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Development of Adaptive IWEX a Full Matrix Capture Imaging Technique for In-Ditch Crack-Like Evaluation

Project No: DTPH56-13-T-000008

Harvey Haines, 2018 June 05

Reason for Project

- ILI crack tools, such as CMFL, UT-CD, and EMAT are providing valuable data
- Need to understand the inherent error in these measurements
- For axially oriented crack-like defects like SCC and seam anomalies
  - Models are used to predict failure pressure and remaining life
  - Conservatism is large because of uncertainty of ILI
- Field verification by in-ditch NDE such as phase array (PA) has large uncertainty

- Need better in-ditch measurement to:
  - Measure the error
  - Understand the source of the error
  - Help develop methods to either reduce or account for the error

Project Objective

Sizing of complex crack-like defects such as SCC and seam weld anomalies in the field:

1. Can reduce ambiguity in signal interpretation and therefore reduce operator error
2. Can accommodate various defect shapes regardless of orientation
3. High resolution to discrimination between various types of:
    - defects (LOF versus hook cracks)
    - artifacts (seam under-trim versus plate offset)
    - multiple defects (cracks within an SCC colony)
4. Is rugged, robust and economically viable for use by the industry.

Project Scope

Worked on 2 Phases

- Phase 1 Sept 2013-2015
    - Worked to see if IWEX UT imaging, developed for girth weld inspection, could be transformed to inspect axial seams and SCC (5 Tasks)
- Phase 2 2015-Dec 2017
    - Further developed technology to account for deviation in normal line pipe from a perfect cylinder to improve focusing and alignment of the images (5 Tasks)

Project Participants

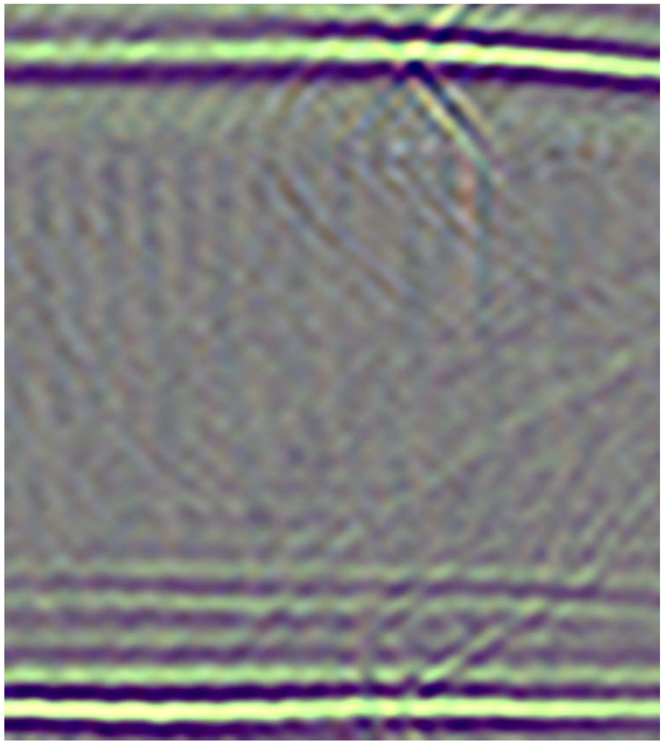
- Funding from PHMSA, TransCanada Enbridge, Koch, and Marathon
  - All 5 provided funding and the pipeline partners provided samples for testing
- Research and development performed by:
  - Applus RTD Technology Center in Houston, Texas
  - Applus RTD Technology Competency Center in Rotterdam, Netherlands
  - Kiefner and Associates in Columbus, Ohio

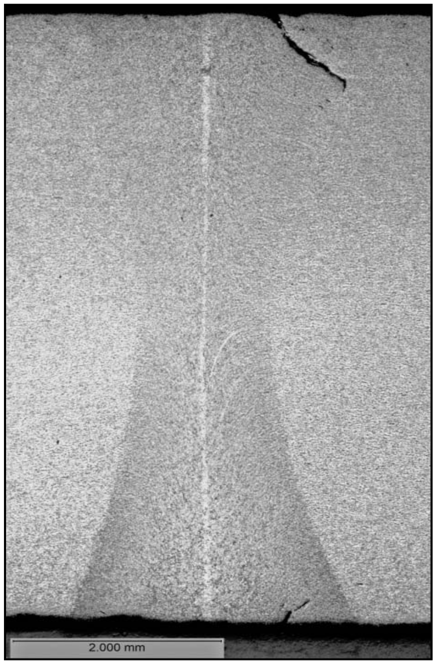
Overview of Phase II of Development

- Improved Calibration of existing plastic wedge IWEX
    - Reduced setup time in field
    - Improved image alignment
    - Good results for cylindrical pipe
- Improved interpretation software for IWEX images
    - Better faster reports
    - Auto detection, sizing tools, and profiling
- Developed Adaptive processing for improved imaging
    - Improves alignment of images for non-cylindrical pipe
    - Uses flexible water wedges to follow contour of pipe
    - Currently slow lab technique – needs acceleration for field use
- Tested Inversion processing of FMC data
    - Best images – uses all the data, both longitudinal and shear waves
    - Too processing intensive for practical use – nice research result

