MWM-Array Characterization of Mechanical Damage and Corrosion

Industry De-Brief

Presented by:

JENTEK Sensors, Inc.

Contract Number: DTPH56-10-T-000009
Modification #0001

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=354

PHMSA - Office of Pipeline Safety
May 14, 2015

Agenda

- Welcome & PHMSA Introductions
  - Jim Merritt
- Project Summary
- Results & Recommendations
- Q&A and Discussion
- Adjourn

Meeting Information

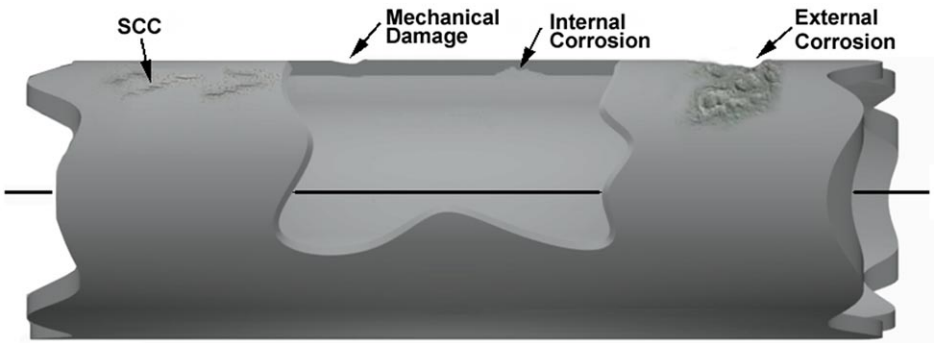
- Thursday, May 14, 2015
- 2PM - 3PM (EDT)
- Conference Call Line:
  - Phone: **877-336-1839**
  - Access Code: **2781644**
- LiveMeeting URL:
  https://www.livemeeting.com/cc/phmsa/join?id=B8T6MH&role=attend&pw=w%23b%3CCN49c

Research Team

- **JENTEK Sensors Inc.:**
  - Neil Goldfine, President, JENTEK Sensors, Inc.
  - Todd Dunford, Principal Investigator (Presenter)
  - Andrew Washabaugh
  - Yanko Sheiretov
  - Scott Denenberg
  - Shayan Haque
- **Industry Participants:**
  - John O'Brien, Chevron
  - Mures Zarea, GDF-Suez
  - Didier Caron, GDF-Suez
  - Mark Lozev, BP
  - Richard Kania, TransCanada
  - Mark Piazza, Colonial Pipeline (and PRCI)
- **PHMSA:**
  - James Merritt

Project Objectives

- This recently-completed program was aimed at advancing JENTEK's magnetic field-based eddy current technology to provide **quantitative assessment** of damage – mechanical damage and corrosion – in pipelines. There was also a limited focus on SCC imaging and weld inspection.
- For mechanical damage, the focus was on quantitative characterization of geometric variations and multidirectional residual stresses, as well as crack detection at mechanical damage sites.
- For corrosion, the focus was on enhanced high resolution imaging of both external and internal corrosion through coatings/insulation and weather protection.

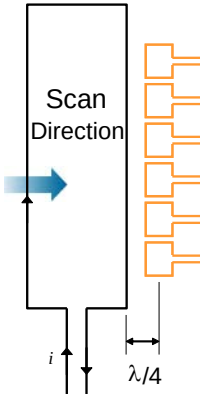


Technology Background

Technology Description

1. Sensors: MWM®-Arrays

- **Paradigm shift** in sensor design (first priority is predictable response based on physics-based modeling)



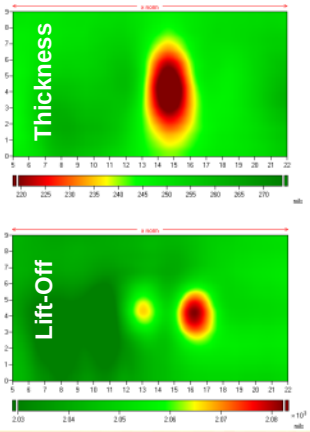
2. Next Generation 8200 GridStation® Electronics

- 10x signal-to-noise improvement
- Very low frequencies (deep penetration)
- Crack detection through up to 0.5 inches of material
- Reduced drift

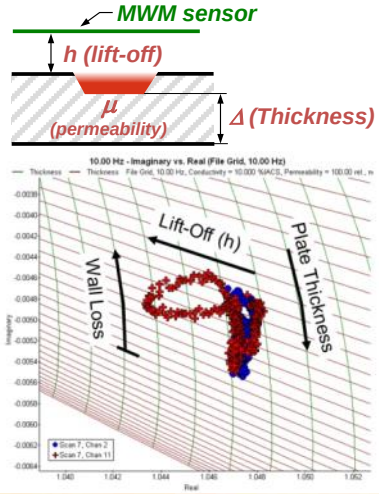
3. GridStation Software using Hyperlattices®

