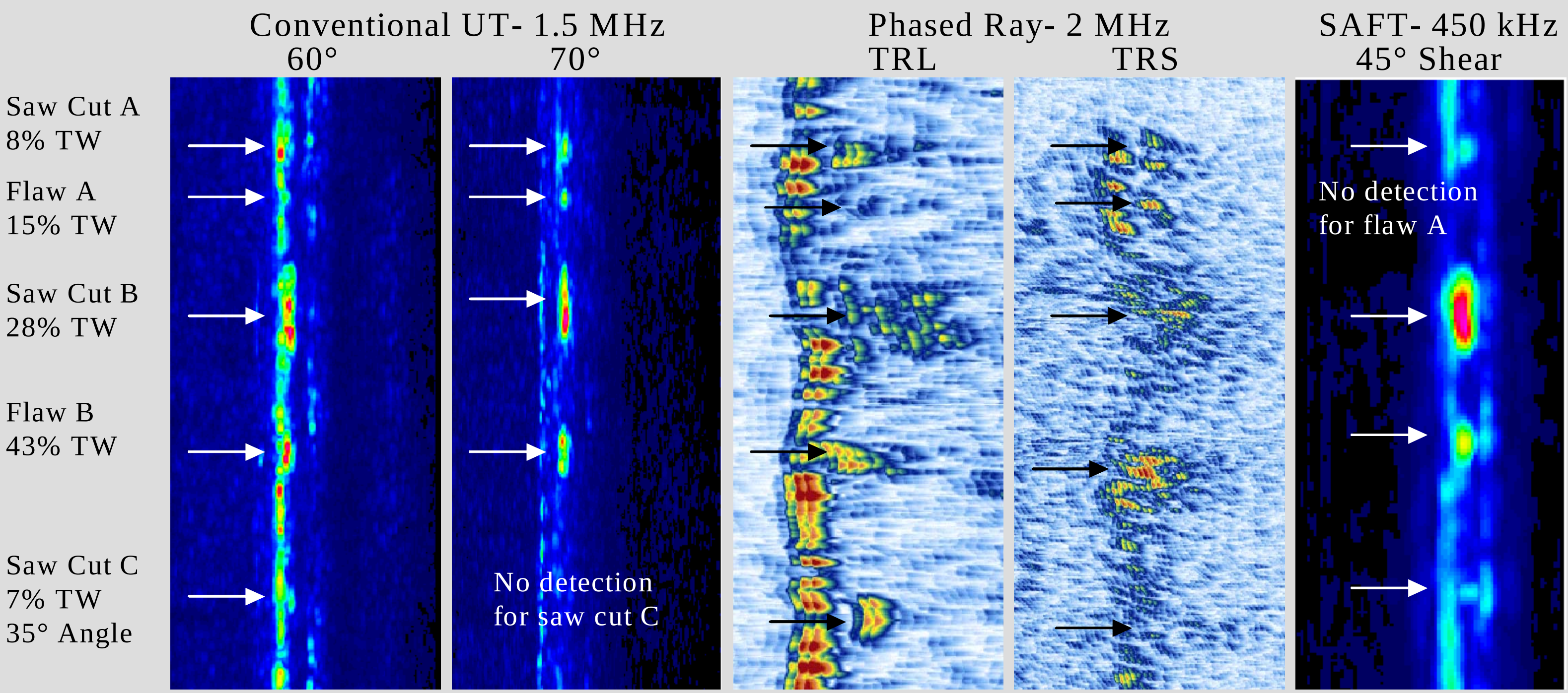
Initial Specimen Scans

Initial specimen was sectioned into 3 segments and UT scans acquired with magnetic track scanner; water-coupled