Background

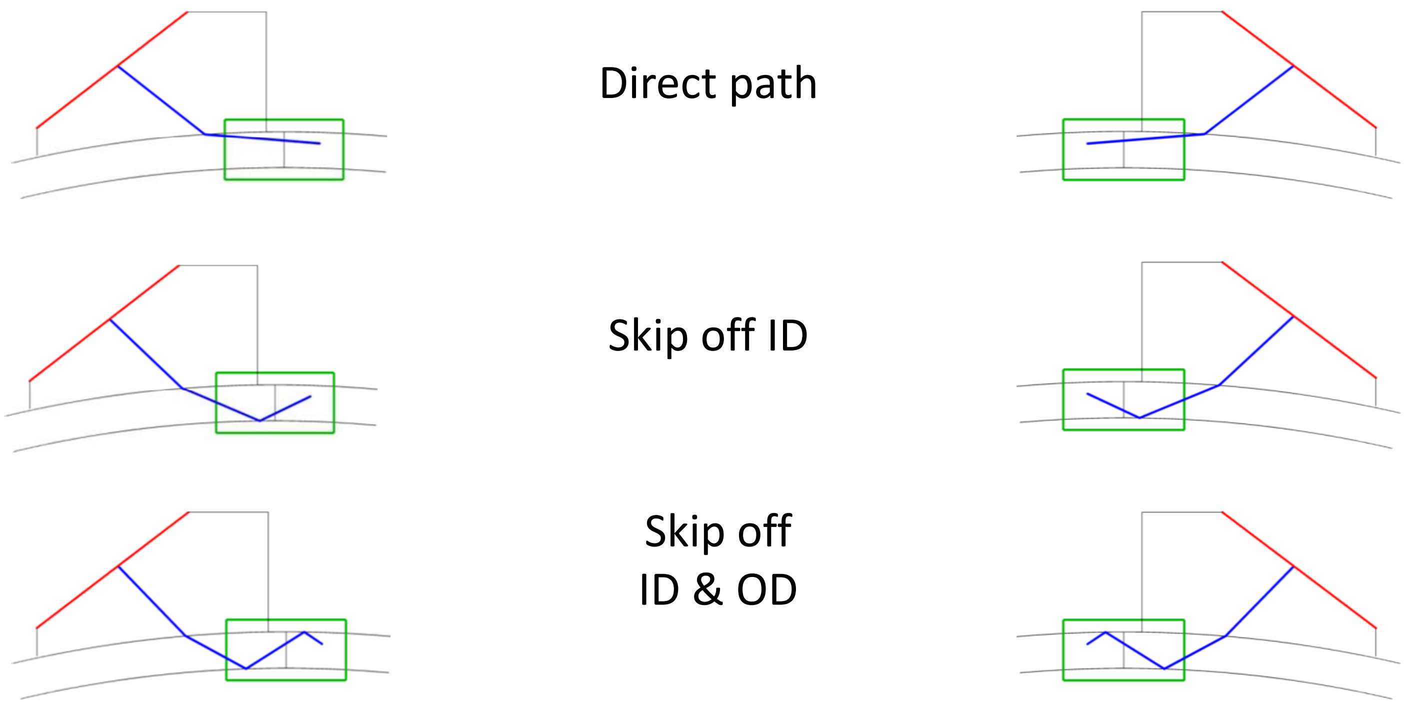
- IWEX developed for imaging Girth Welds
    - Can be treated as flat plates
- 2012 tests showed hook cracks could be imaged in ERW seams
    - ERW seam cross-sections are cylinders (new geometry)





Multiple paths are taken into account

- IWEX acquires full matrix capture (FMC) data and processes data virtually in a computer
- Up to 13 images from different paths are produces with reflections off ID and OD surfaces



How is IWEX different from Phased Array?

- Phased array forms beams with the array
- These beams pulsed and received with the same transducer or a 2nd paired transducer

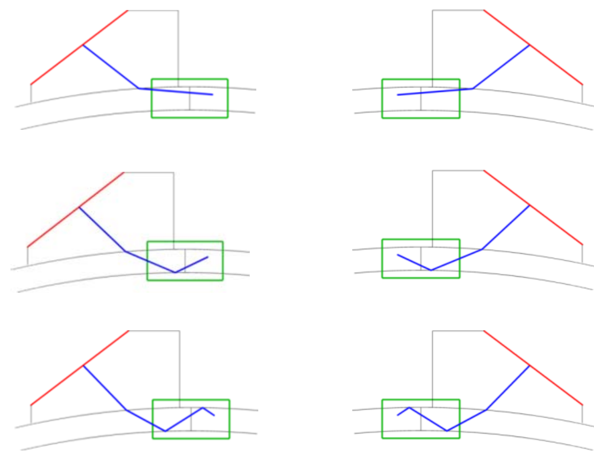
- IWEX reconstructs reflected flaw surfaces and points through image processing
- Allows reflectors off planar surface flaws of any orientation
  - Sound is generated from individual elements which interact with OD and ID surfaces and any and all flaws.
  - Reflected, refracted, and diffracted energy is received across both transducer arrays.
  - Because sound can be generated at one point and received at a different point, imaging is not restricted to pulse echo beams.

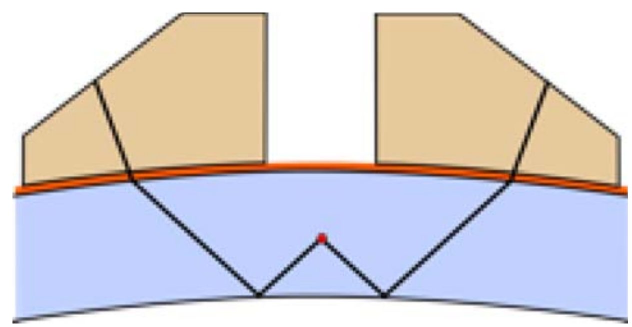
Outline of Work Performed In Phase II

- Need for better calibration
  - Calibration in field taking too long
  - Alignment of OD & ID images insufficient for alignment of defects
  - Better calibration producing good images for most cases.
- Improved interpretation software needed because of plethora of anomalies
- Better calibration is insufficient for good image alignment in some cases
  - Caused by small deviations from assumed cylindrical pipe
    - Offset plate edges with poor ID trim
    - Wall thickening in seam from post weld heat treatment
    - Flat spots caused by improper crimping during manufacturing
- Developed Adaptive IWEX processing with flexible water wedges
  - Produced markedly improved results in two case examples
    - 22-in pipe with offset plate edges and flat crimping near seam
    - 24-in pipe with thickened post weld heat treatment

