

Inspection of Refinery Piping and Vessels from the Outside for External and Internal Corrosion

Neil Goldfine, Todd Dunford, Scott Denenberg, Yanko Sheiretov, Andrew Washabaugh, Shayan Haque

JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013

Tel: 781-642-9666; Email: jentek@jenteksensors.com

web: jenteksensors.com

API Beijing, China

9-13 September 2013

Primary Session: Downstream

NDT & SHM Applications for MWM-Arrays, *a flexible eddy current sensor technology*

NDT

Nondestructive Testing

SHM

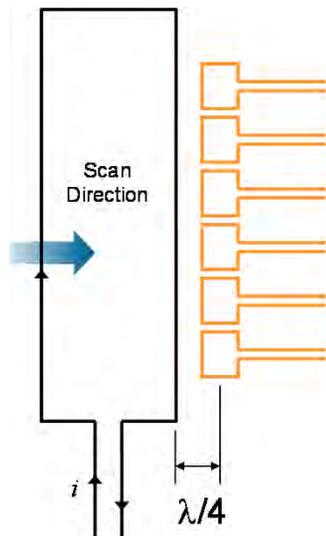
Structural Health Monitoring



MWM-Array Sensor Selection

- Decay rate determined by skin depth at high frequency and sensor dimensions at low frequency
- Large dimensions needed for thick coatings/insulation
- Low frequencies needed to penetrate through steel pipe wall

VWA001 MWM-Array*



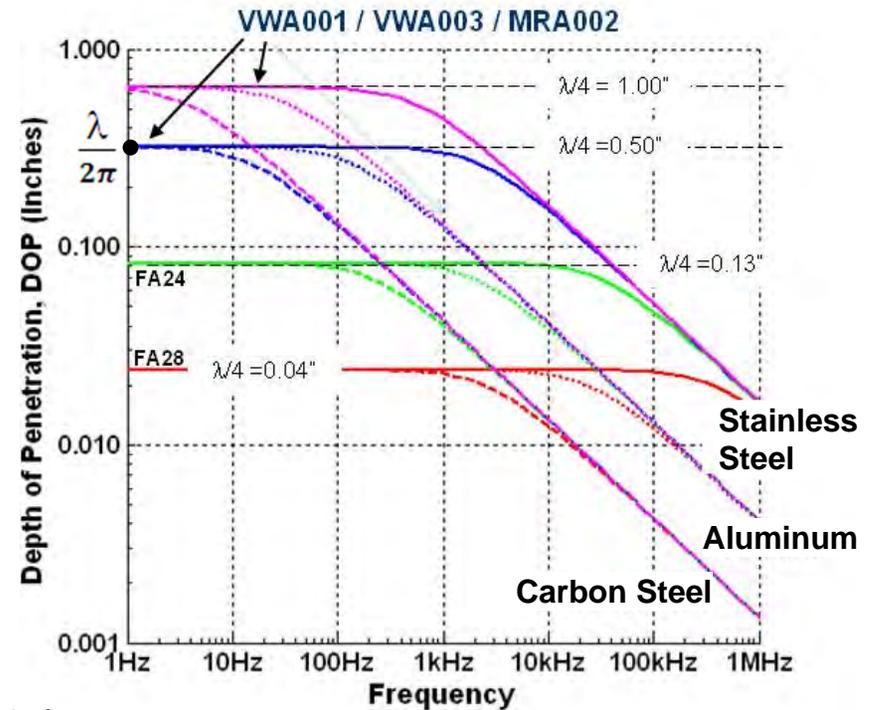
*Note: Other MWM winding designs provide better performance

$$\text{Depth of Penetration} = 1/\text{Re}(\Gamma_n)$$

$$\text{Low Frequency Limit} = \frac{\lambda}{2\pi}$$

$$\Gamma_n = \sqrt{(2\pi n / \lambda)^2 + j2 / \delta^2}$$

$$\text{Skin depth: } \delta = \sqrt{\frac{1}{\pi f \mu \sigma}}$$



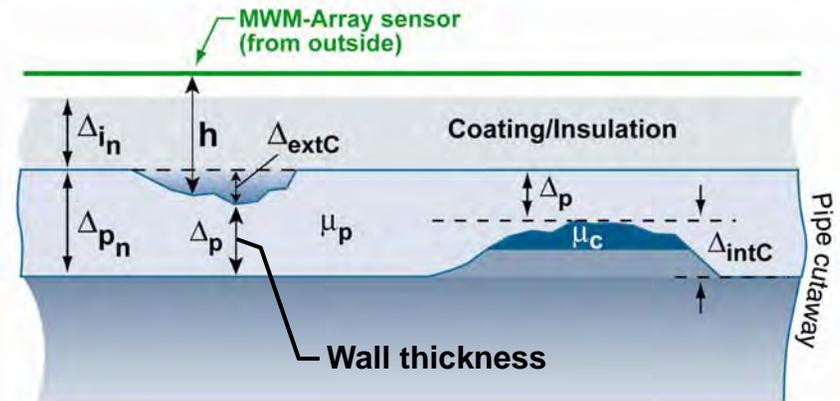
1 inch = 25.4 mm

HyperLattices & Multivariate Inverse Method (MIM)

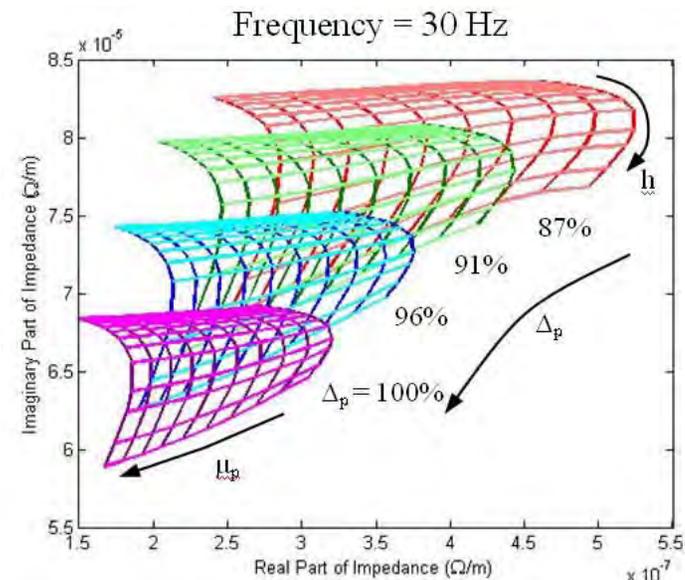
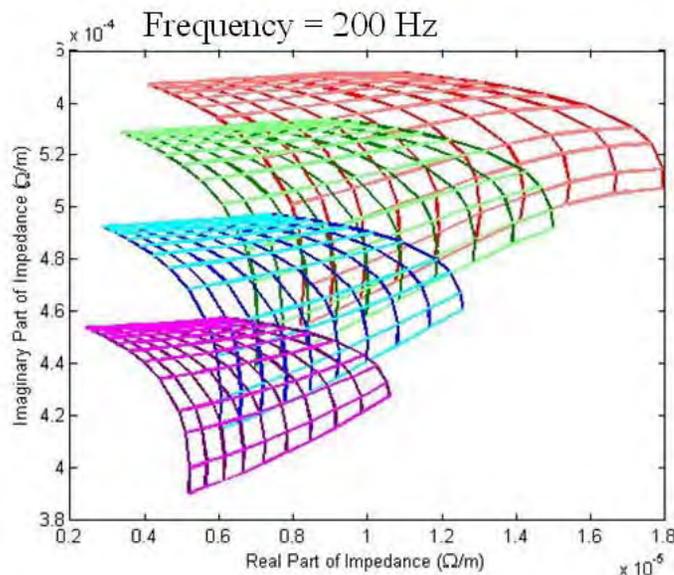
Hyperlattices are Precomputed Sensor Response Databases

MIM

- Rapid means for converting multiple frequency MR-MWM-Array data into material and geometric properties
- Grids (two-unknown databases), Lattices (3-unknowns), Hyperlattices (4+ unknowns) are generated and stored in advance
- Rapid search through database for solution