Part 1 Results

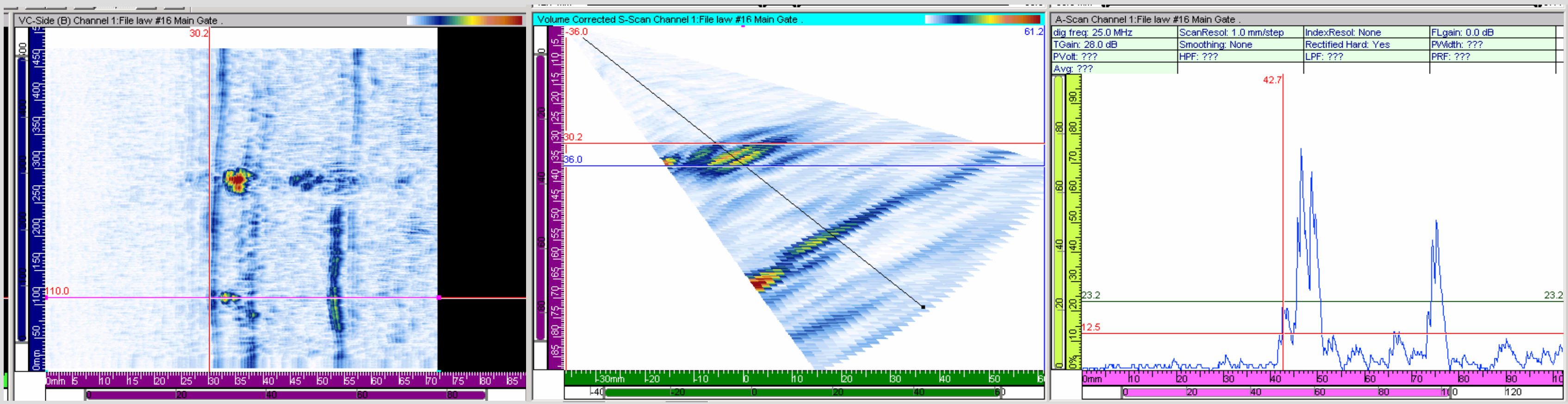
- All UT methods detected most flaws, but phased array out-performed all methods for shallow through-wall flaw detections



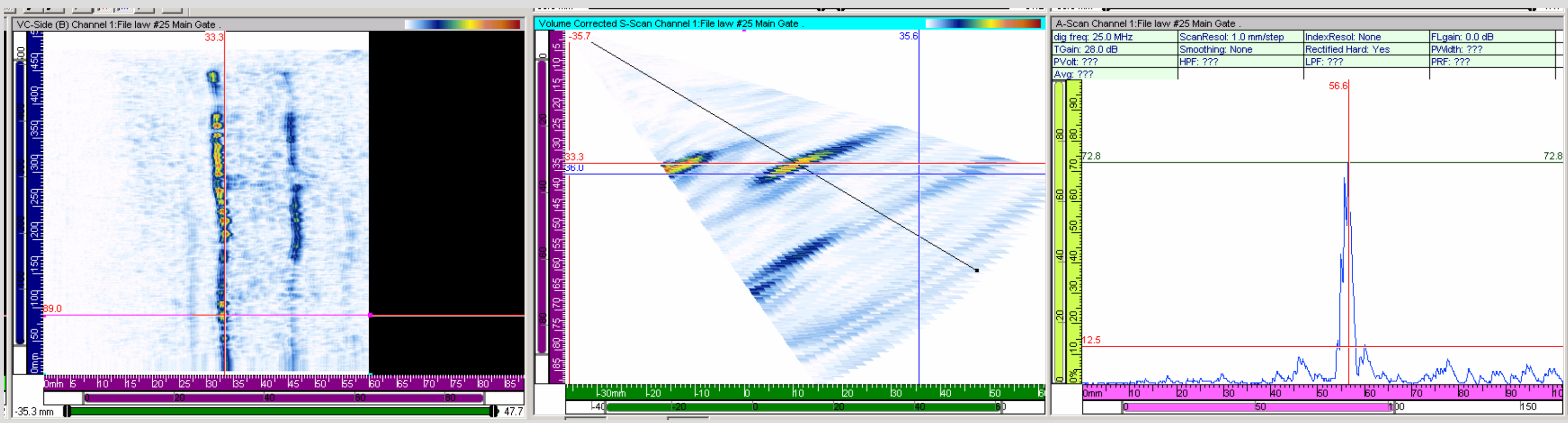
Comparison of typical responses from automated conventional UT, Phased array, and low-frequency SAFT; note TRL phased array showed best overall performance.