- **Rapid, autonomous data analysis**
  Performs multivariate inverse method (MIM) using precomputed databases
  - Defect Images
  - Performance Diagnostics
  - Noise Suppression

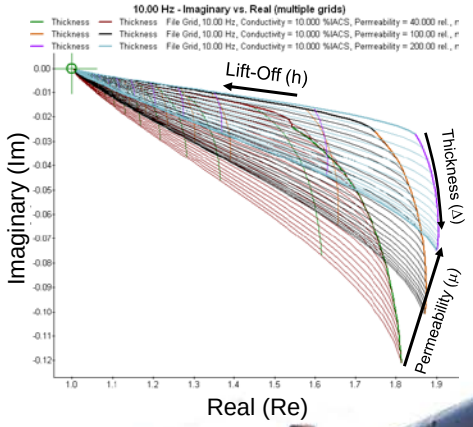
Images



Analysis

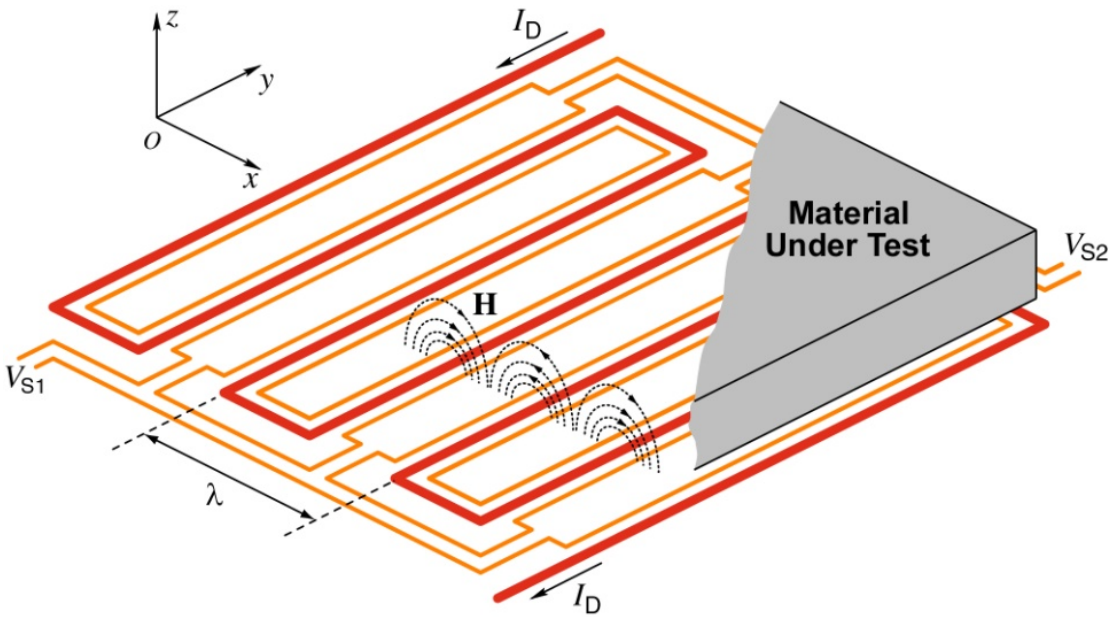


Solve Multiple Unknown Problems MIM



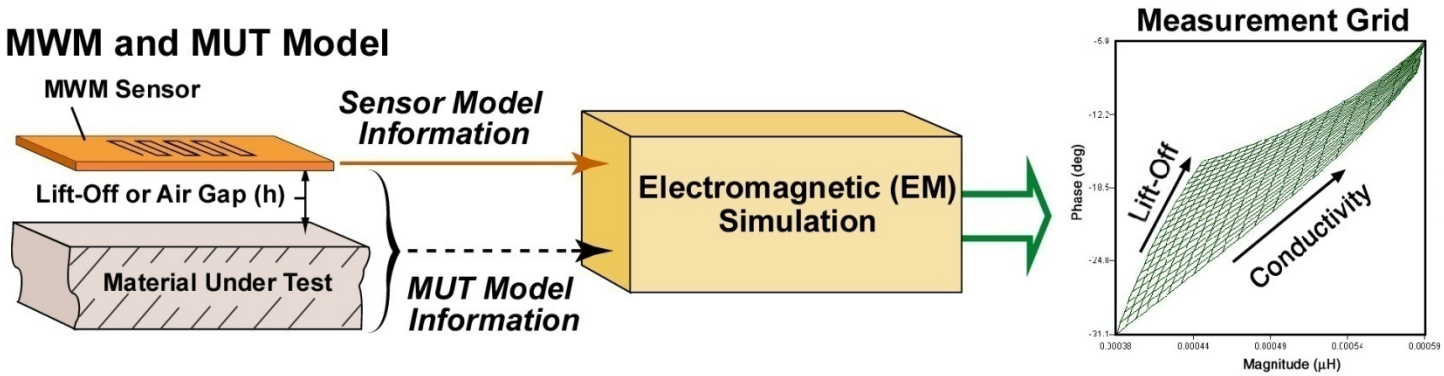
MWM® & MWM-Array Background

- Designed using winding constructs that are easy to model
- Enables response prediction for typical pipe/coating constructs
- Magnetic field-based method
- Variations in magnetic field reflect test material condition