UT imaging requires more detailed calibration

1. System latency
   The system latency specifies the delay in the measurement chain between sending and receiving, without taking travel time in the wedge and pipe material into account.
2. Wedge angle
   The wedge angle specifies the relative angle between the linear array and the pipe surface. It is measured relative to a tangent line touching the pipe at the bond line.
3. Wedge velocity
   The longitudinal sound velocity in the wedge influences the travel time from the array to the outer pipe surface.
4. Wedge index
   The wedge index describes the distance from the array center to the outer pipe surface, measured perpendicular to the pipe surface.
5. Wedge offset
   The offset measures the straight line (secant) between the bond line and the corner of the wedge at the pipe surface towards the bond line.
6. Wall thickness
   The wall thickness specifies the thickness of the pipe material. It influences paths including reflections at the inner diameter.
7. Material velocity
   The shear velocity in the pipe material influences the travel time and the angle of refraction.
8. Water layer
   There may be a layer of couplant between the bottom of the wedge and the outer pipe surface. The sound velocity is supposed to be similar to water.
9. Curvature / pipe diameter
   The curvature of wedge and pipe may not be exactly as assumed. This is modeled by changing the diameter of the pipe.
10. Roof topping / weld line peaking
    The pipe may not be perfectly cylindrical due to the way that the sheets are crimped before welding. This effect is described by the angle at which the sheets meet at the bond line. The point of rotation is chosen to be at the outer surface at the bond line. For a perfectly cylindrical pipe, the angle is 0°. A negative angle describes inward peaking; a positive angle describes outward peaking.

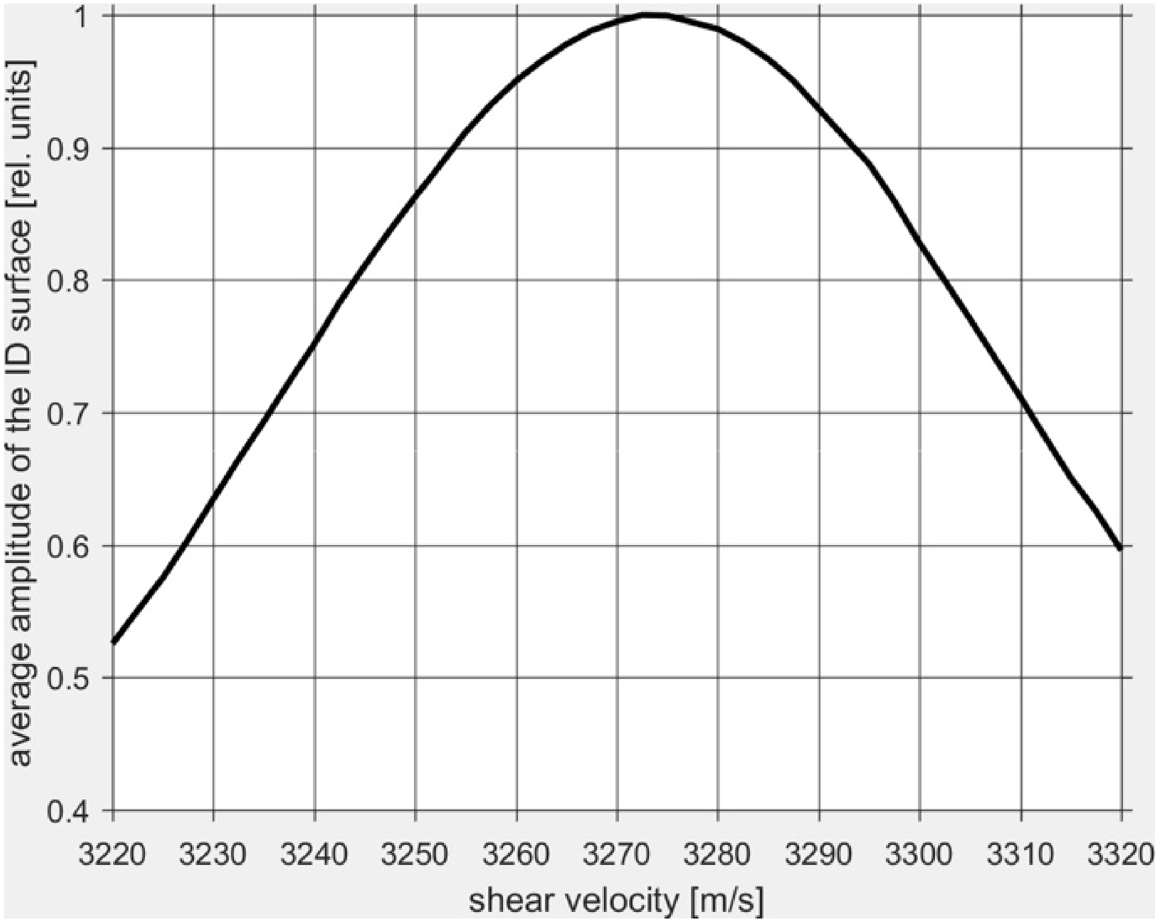




Research showed accuracy needed

Parameter	required accuracy
system latency	± 50 ns
wedge angle	± 0.2°
wedge velocity	± 10 m/s
wedge index	± 0.1 mm
wedge offset	± 0.1 mm
wall thickness	± 0.1 mm
material velocity	± 20 m/s
water layer	± 0.1 mm
curvature (diameter)	± 0.1 inch
roof topping	± 1.6°