Example Lattices

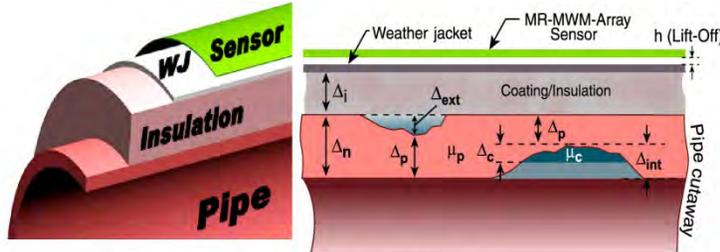


Corrosion Under Insulation (CUI) Inspection

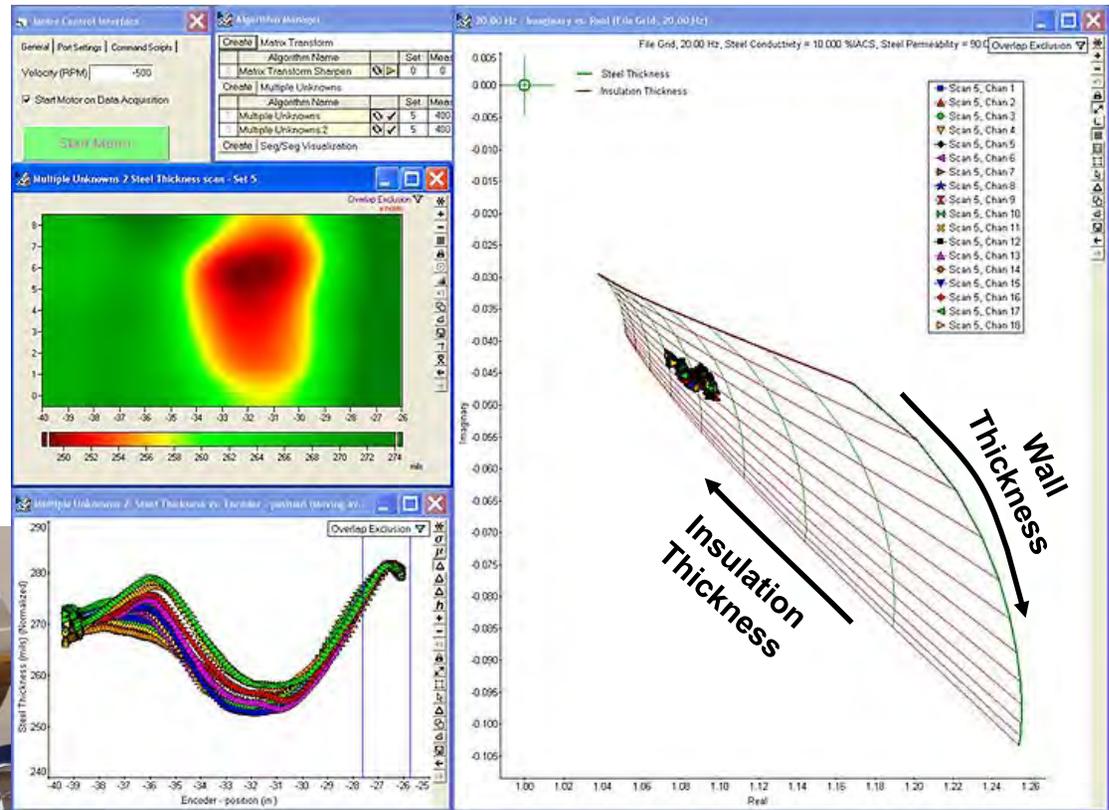


MWM-Array Inspection for CUI

Problem Definition



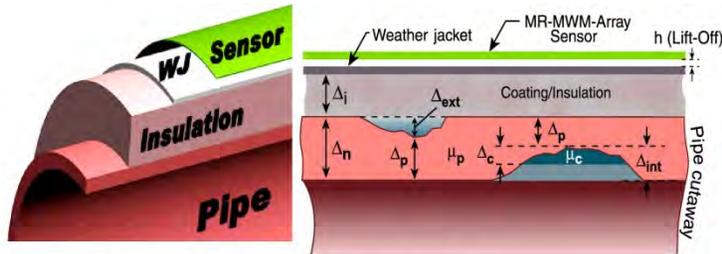
- Δ_p = Remaining pipe wall thickness
- μ_p = Pipe wall magnetic permeability
- Δ_{ext} = External wall loss
- Δ_{int} = Internal wall loss
- Δ_n = Nominal pipe wall thickness
- h = Lift-off
- μ_c = Permeability of internal corrosion product layer
- Δ_c = Thickness of internal corrosion product layer
- Δ_i = Coating/insulation thickness



Wall loss imaging for internal and external corrosion through insulation and weather jacket

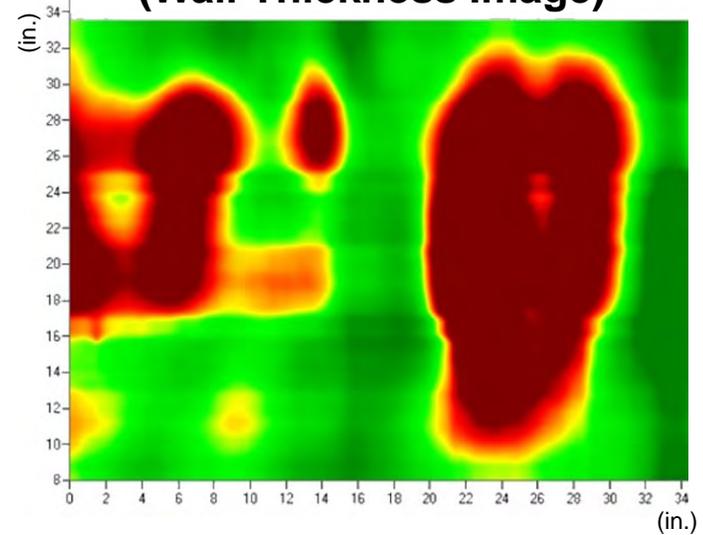
MWM-Array Inspection for CUI

Problem Definition

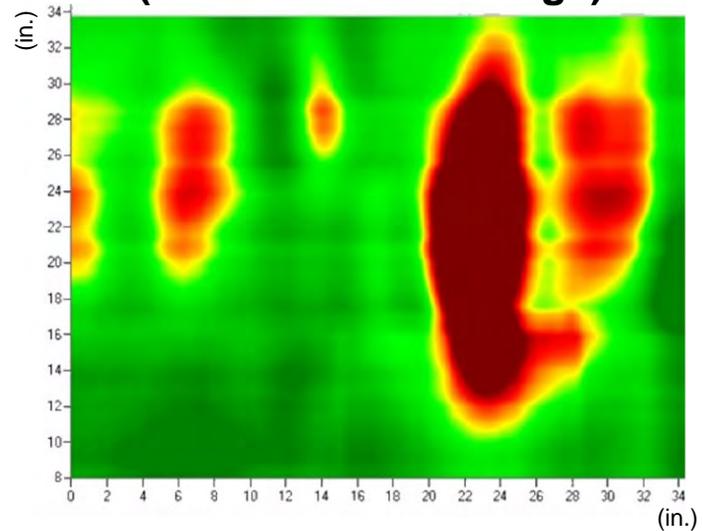


- Δ_p = Remaining pipe wall thickness
- μ_p = Pipe wall magnetic permeability
- Δ_{ext} = External wall loss
- Δ_{int} = Internal wall loss
- Δ_n = Nominal pipe wall thickness
- h = Lift-off
- μ_c = Permeability of internal corrosion product layer
- Δ_c = Thickness of internal corrosion product layer
- Δ_i = Coating/insulation thickness

Pre-Alpha System Performance (Wall Thickness Image)



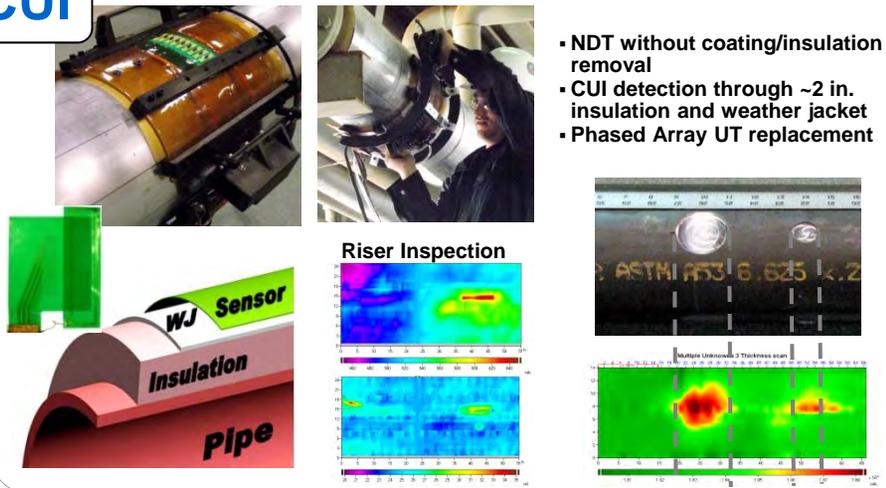
Improved Resolution with Alpha System (Wall Thickness Image)



Oil & Gas Application Examples

CUI

Corrosion Under Insulation



- NDT without coating/insulation removal
- CUI detection through ~2 in. insulation and weather jacket
- Phased Array UT replacement