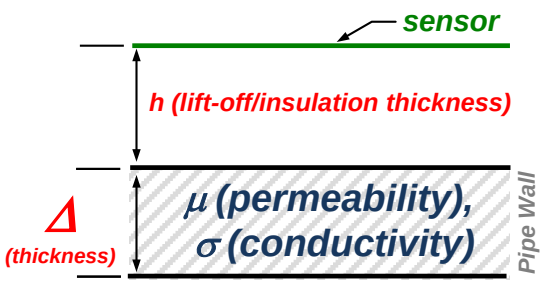


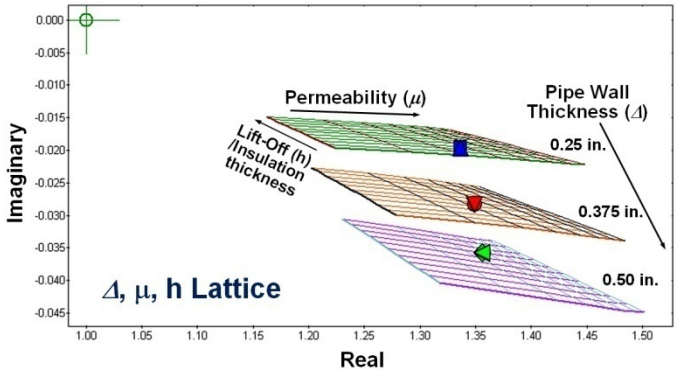
MWM & MWM-Array Sensors are Designed to Match Models
(Predictable Responses)

JENTEK Grid Methods Provide Rapid Data Processing



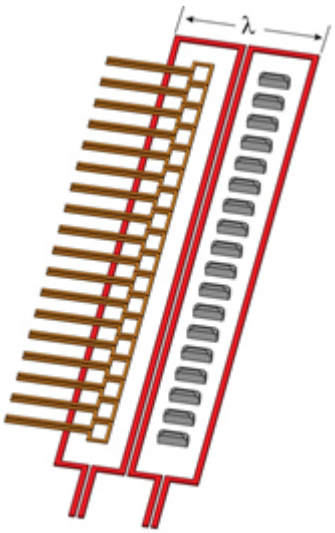
Lattices for Estimating Multiple Properties