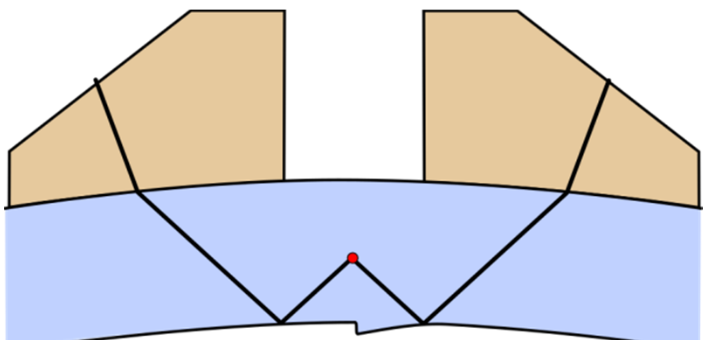
Example: Solving for Shear Velocity of Pipe Steel



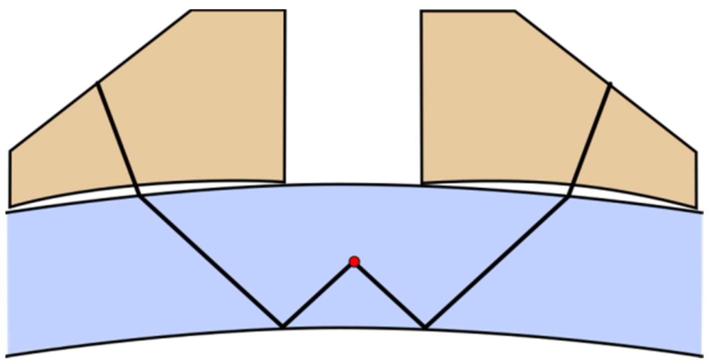
- ID pipe surface average amplitude for different shear velocities

Results of advance calibration

- Scanning much easier with calibration taking only a few minutes
- Does not account for out of roundness of pipe
    - Not an uncommon problem



offset plate edges

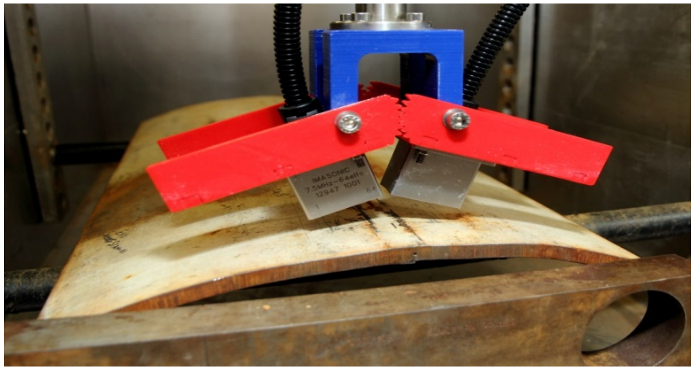


flat pipe in crimped area

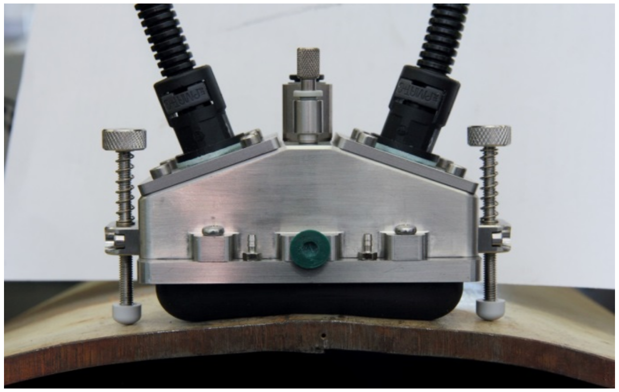
Adaptive IWEX

- Adaptive IWEX developed to address "out of roundness" of pipe
- Requires a wedge that can conform to the pipe roundness
- Adaptive processing that can compute OD & ID surface profiles from the FMC data