Riser Inspection

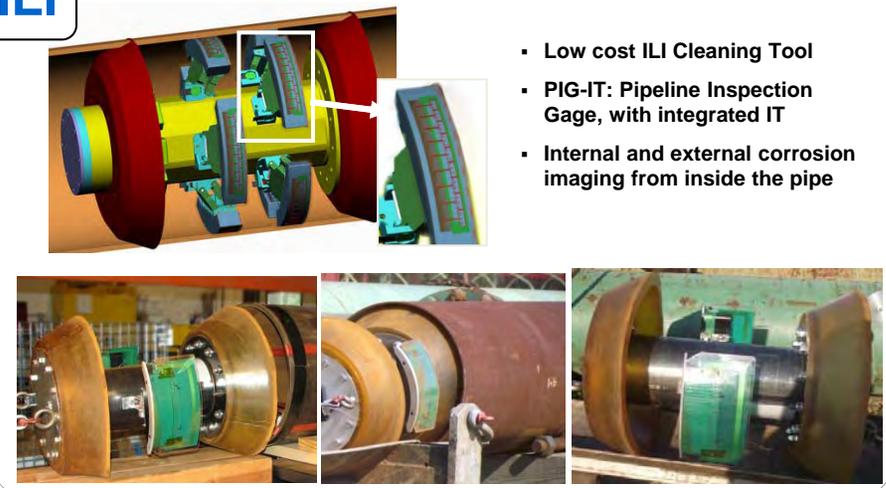
WJ Sensor
Insulation
Pipe

ASTM A53 6.625 x .2

Multiple Unknowns Thickness scan

ILI

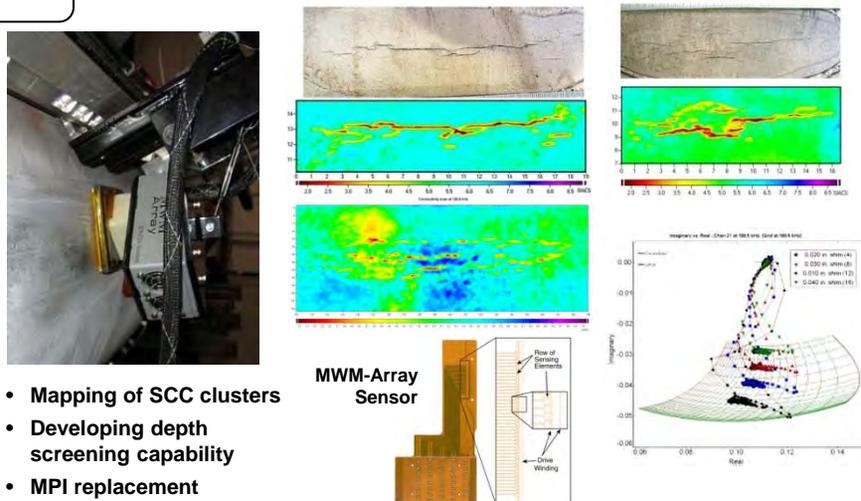
In-Line Inspection



- Low cost ILI Cleaning Tool
- PIG-IT: Pipeline Inspection Gage, with integrated IT
- Internal and external corrosion imaging from inside the pipe

SCC

Stress Corrosion Cracking



- Mapping of SCC clusters
- Developing depth screening capability
- MPI replacement

MWM-Array Sensor

Riser of Refining Elements

Drive Winding

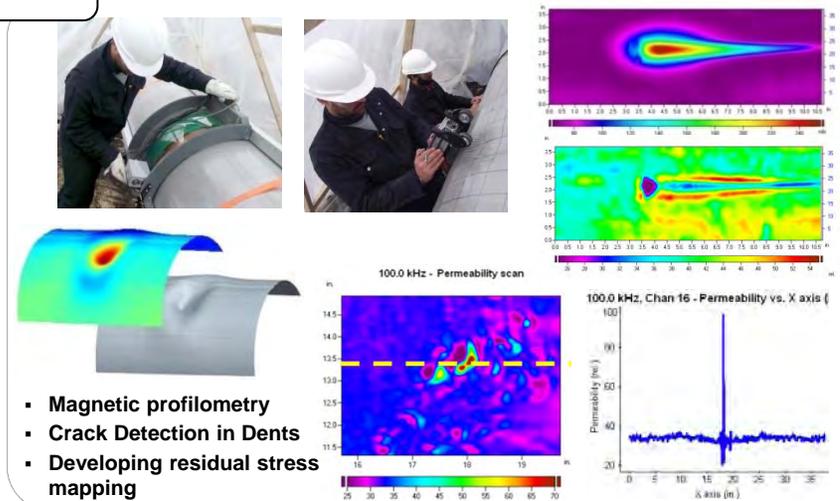
Imaginary vs. Real Chan 21 of 168 (ms) (Scale at 1000 ms)

Legend:

- 0.020 in. when (A)
- 0.030 in. when (B)
- 0.010 in. when (C)
- 0.040 in. when (E)

MD

Mechanical Damage



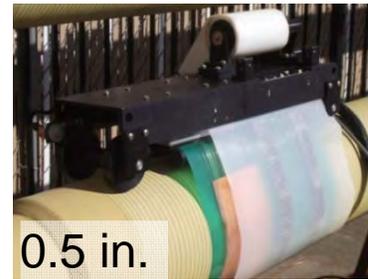
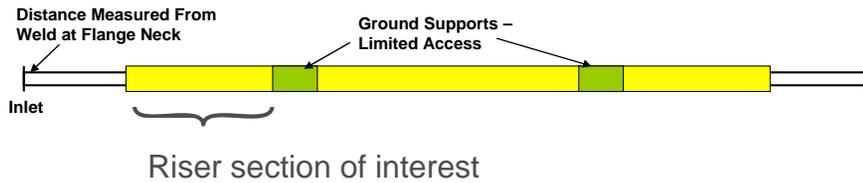
- Magnetic profilometry
- Crack Detection in Dents
- Developing residual stress mapping

100.0 kHz - Permeability scan

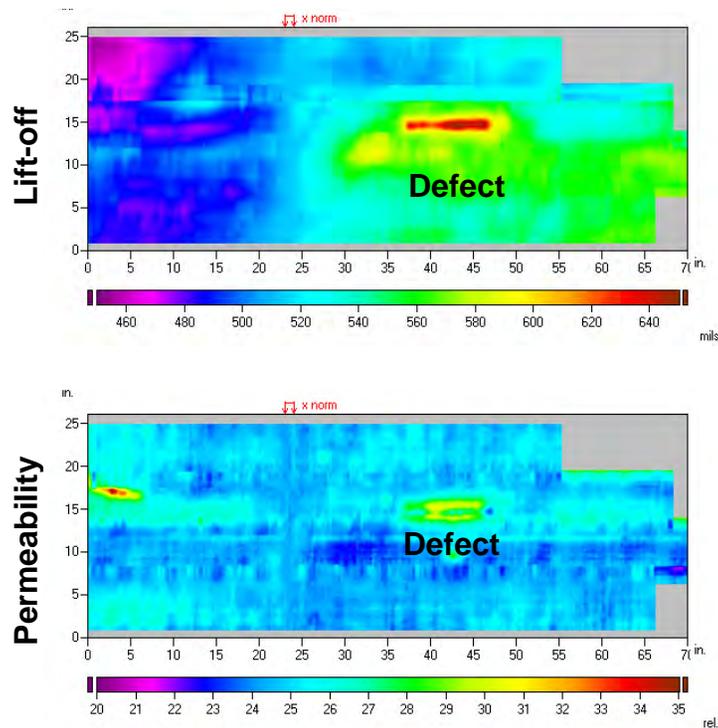
100.0 kHz, Chan 16 - Permeability vs. X axis (

Previous MWM-Array Results

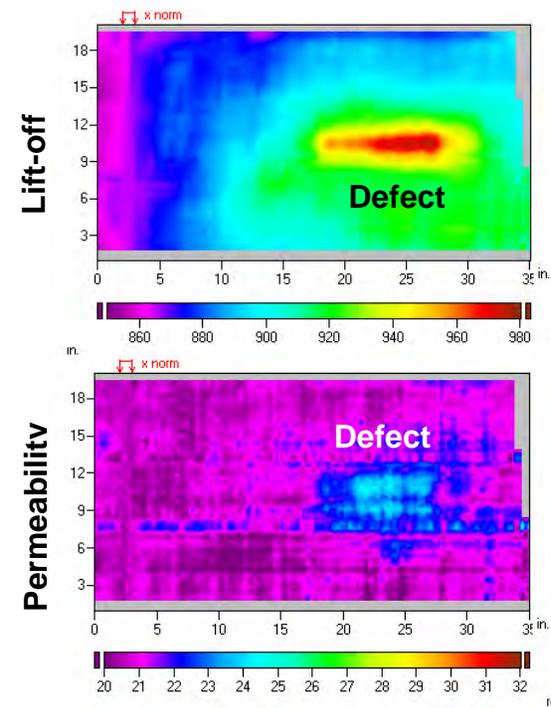
Using VWA001 MWM-Array



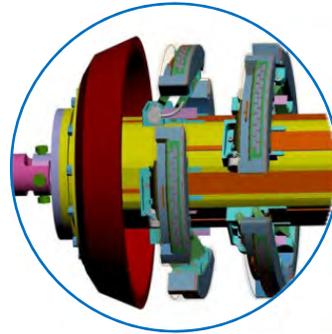
0.5 in. coating



1.0 in. coating



In-Line Inspection (ILI) Tools



JENTEK ILI Development and Demonstrations

Generation 1 – 2010 (Completed)

Preliminary capability demonstration, December 2010

- Small MWM-Array mounted on a tool and pulled through straight sections
- High freq. test to help understand issues for integrating sensors into an ILI tool



Generation 2 - 2011 (Completed)

Enhanced capability demonstration, September 2011

- Large MWM-Arrays to accommodate larger lift-offs (e.g., 0.25-1.00 in.)
- Integrated electronics with only power supply tether (24v)



Generation 3 – 2012/2013 (Ongoing PRCI Program)

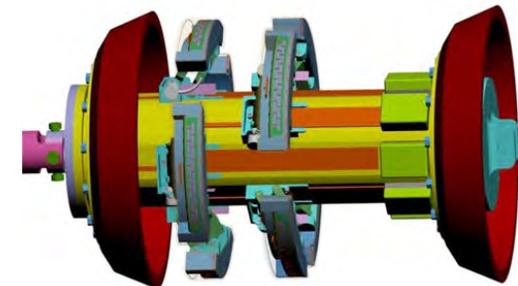
Increase channel count and data rate – Q3 2013

- Increased number of channels to provide complete coverage
- Higher data throughput per channel to increase the maximum speed of the tool through the pipe
- Include on-board power onto tool
- Improved durability and hardening of the instrument, including isolation from the environment.