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

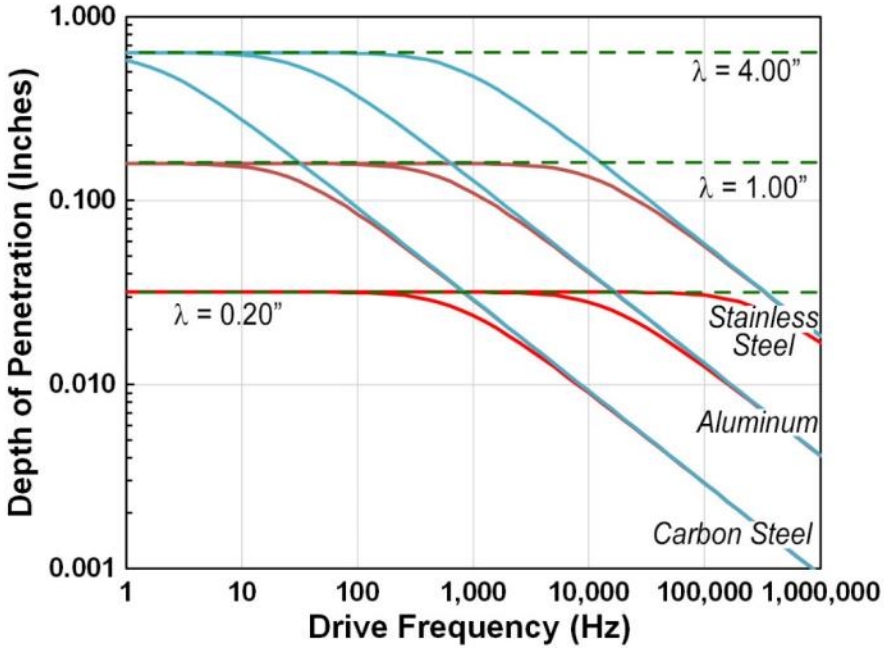


Depth of Penetration = $1/\mathrm{Re}(\Gamma_n)$

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

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

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

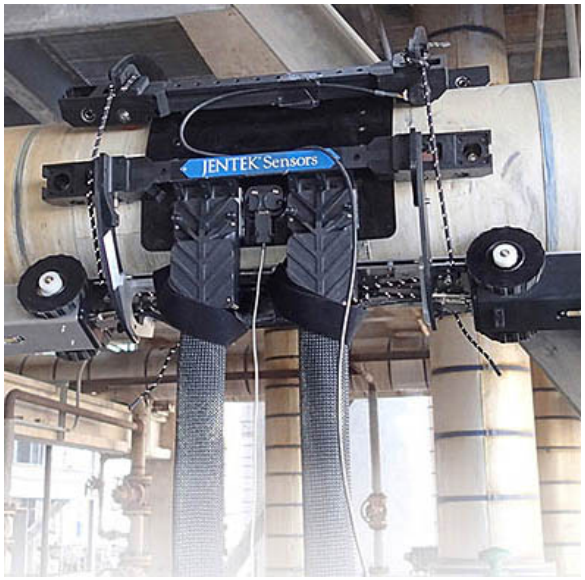


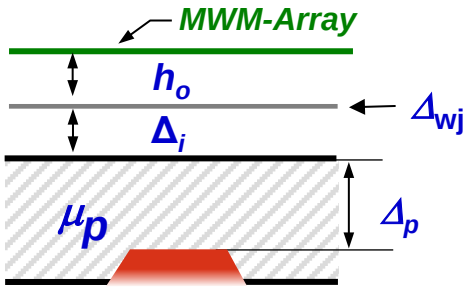
1 inch = 25.4 mm

Summary of Project Results

Detection and Characterization of Internal and External Corrosion through Insulation and Weather Jacket