Started with immersion scanning

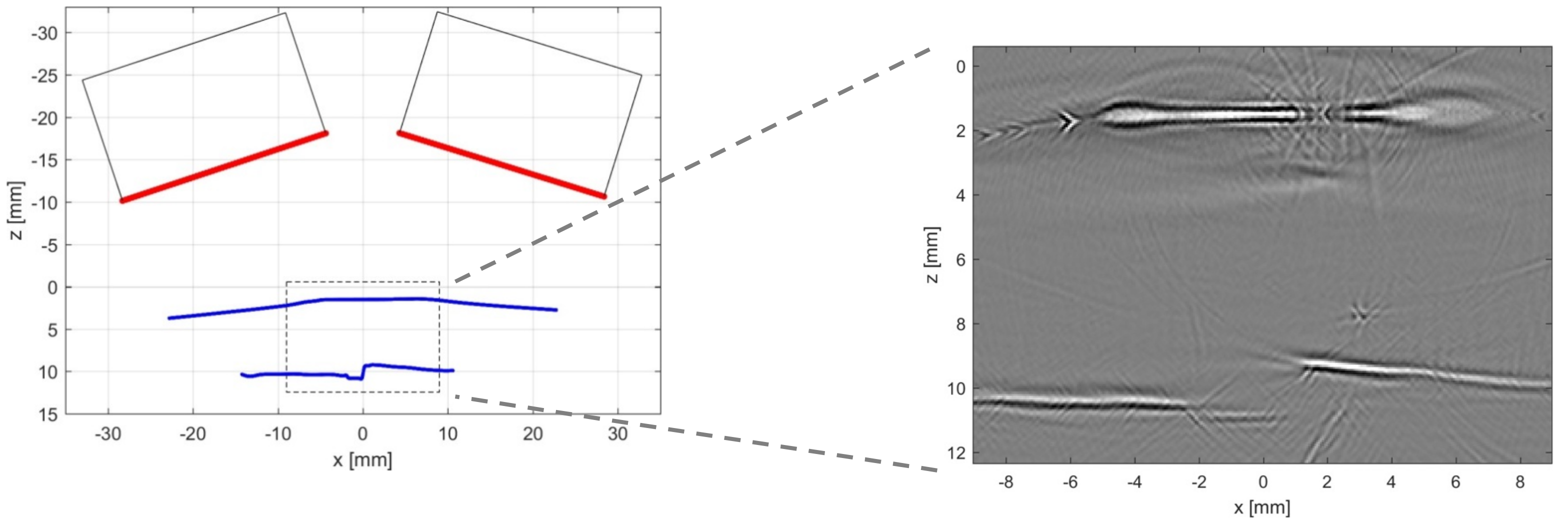


Finished with a water wedge



Example of Immersion Testing

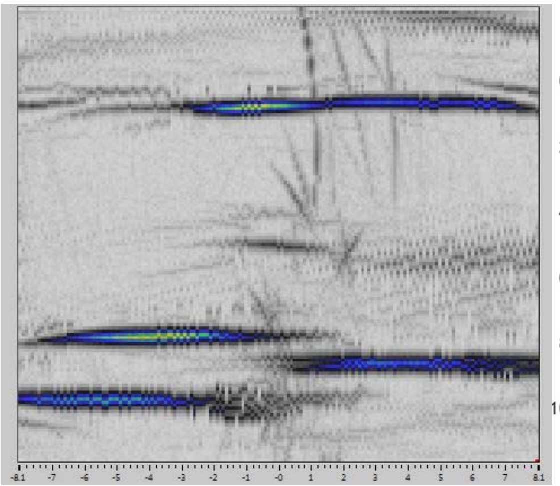
- Transducers placed with sample in water tank
- Investigated dotted area in figure on left
- Produced image on right
  - Contains OD Notch and offset plate edges