PA Response for Small Flaw - TRL

Near-side response for Flaw A - 15% through-wall

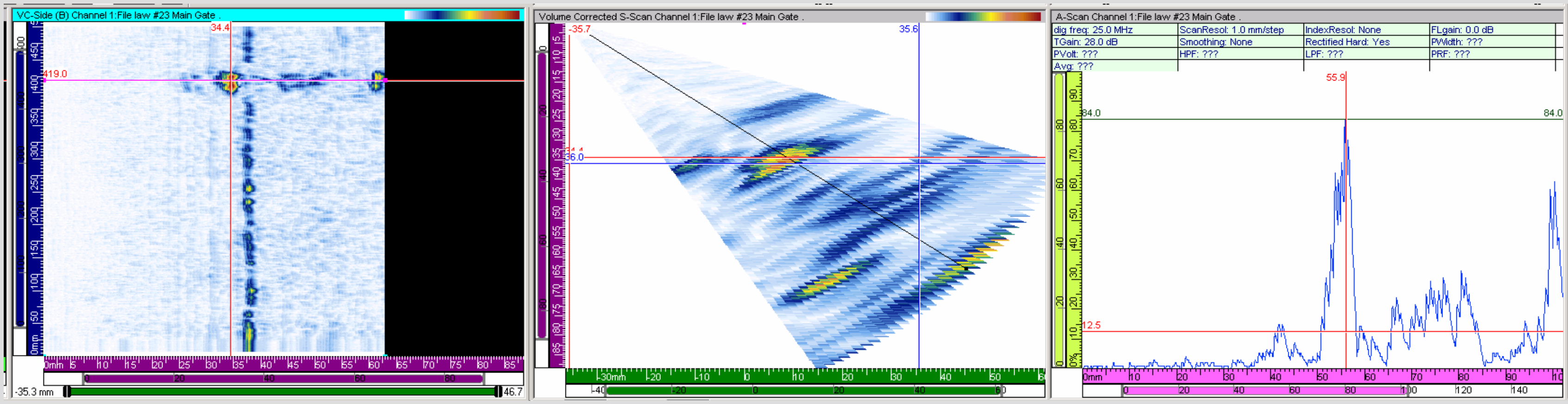


Far-side response for Flaw A – no tip diffracted signal

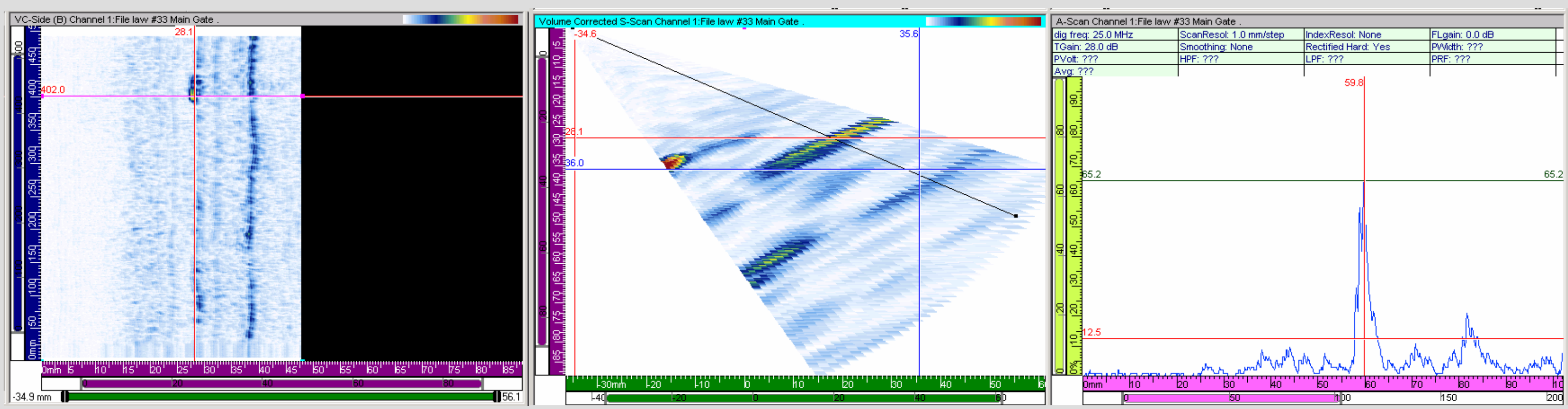


PA Response for Large Flaw - TRL

Near-side response for Flaw E - 48% through-wall