Problem Definition





$$h, \Delta_{wj}, \Delta_i, \Delta_p, \mu_p$$

h_o = distance between sensor & external surface of weather jacket

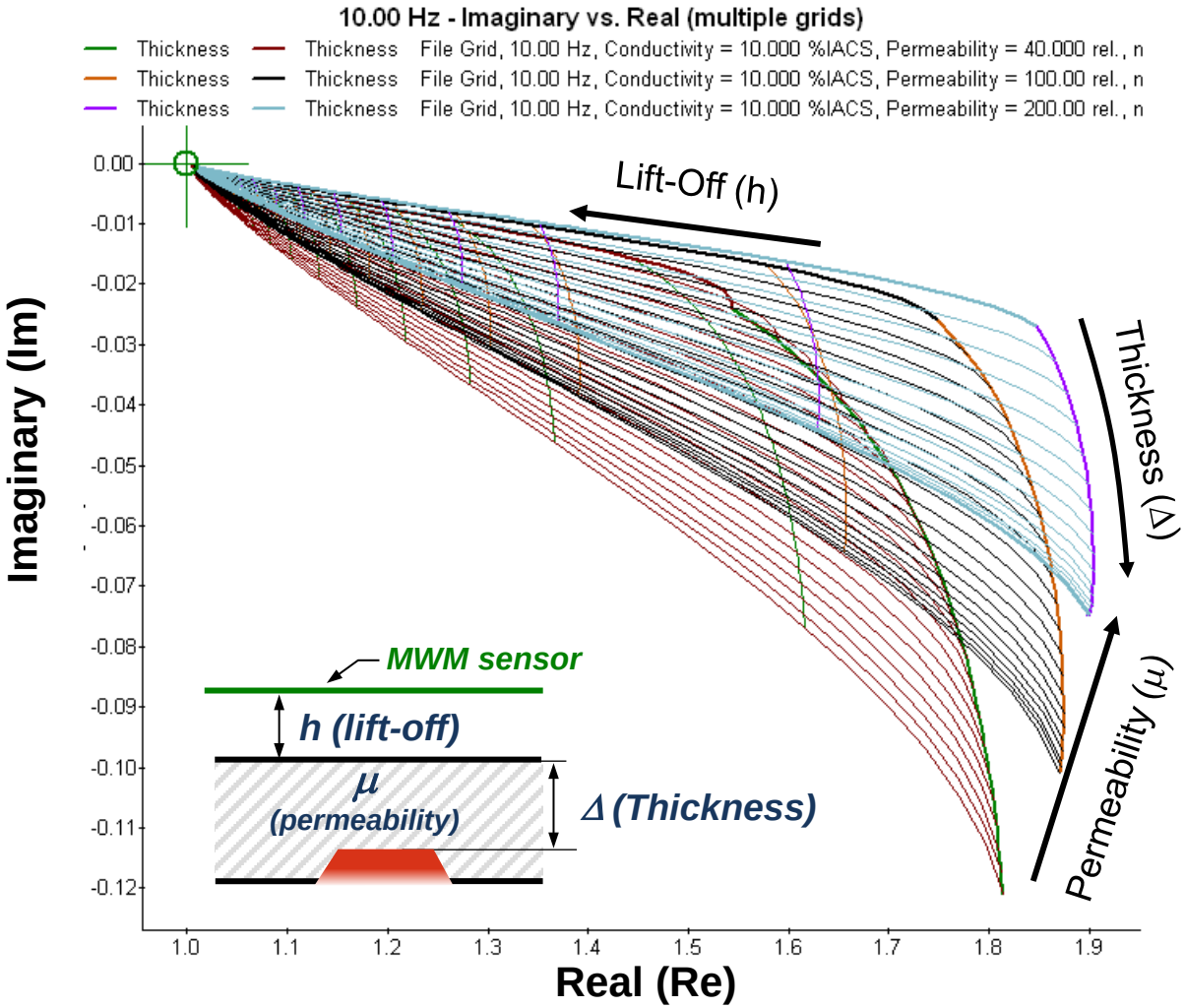
Δ_{wj} = weather jacket thickness

Δ_i = insulation thickness + external metal loss

Δ_p = remaining pipe wall thickness

μ_p = pipe magnetic permeability

Technology Description: 3-Unknown Lattices



- GridStation Lattices for MR-MWM-Array **wall loss imaging**
- Used for **external and internal** wall loss imaging

|Z| = Magnitude

θ = Phase

$$|Z| = \sqrt{Re^2 + Im^2}$$

$$\theta = \arctan(Im/Re)$$

$$Re = |Z|\sin(\theta)$$

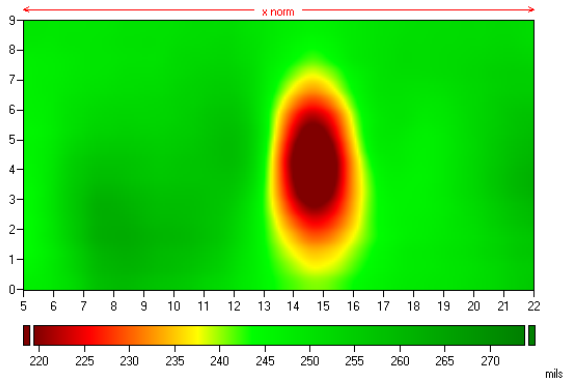
$$Im = |Z|\cos(\theta)$$

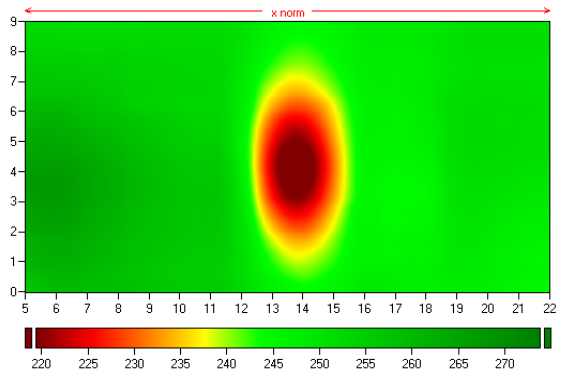
Lab Demonstration of ID/OD Discrimination