Generation 4 – 2013/2014 Options

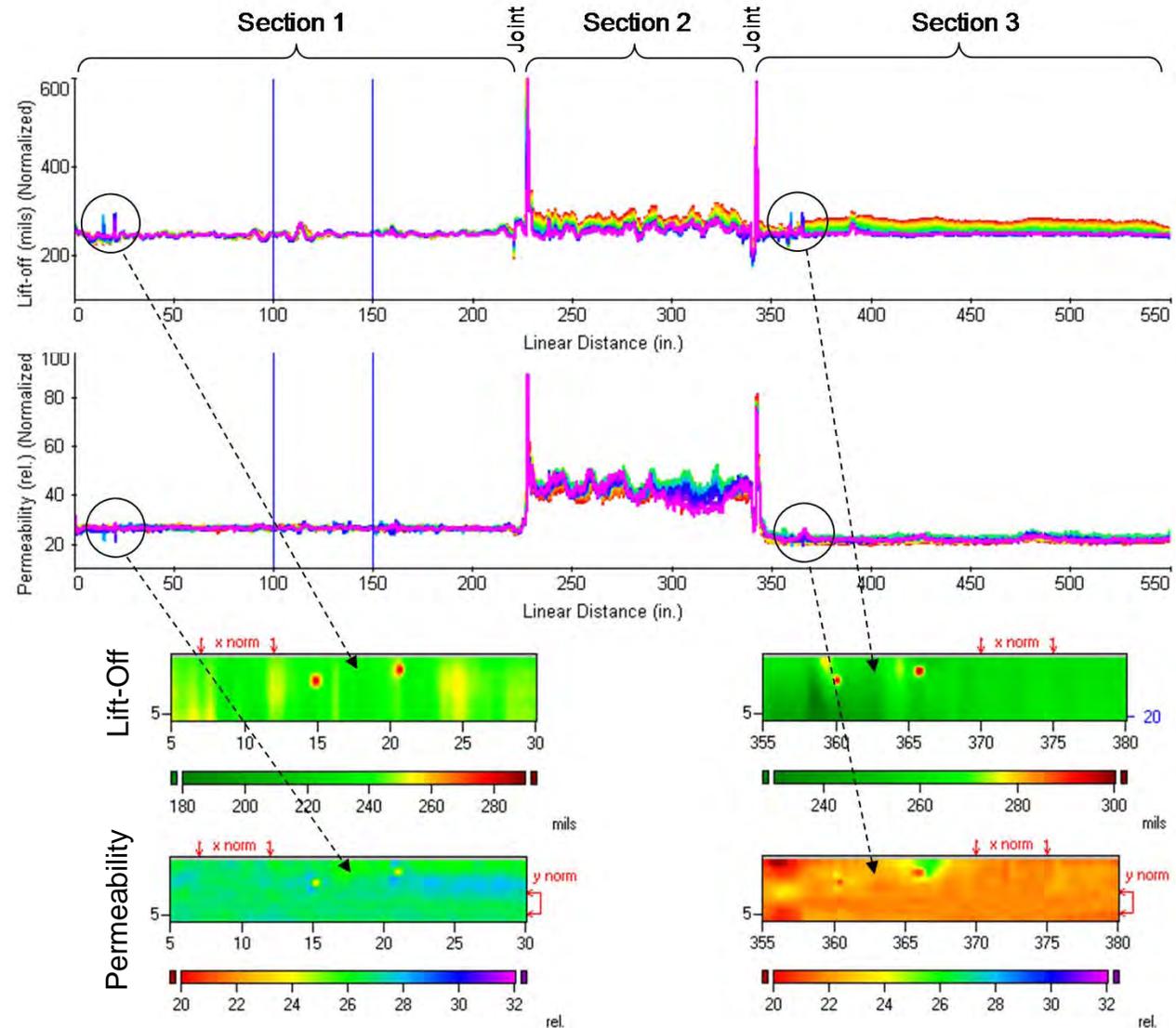
Integrated Capability Development and Demonstration

- Improved durability and hardening of the instrument, including sealing for environmental protection in oil and gas environments and shock protection
- Reduce power consumption for battery operation of instrumentation
- Reduce the size of the electronics to consolidate the tool into one module
- Team with an ILI tool vendor to support testing in a flow line
- Perform first flow line test

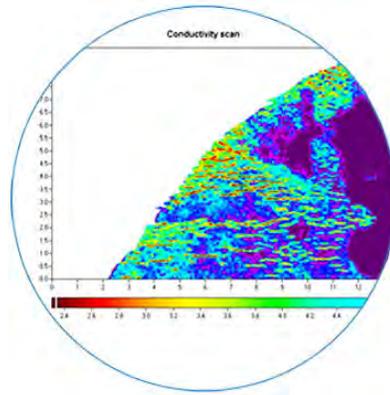


Generation 2 Technology: Pull Test Results

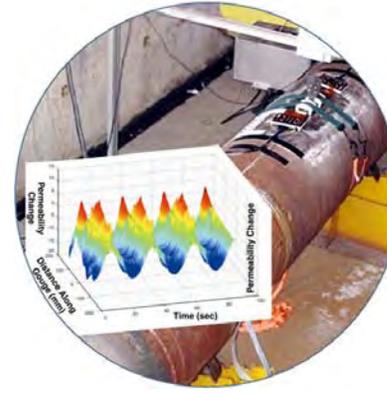
MWM-Array 2
Pull Speed ~0.36 mph



Cracks

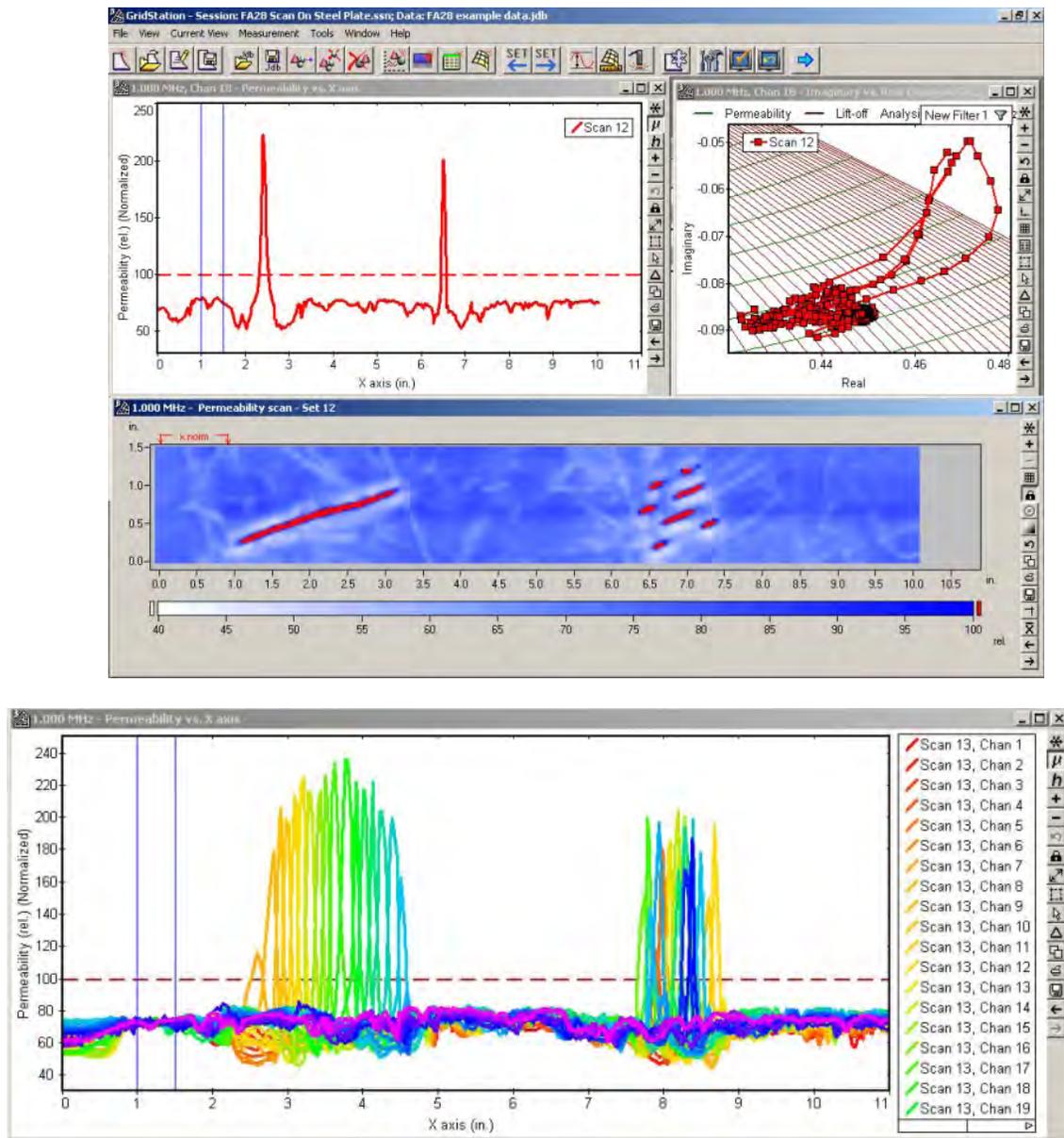


NDT



SHM

Crack Imaging & Depth Measurement Capability



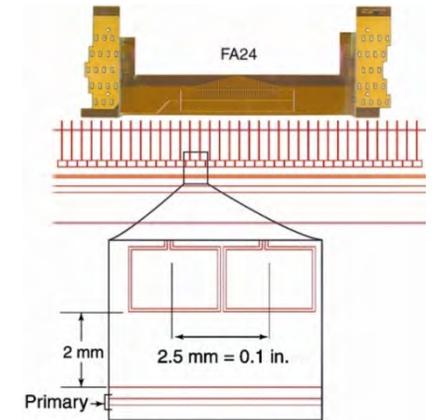
- Crack Detection
- Multiple-Channel MWM-Array Crack Depth Measurement
- C-Scan Imaging on Flat and Curved Surfaces, using Conformable MWM-Arrays and MR-MWM-Arrays