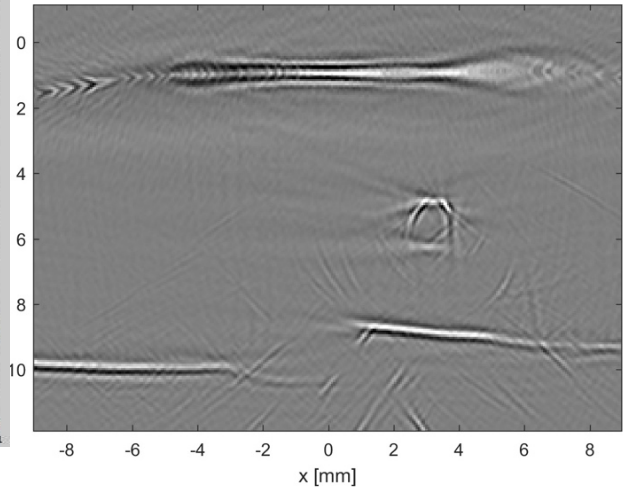
22-in pipe with side drilled hole

photograph

plastic wedge IWEX

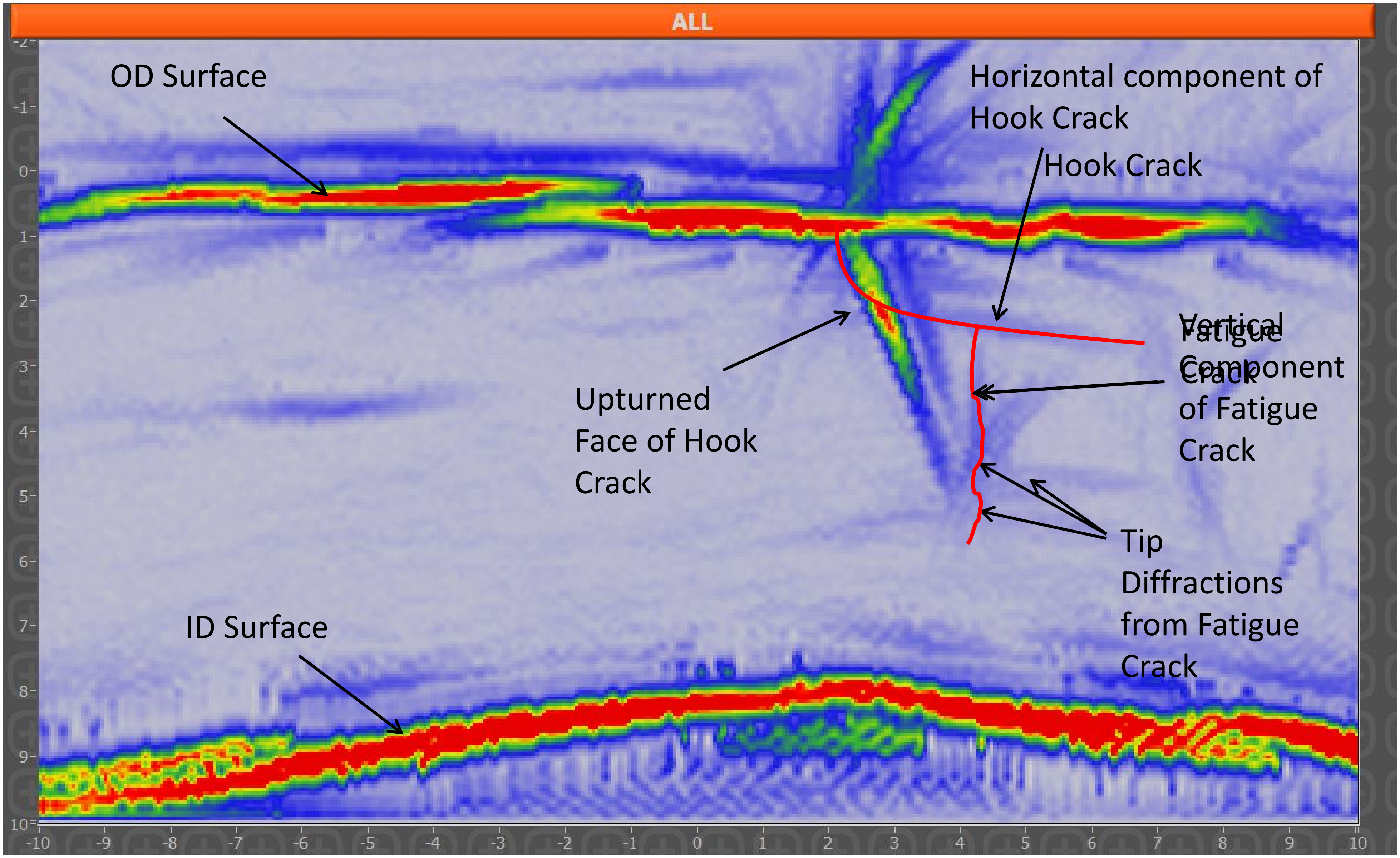


immersion IWEX

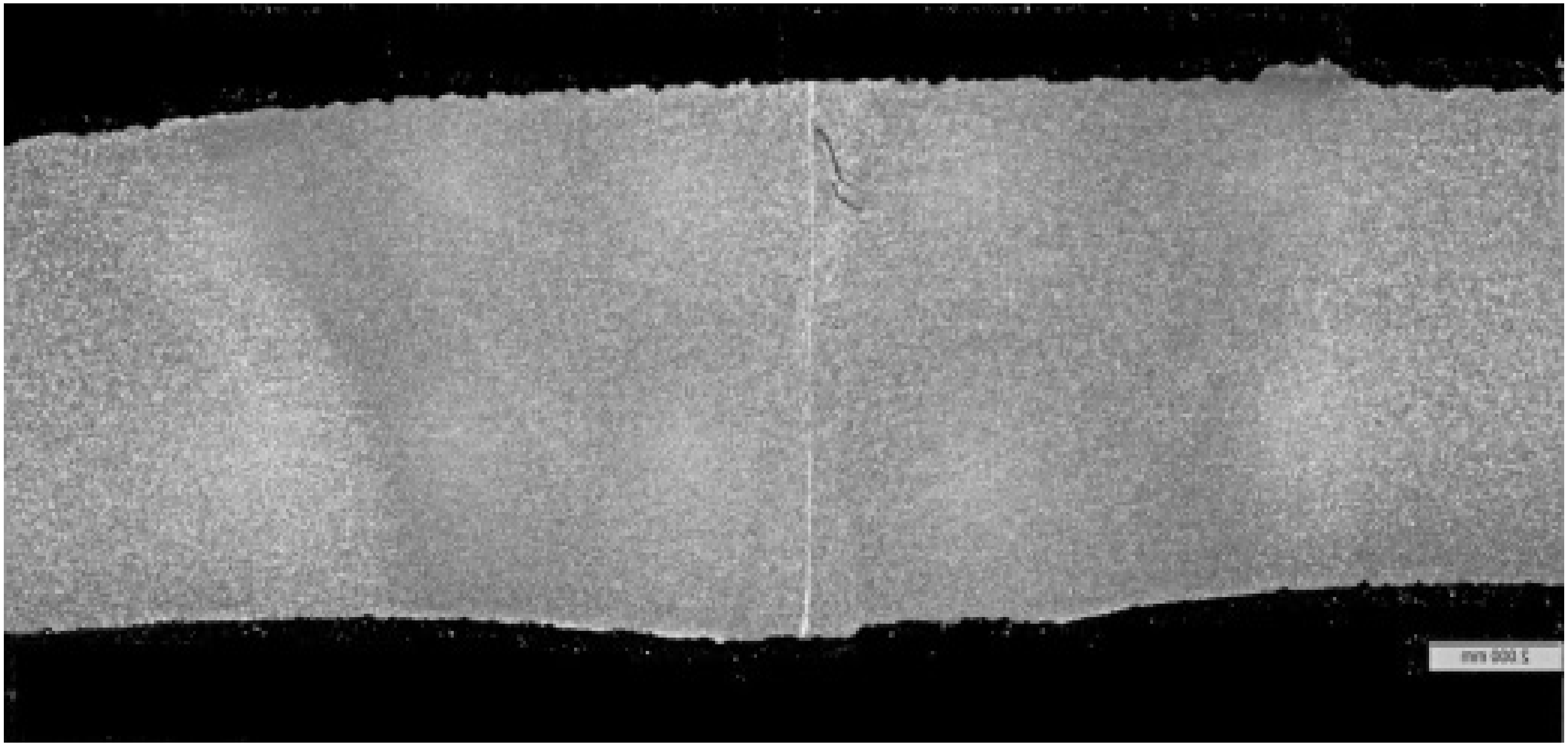


- Alignment between modes measured from the left and right side is better in immersion.
- Side drilled hole indications do not line up with plastic wedges.
- False reflected image left of the bond line where wt is thicker than nominal is eliminated, because actual wt is determined from adaptive processing.
- Immersion interpretation is easier reducing human factors