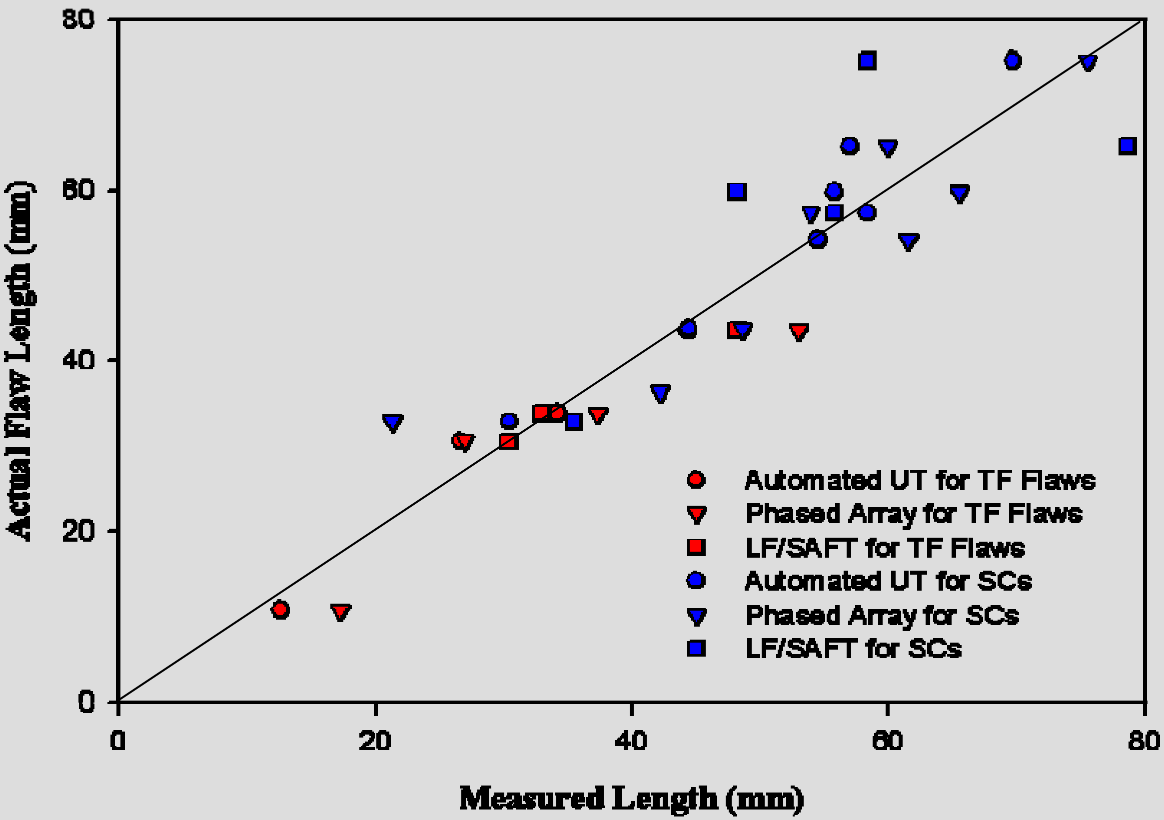


Far-side response for Flaw E



Length-sizing of Flaws

- All UT techniques were capable of adequately length-sizing flaws on the far-side of austenitic welds; no TOF depth sizing possible



TF = Thermal fatigue crack

SC = saw-cut

Length-sizing (Cont'd.)