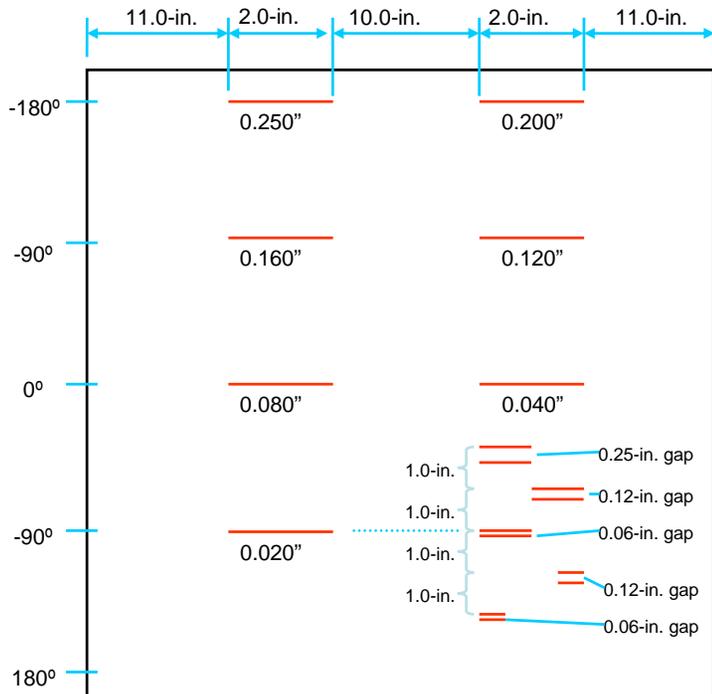
Representative data on flat plate specimen with EDM notches

EDM Notch Pipe Samples

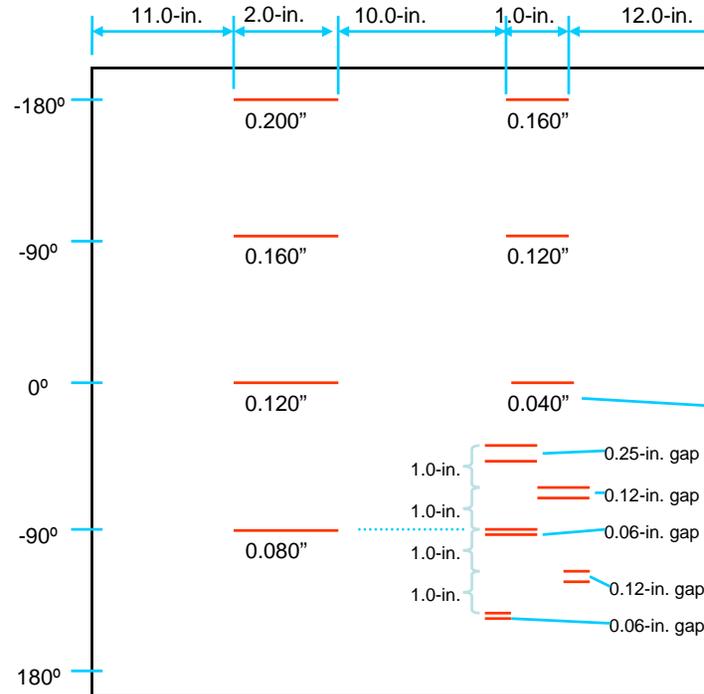
- 36-in. long, 8-in. diameter pipes
- Axial EDM notches located at various positions around each pipe
- Scanned with FA24 (medium size) MWM-Array
 - Wider array and sense elements compared to FA26



Schedule 80 Sample



Schedule 40 Sample

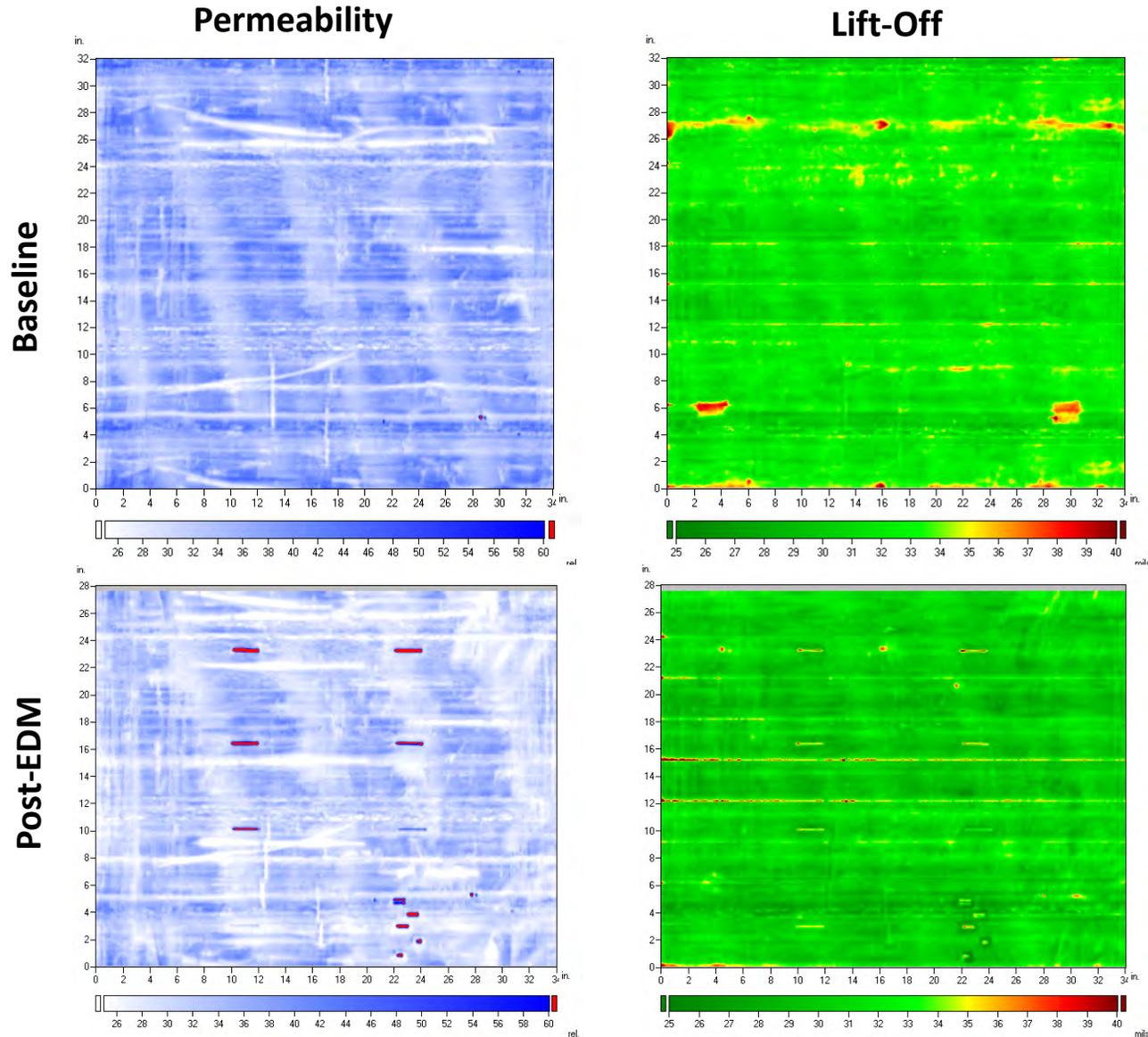


Depth of notch is indicated

Pairs of notches, either 0.5-in. or 1.0-in. long, each notch being 0.080" deep (sched. 80) or 0.040" deep (schedule 40). The vertical spacing is indicated.