External Wall Loss

Internal Wall Loss

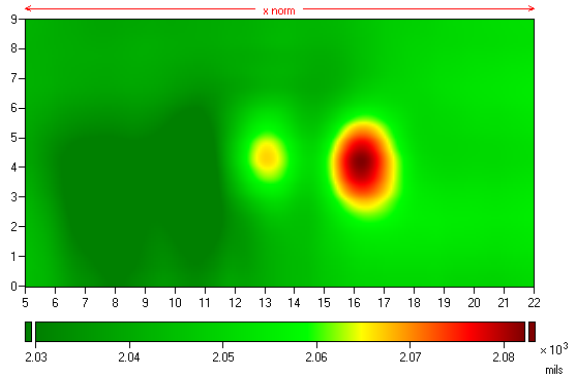
Thickness

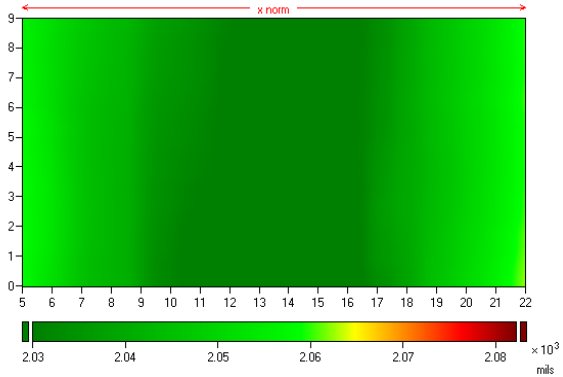




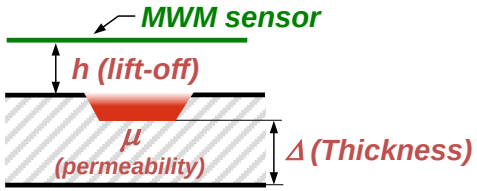
Thickness

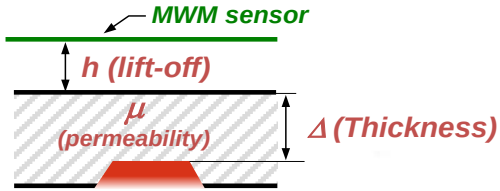
Lift-Off





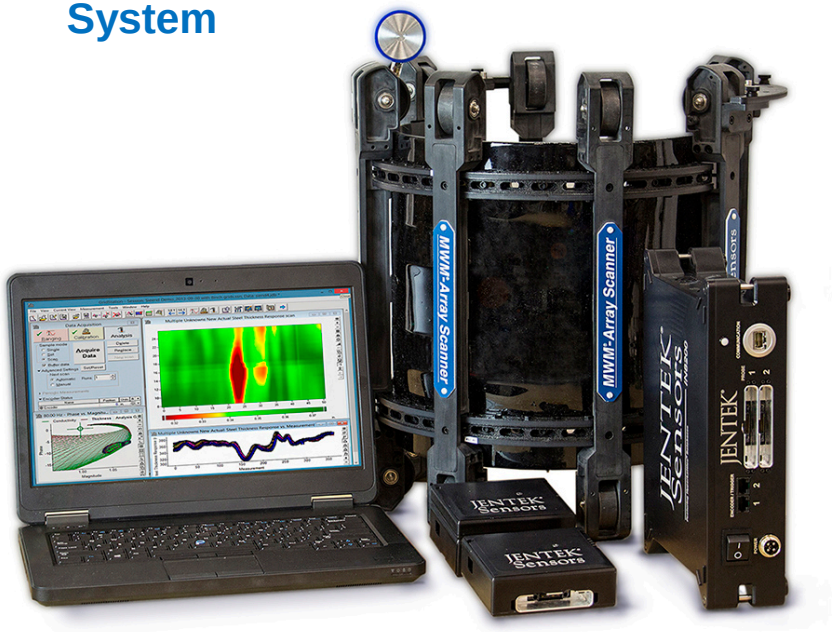
Lift-Off





Solution: Corrosion Imaging System

8200 Non-Integrated System



8200 Integrated System

Setup & Calibration Time: ~ 20 minutes
Scan Speeds: 2 – 3 in./sec.

Performance Evaluation of Corrosion Imaging System

Results comparison with known natural corrosion defects both on the OD (CUI) and the ID:

Axial Length (inches/mm)	Circumferential Length (inches/mm)	Mean Depth (inches/mm)	Hit/Miss
1.5/38.1	1.5/38.1	0.12/3.0	Hit
9.0/228.6	1.5/38.1	0.06/1.5	Miss
2.0/50.8	1.5/38.1	0.08/2.0	Miss
4.0/101.6	1.25/31.75	0.12/3.0	Hit
4.0/101.6	4.0/101.6	0.08/2.0	Hit*
4.0/101.6	4.5/114.3	0.08/2.0	Hit*
1.75/44.45	2.75/69.85	0.1/2.5	Hit
2.75/69.85	2.5/63.5	0.12/3.0	Hit
1.0/25.4	0.75/19.05	0.16/4.0	Miss

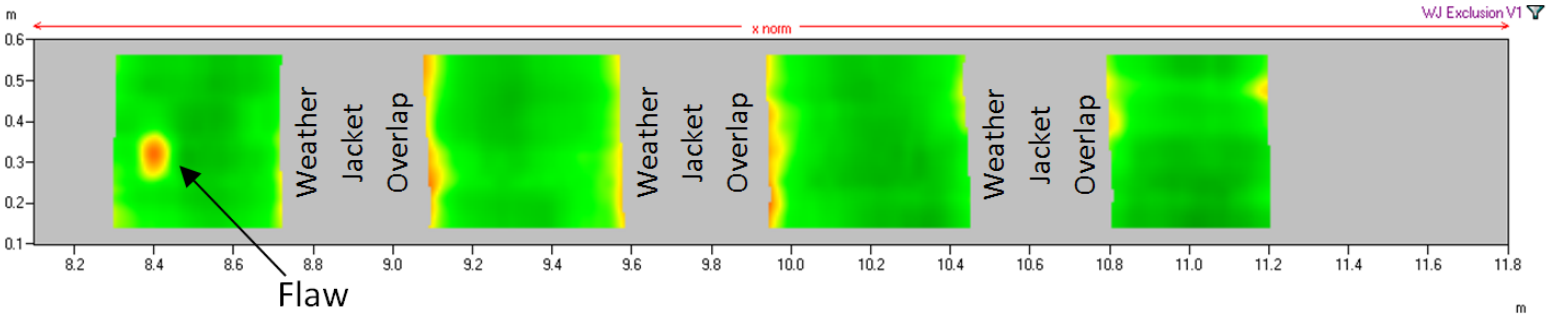
0 produced two distinct indications in the scan data. The individual areas ations were identified on a best-effort basis.