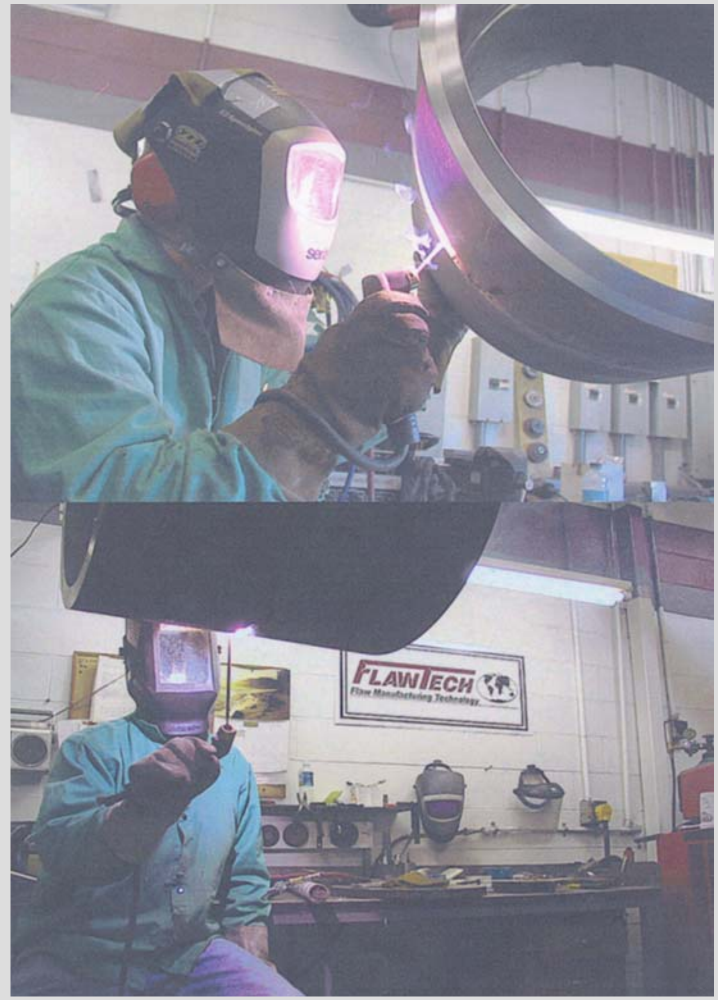
Far-Side Length-Sizing Results for All Ultrasonic Methods				
Thermal Fatigue (RMS Error)	Best Technique		Saw-Cuts (RMS Error)	Best Technique
Conventional	2.2-mm	70° -6dB	4.0-mm	70° LOS
LF/SAFT	3.4-mm	400 kHz, 45° Shear LOS	9.2-mm	400 kHz, 45° Longitudinal -6dB
Phased Array	6.3-mm (Note 1)	TRL LOS	6.3-mm	TRL LOS
Note: For very small thermal fatigue cracks (<10% thru-wall), the TRS -6dB technique was better with an RMS Error of 8.9-mm.				

RMS error for LOS and -6dB methods were well within ASME Code Appendix VIII requirements (19 mm)