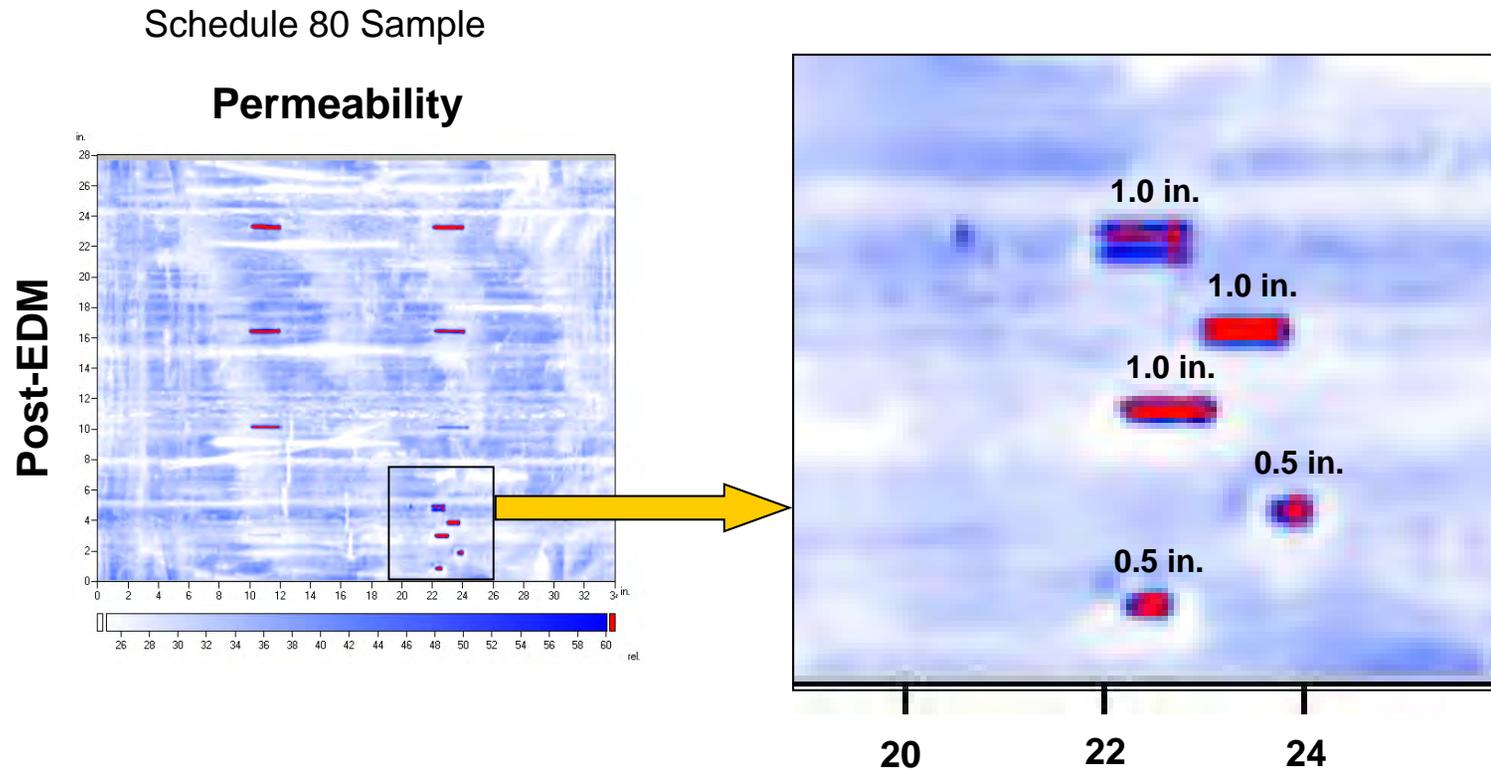
FA24 MWM-Array Scan of EDM Notch Pipe Sample

Baseline & Post-EDM Fabrication Data on Schedule 80 Sample



Crack Imaging & Depth Measurement Capability

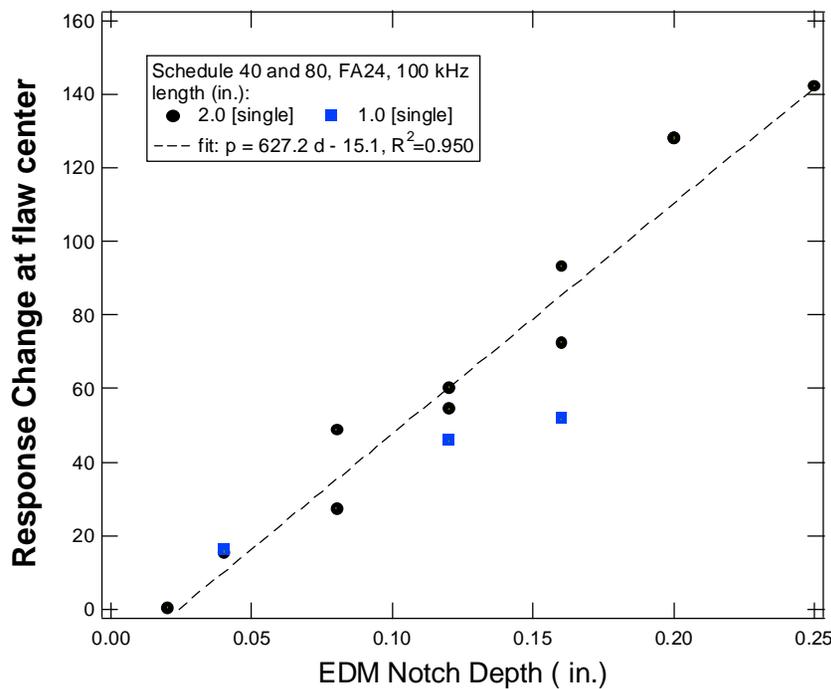
- Representative FA24 data at 100 kHz
- Notches clearly indicated as increase in permeability
- Pairs of notches show resolution capability



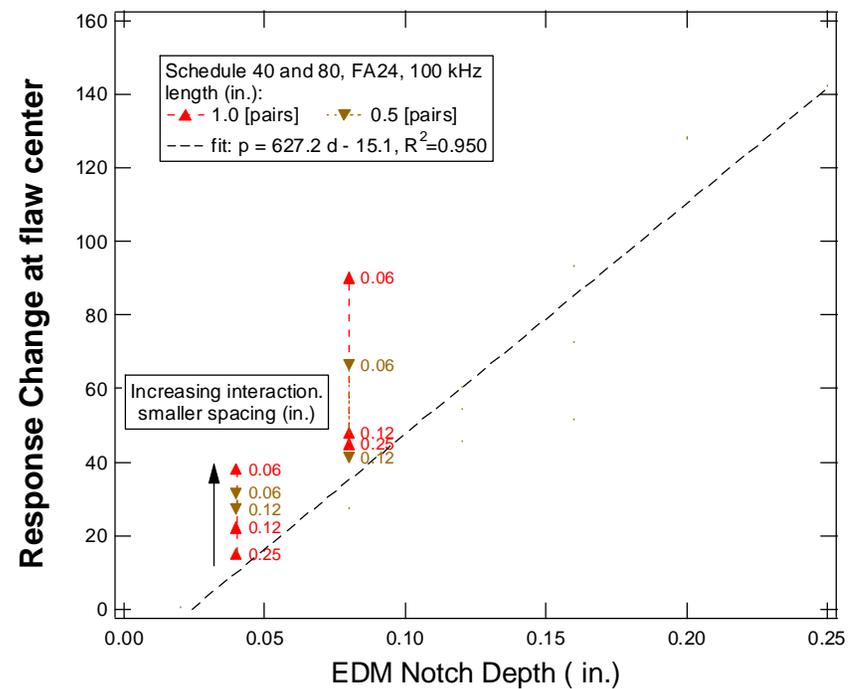
Crack Imaging & Depth Measurement Capability

- Reasonable measurement correlation between depth and effective permeability change
- Pairs of notches show increased response as notches are closer together
- Sensitive to notch depth over this range