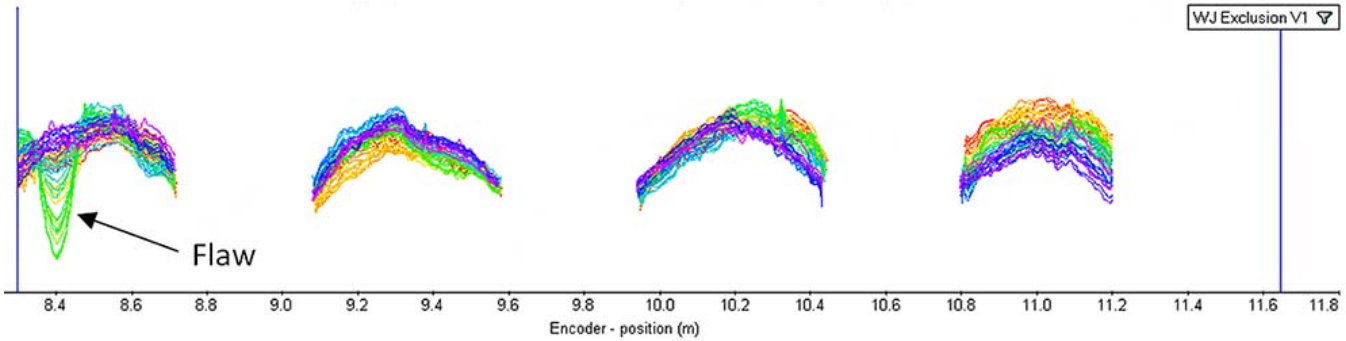
Performance Evaluation Results (December 2013)

External Corrosion – Sample B

Pipe Data:
20” Diameter, 0.250” wall
2” insulation with aluminum weather jacket

Flaw Data:
2.75” (Axial), 2.50” (Circumferential), 0.12 Deep (48%)

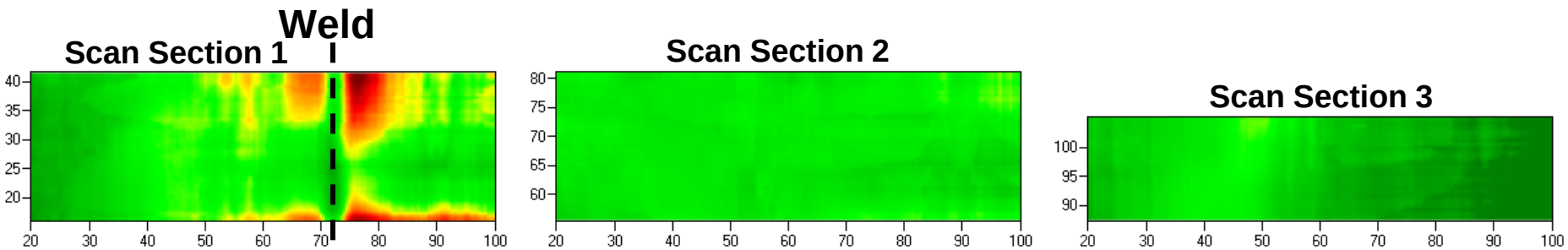




Performance Evaluation Results (July 2013)

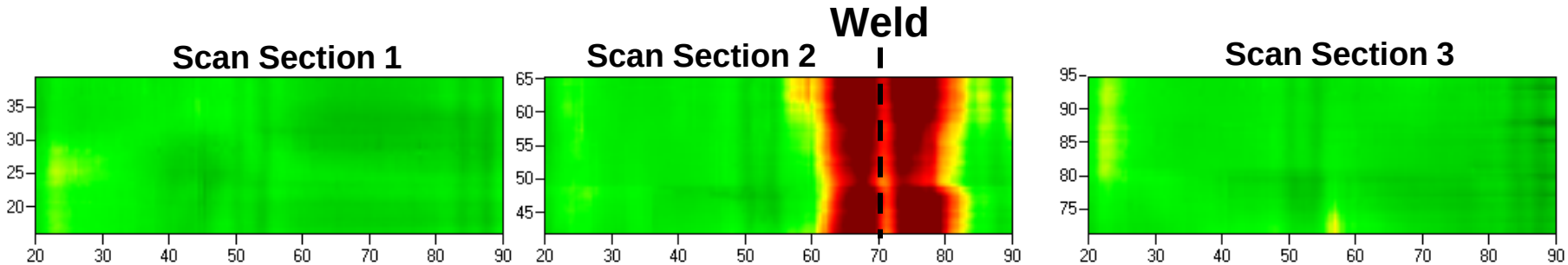
Internal Corrosion Sample A

16” Schedule 80 (0.500” wall)
2” insulation with aluminum weather jacket
0.100” max wall loss (20%) over 20-25 inches (full circumference)