Field-Welded Specimen

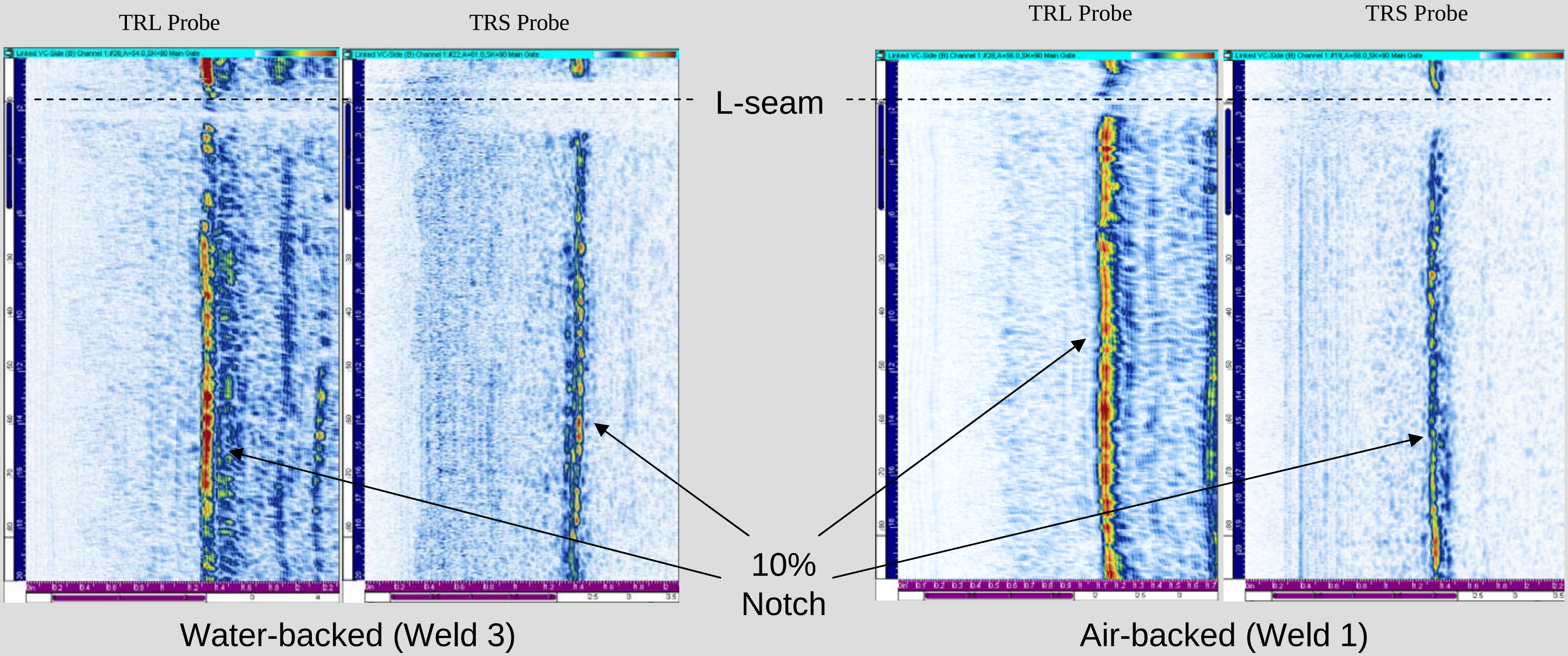
- Contains 3 field-like welds, all with circumferential 10%, 360° notches in HAZ:
  - Vintage 304-L austenitic stainless steel
  - All welds performed in position
    - Weld 1 – horizontal; air-backed
    - Weld 2 – vertical; air-backed
    - Weld 3 – horizontal; water-backed
  - 3 small (5, 10 and 15%) flaws also implanted on Weld 2