Single Crack



Crack Pairs

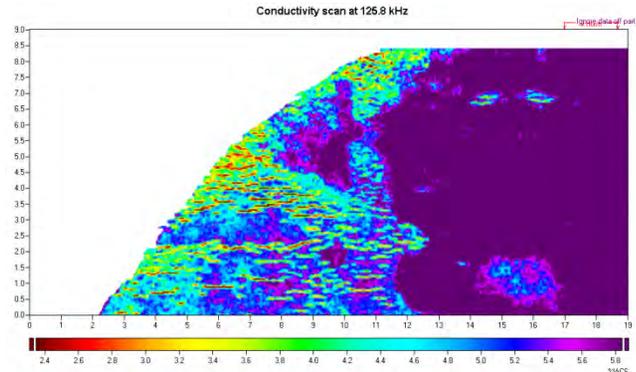


FA28 MWM-Array Imaging of SCC

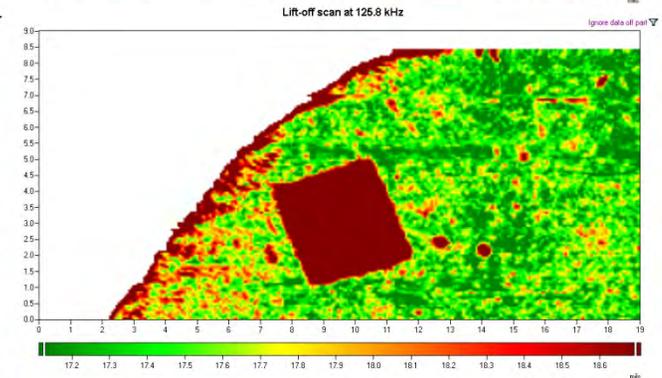
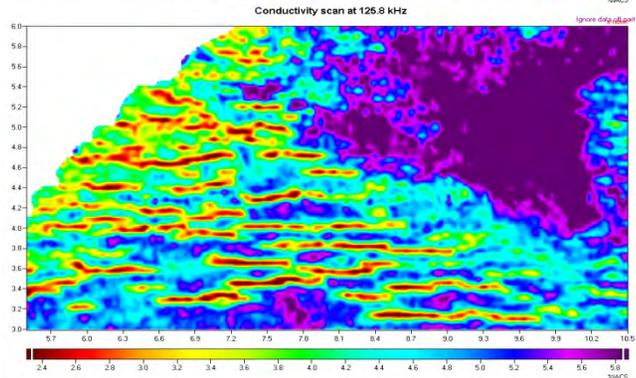
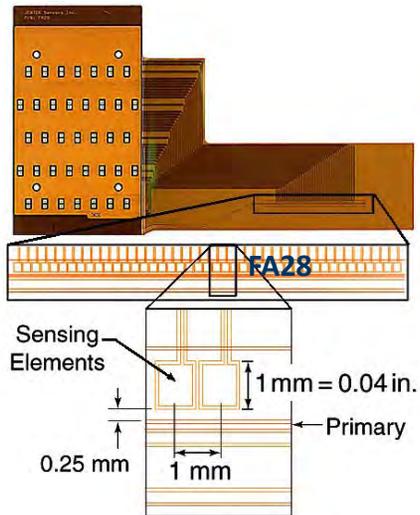
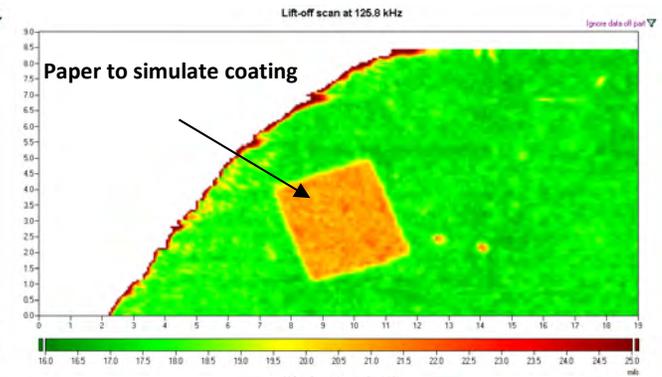
Pipeline Sample Provided by
Applus/RTD