24-in Example of Miss-Alignment



24-in Pipe Metallographic Section

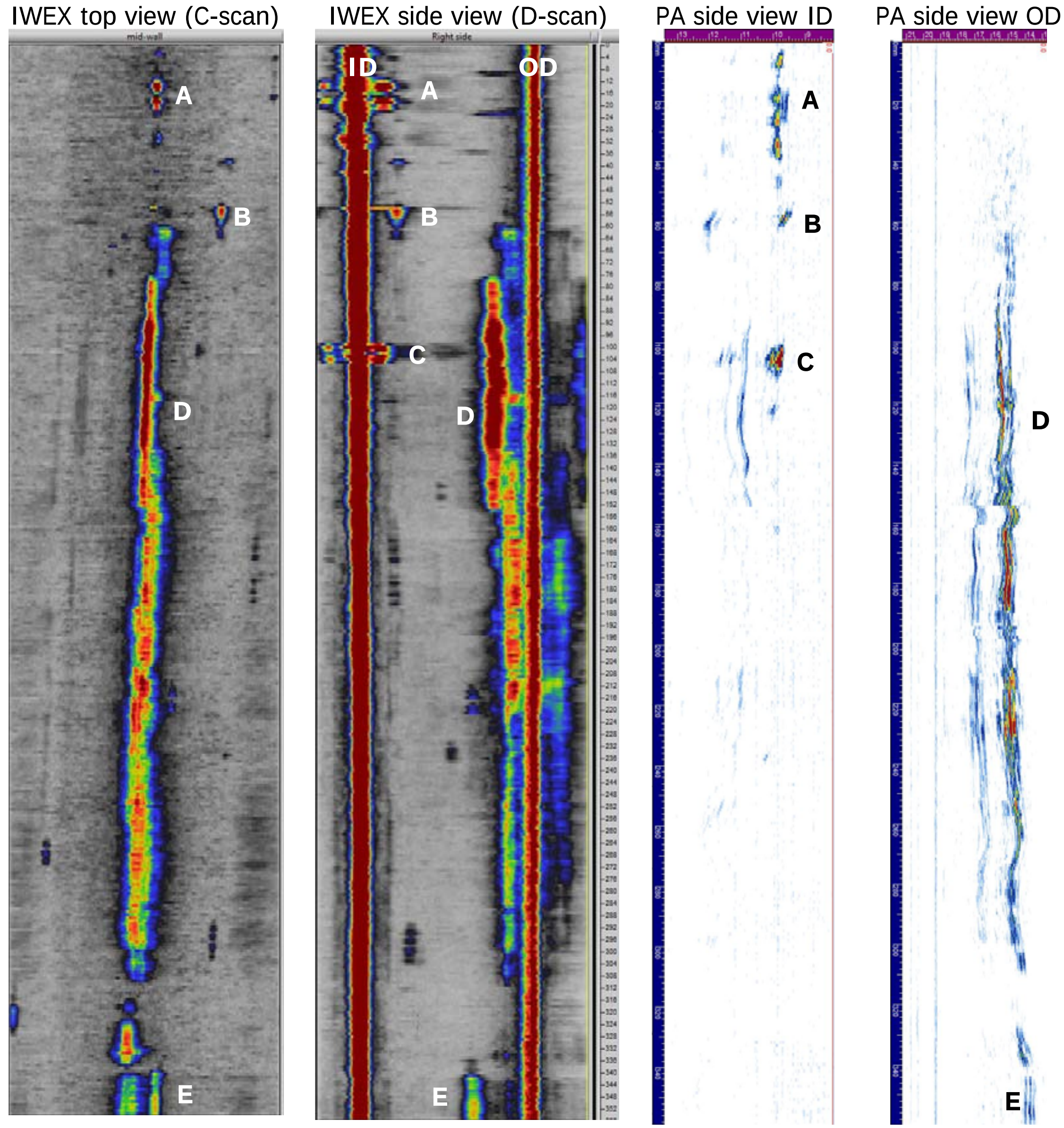


One cause of miss-interpretation
was miss-alignment
from thickened pipe near the seam
from post weld heat treatment.

Adaptive IWEX comparison to Phased Array 24-in pipe

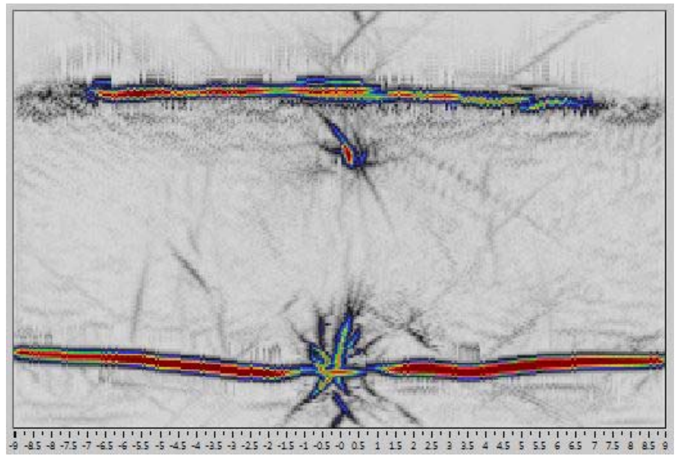
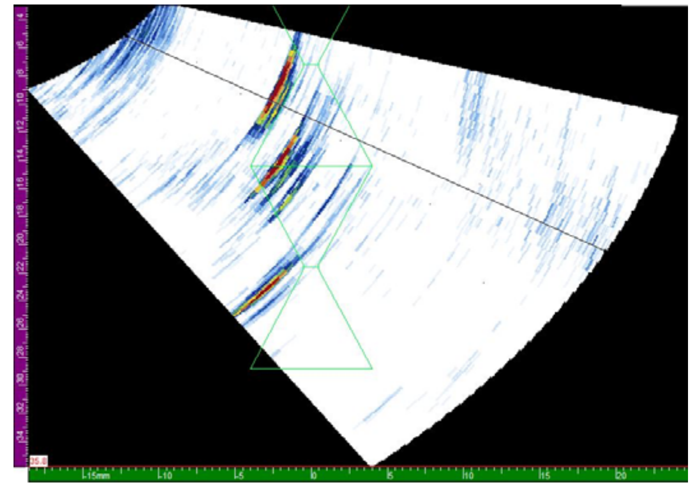
Strip charts of data