Simulating Field Welds



PA Results on Field-Like Welds

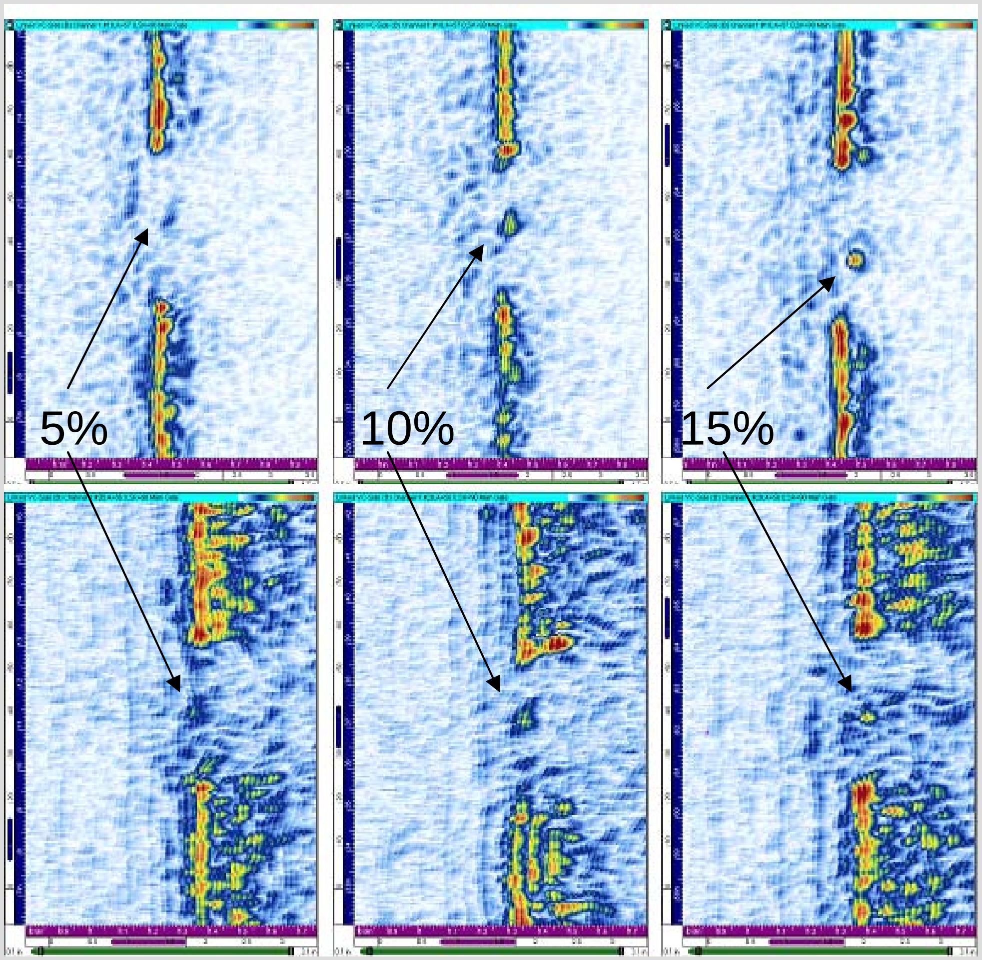
- 10% notch shows short-range variability, but no regional areas of weld with significantly decreased response
- TRL has better S/N; TRS signals more temporally discrete



Field-Like Weld Results (con't)

TRL

TRS



- Responses for small implanted TF cracks from far-side of weld
  - TRS better for 5% and 10% flaws
  - TRL shows less beam distortion
  - No tips for sizing

Conclusions

- Results show conventional, low-frequency/SAFT and phased array technology capable of detecting and length-sizing flaws on the far-side of austenitic welds
  - Phased array provided best overall results, based on detecting all targeted flaws and better signal-to-noise ratios
- For cracks, responses may be limited to specular reflections from flaw face
- Depth-sizing (through-wall extent) of flaws using time-of-flight techniques is not possible - no crack tip responses
- Welding process (heat flow) has greater effect than *welding position* on acoustic transmission
  - Air-backed weld shows less attenuation and scattering
  - No regional areas (due to welding position) were observed