Conductivity Images

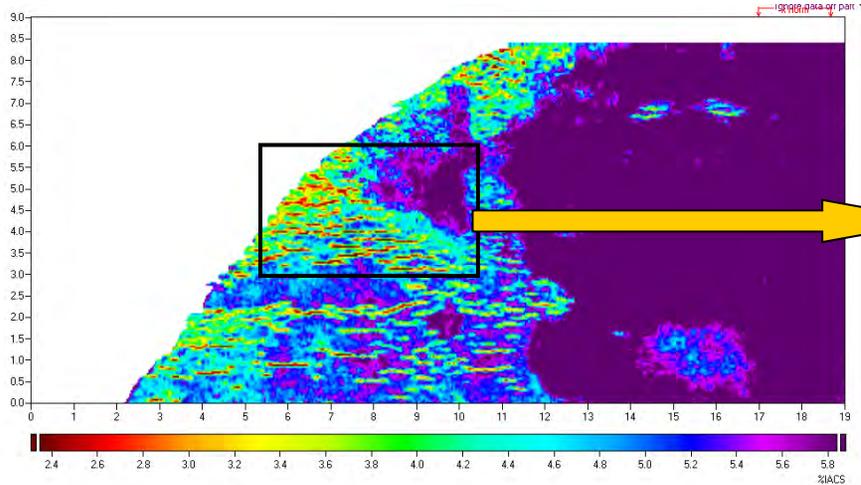


Lift-Off Images

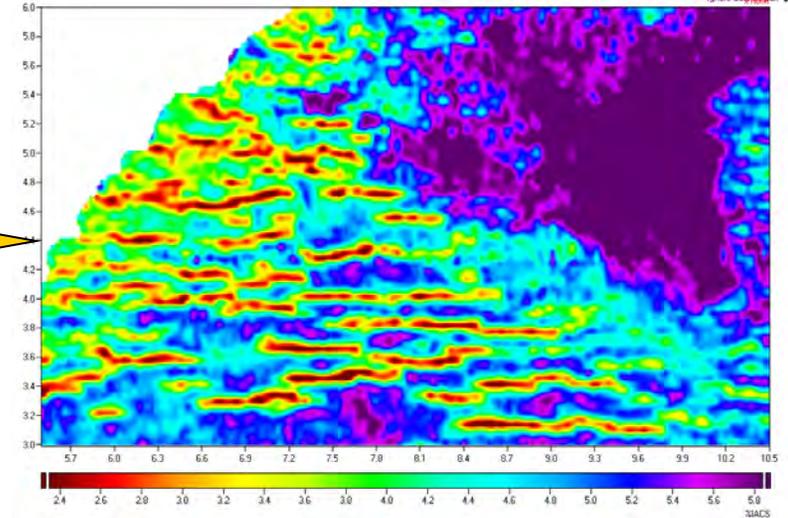


FA28 Imaging of Stress Corrosion Cracking

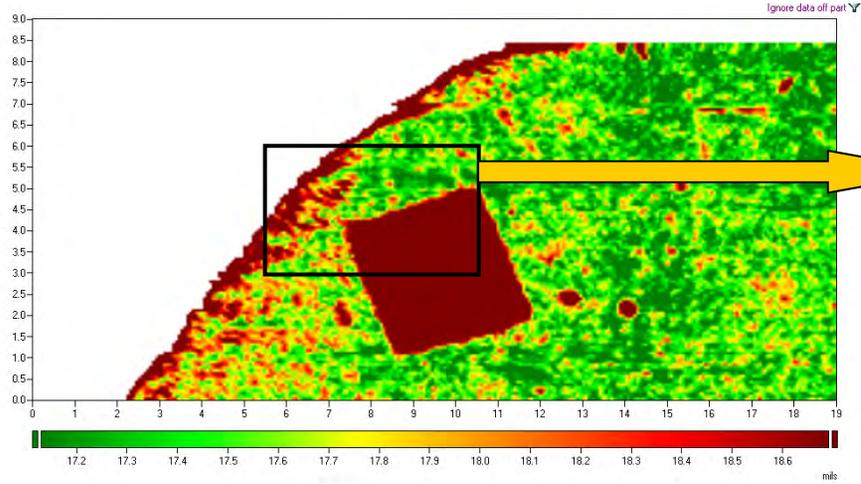
Conductivity Scan



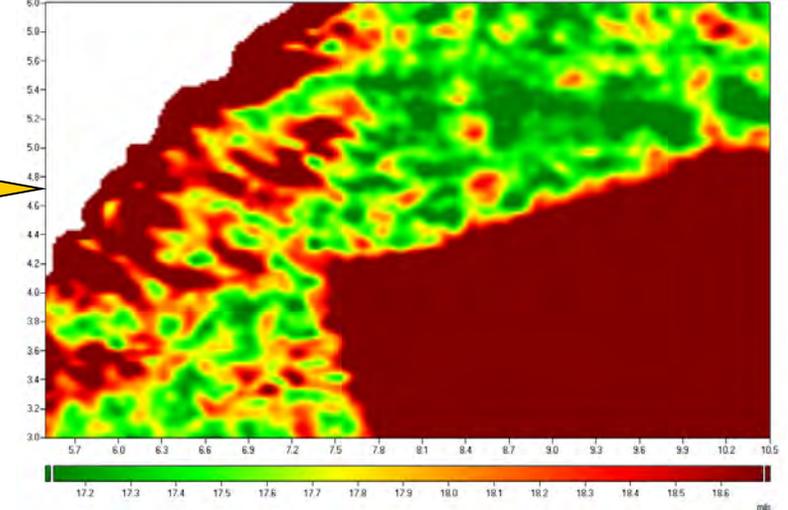
Close-Up of Conductivity Scan



Lift-Off Scan - Through Coating



Close-Up of Lift-Off Scan

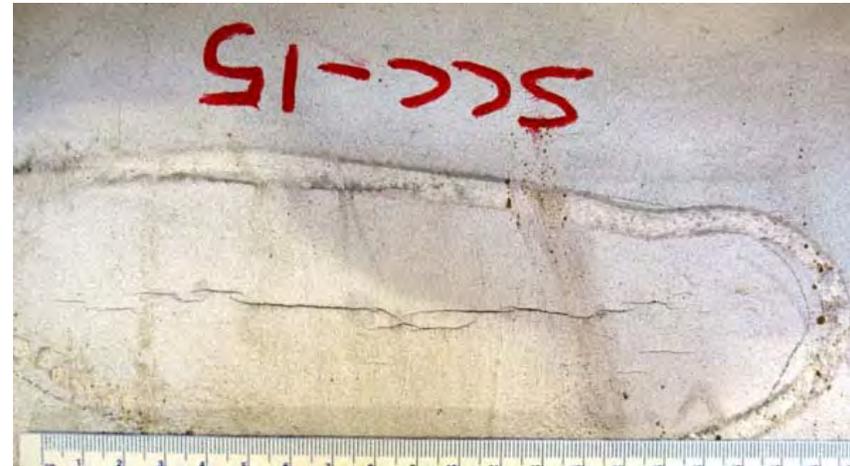
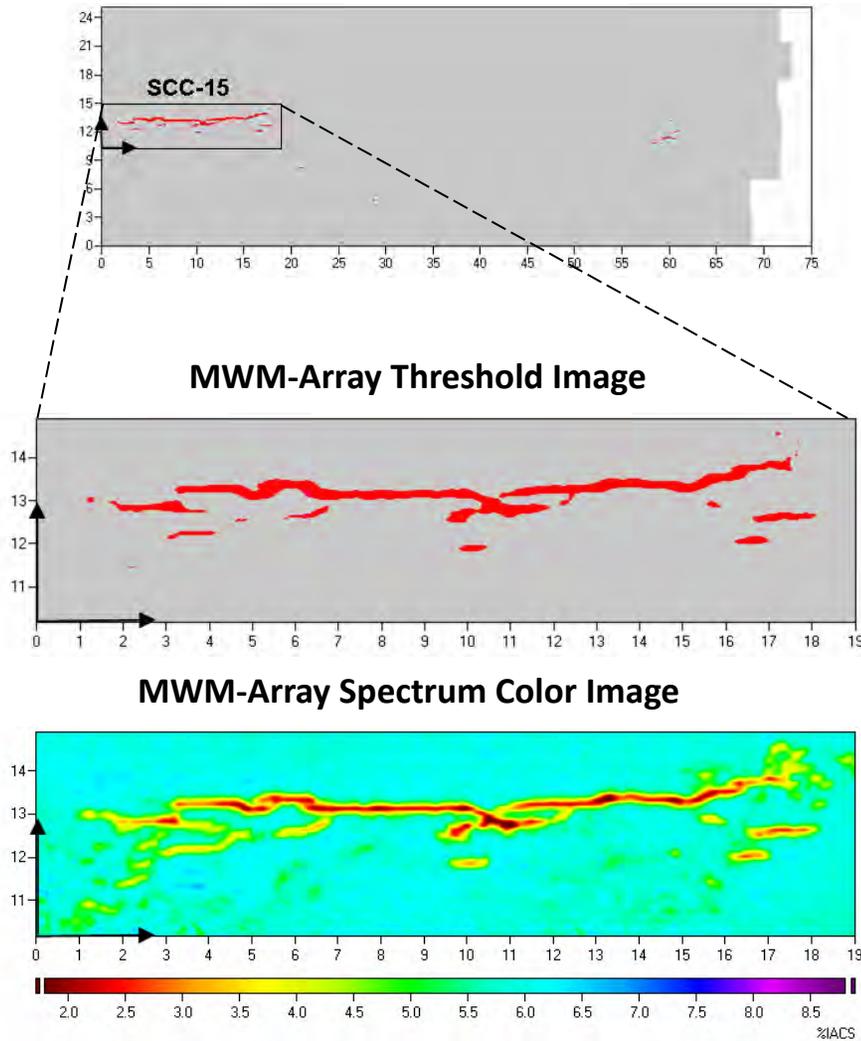


MWM-Array Imaging of SCC in Pipeline Sample

Scans of Pipe Section with Identified SCC (FA28 sensor)

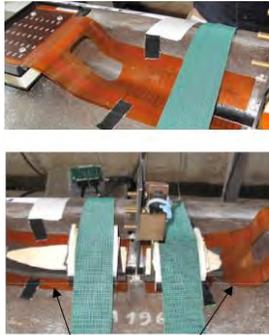


(RTD p/n NPS34 #1)

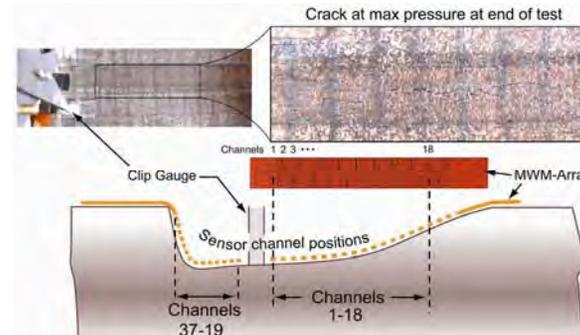


Full-Scale Fatigue Test at Mechanical Damage Site

under DOT and PRCI funding with GDF Suez

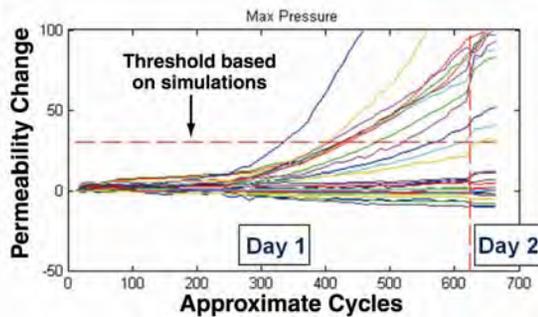
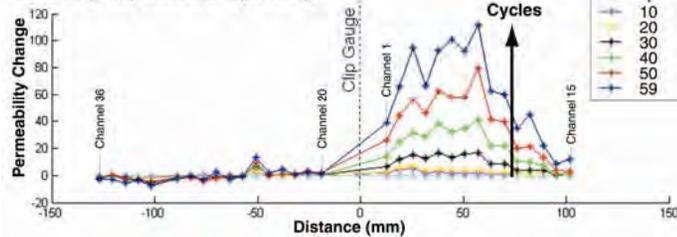


FA178 MWM-Arrays



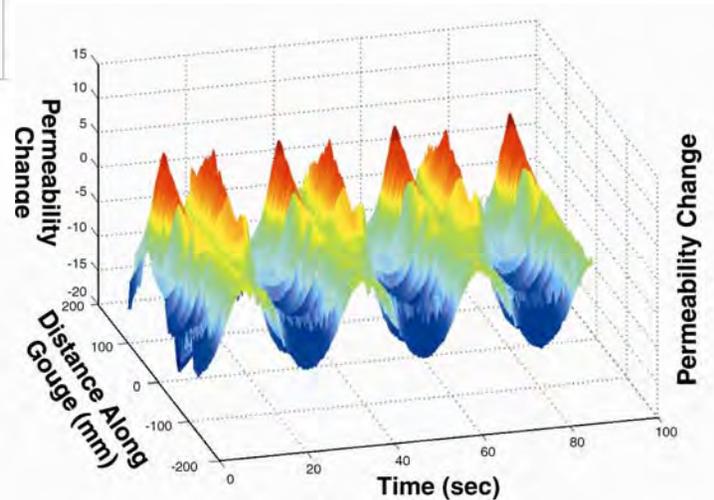
Damage Monitoring

During dynamic cycling

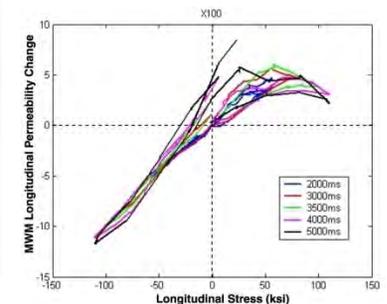
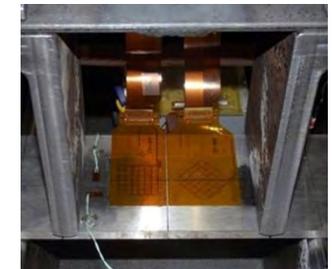


Stress Monitoring

Dynamic pipeline pressure testing

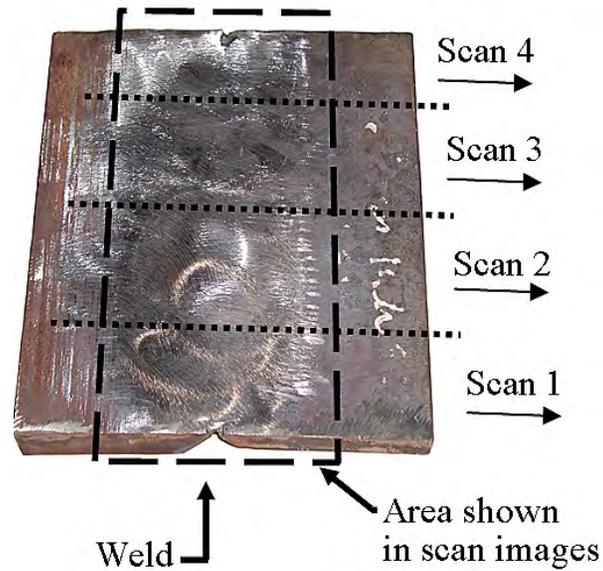


4-pt static load testing of coupon

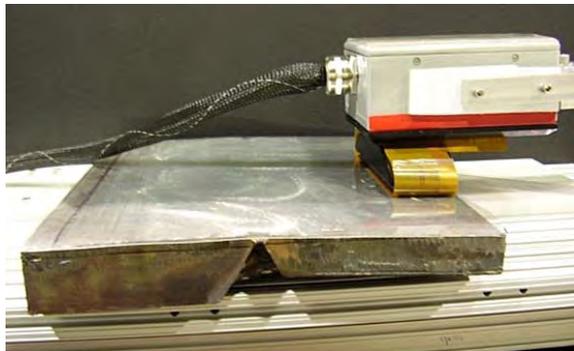


Weld Imaging

MWM-Array Residual Stress Imaging



Permeability/stress scanning across the weld



For Post-weld heat treatment (PWHT)

Effect of Thermal Stress Relief on Weld in Witness Coupon, Pressure Vessel Steel