- IWEX on left
  - Strip charts are spatial
  - Top & Side Views
- PA on right
  - Strip charts-time based
  - Skips of far & near wall
- 5 anomalies A B C D E identified in strip charts



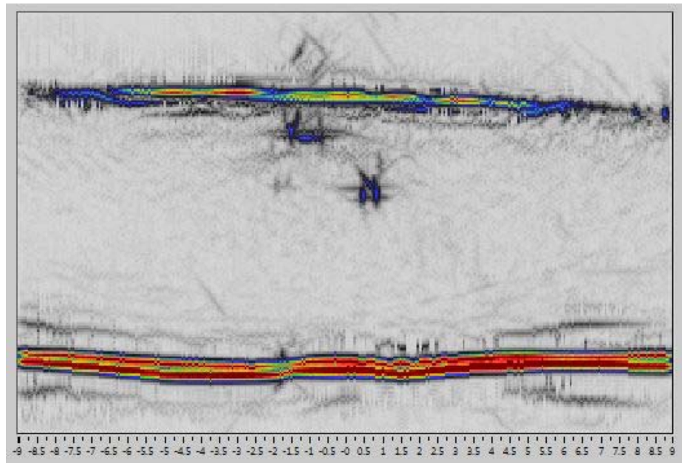
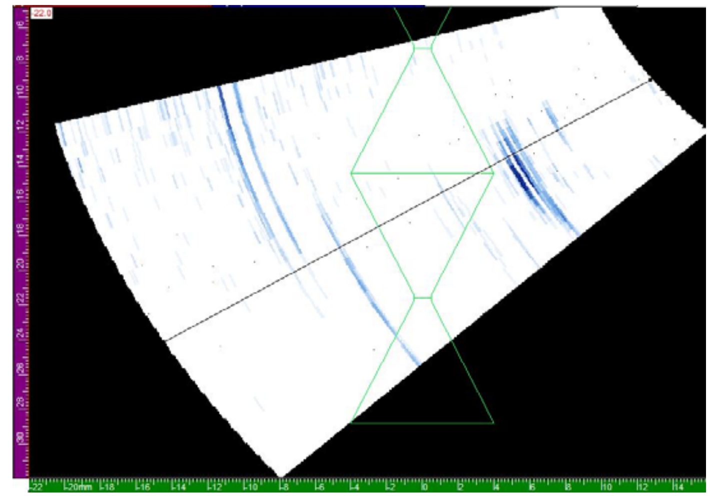
Location C

- Both flaws can be detected using IWEX or PA. However, characterization is more difficult with PA. The inclined orientation of the upper flaw from IWEX indicates an upturned fiber imperfection.
- The cold weld is surface-breaking. This is clearer from IWEX. The amplitude of the bond line at the ID is weaker, caused by the flaw casting an acoustic shadow.
- The upturned fiber imperfection is estimated larger with PA. Caused by the UTI not being perpendicular to the OD. The distance between the tip diffractions is greater than the actual vertical extent of the flaw.

IWEX	Phased array
	
Upper flaw: upturned fiber imperfection Height: 0.4 mm Depth from OD surface: 1.6 mm, WT: 7.7 mm Detected in IWEX-2 (skip)	Height: 1.0 mm Depth from OD surface: 0 mm Sizing: between 0.5 and 1 skip
Lower flaw: cold weld, surface-breaking Height: 1.0 mm Depth from OD surface: 7.3 mm, WT: 7.7 mm Detected in IWEX-0 (direct), IWEX-1 (tandem)	Height: 1.0 mm Depth from OD surface: 4.5 mm Sizing: between 0.5 and 1 skip

Location E

- Flaws from PA are relatively weak. This is caused by a decrease in acoustic coupling at scan position.
- Discrimination is not possible using PA. IWEX shows flaw shapes and the position allowing identification as upturned fiber imperfections.
- These 2 flaws are small. IWEX allows identification of upper and lower flaw tips, where the PA sectorial scan can't provide this detail, even though both PA & IWEX use the same 10 MHz freq.

IWEX	Phased array
	
Upper flaw: upturned fiber imperfection Height: 0.3 mm Depth from OD surface: 1.0 mm, WT: 7.6 mm Detected in IWEX-2 (skip)	Height: 0.7 mm Depth from OD surface: 0.1 mm Sizing: between 0.5 and 1 skip
Lower flaw: upturned fiber imperfection Height: 0.3 mm Depth from OD surface: 2.5 mm, WT: 7.6 mm Detected in IWEX-2 (skip)	Height: undetermined (<0.5 mm) Depth from OD surface: 0.6 mm Sizing: between 0.5 and 1 skip

Summary & Conclusion

- Improved calibration techniques have improved field procedures for acquire well aligned data
  - Especially true for cylindrical pipe
- Discrimination is much easier with IWEX/UT Imaging
  - Because actual flaw surfaces can be imaged
  - Spatial placement of images makes interpretation easier
  - Less susceptible to human factors
- Better alignment will be possible for non-cylindrical pipe with Adaptive IWEX processing and conformable water wedges
  - Processing speed improvements are needed to use routinely in the field.

Technology Transfer

1. Plastic Wedge IWEX is being used in the field
2. Adaptive Processing will need speed acceleration before it can be deployed in the field
3. The visibility of this project is causing other equipment manufacturers to start developing FMC equipment for purchase
4. ASME Section V is writing a standard on using FMC of which Applus RTD is a committee member

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