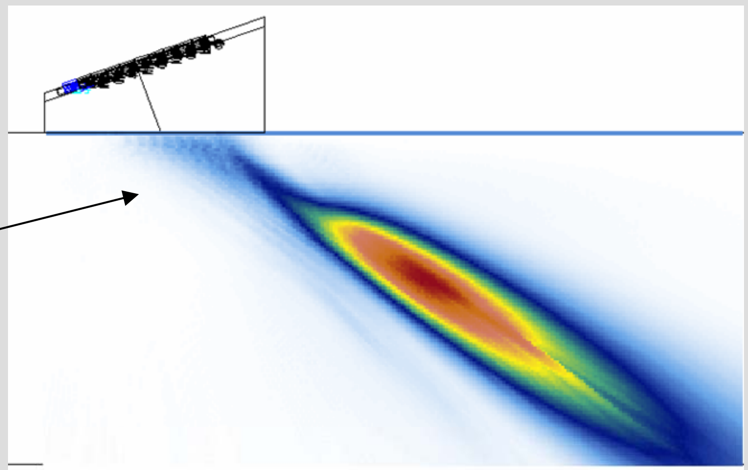
Planned Work

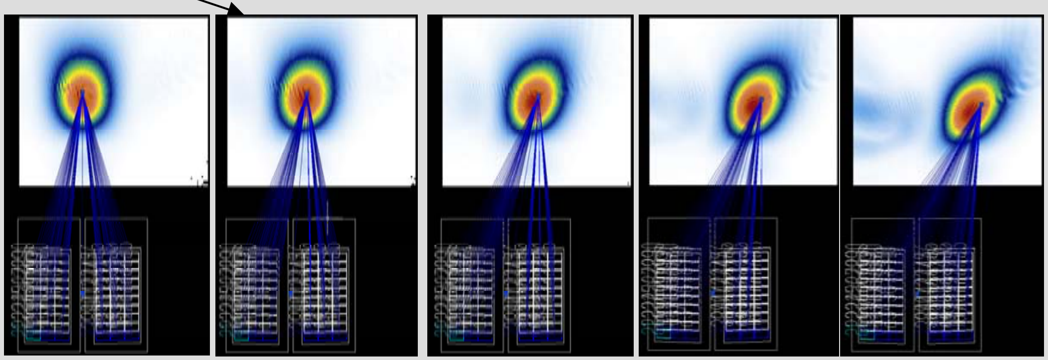
- Apply phased array for far-side detection of IGSCC on field-removed piping at EPRI NDE Center

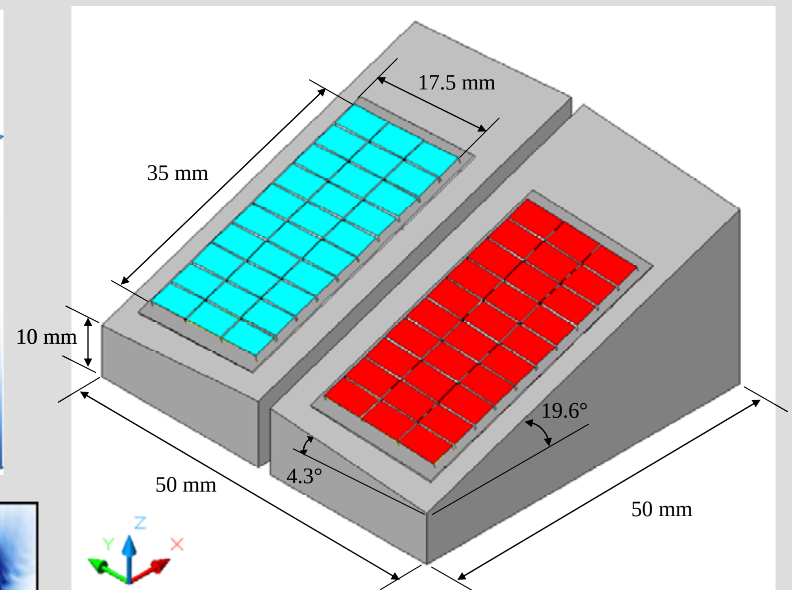
Sound field projections

X-Z plane

X-Y plane (skewed 0° to 20°)







New probe design for detection of IGSCC from far-side

Planned Work (Cont'd.)

- Metallographic analysis of weld grain structures
  - Assess grain size and orientation for different welding processes used in specimens
- Through-weld ultrasonic beam mapping
  - Determine beam distortion and energy profile as a function of propagation angle through varied weld microstructures
- Evaluate advanced techniques to improve far-side tip signal detection
  - Signal processing
  - Combining SAFT with phased array
  - Other noise reduction or image enhancing methods