Internal Corrosion Sample B

16” Schedule 80 (0.500” wall)
2” insulation with aluminum weather jacket
0.175” max wall loss (35%) over 20-25 inches (full circumference)



JENTEK Corrosion Imaging Tool – Current Capability

System capabilities:

- Aluminum or stainless steel weather jacket up to 0.040 inches
- All insulation types up to 3 inches thick
- Internal and external corrosion imaging on carbon steel pipes up to 0.5 inches thick
- Current focus is on piping, but the method works on vessels or other carbon steel structures

Areas of corrosion with dimensions exceeding the following numbers will have a high probability for detection:

- 1 inch diameter @ 65% wall loss (average)
- 2 inch diameter @ 50% wall loss (average)
- 3 inch diameter @ 30% wall loss (average)

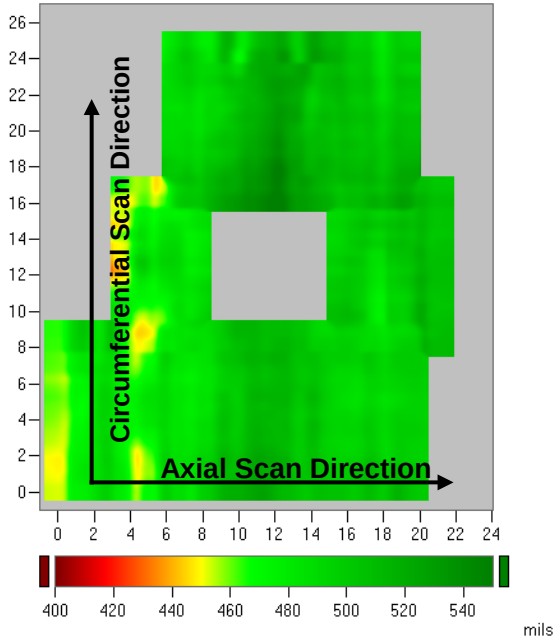
Note: This evaluation was performed on 20 in. pipes with natural corrosion, 0.250 in. wall, 2 in. insulation, and 0.020 in. aluminum weather jacket. The system performance is expected to vary with different pipe configurations.

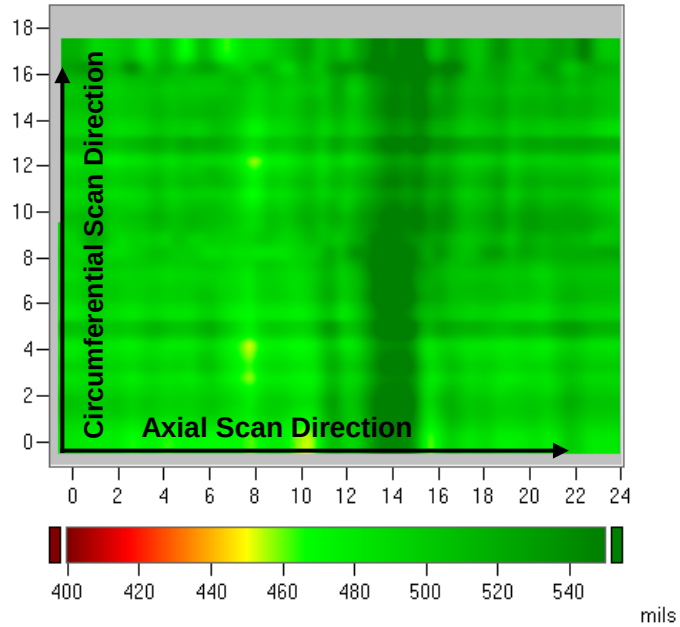
Case Study I - Corrosion Imaging Tool on Refinery Piping

Inspection was performed with the pipe in production at high temperature

Case Study I - Corrosion Imaging Tool on Refinery Piping

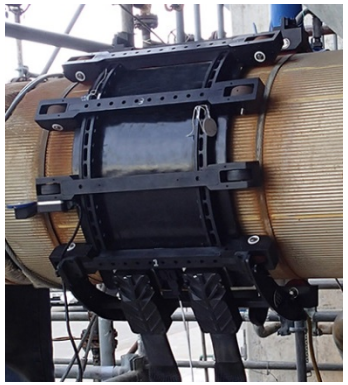
Multiple Unknowns Meas. Steel Thickness Scans

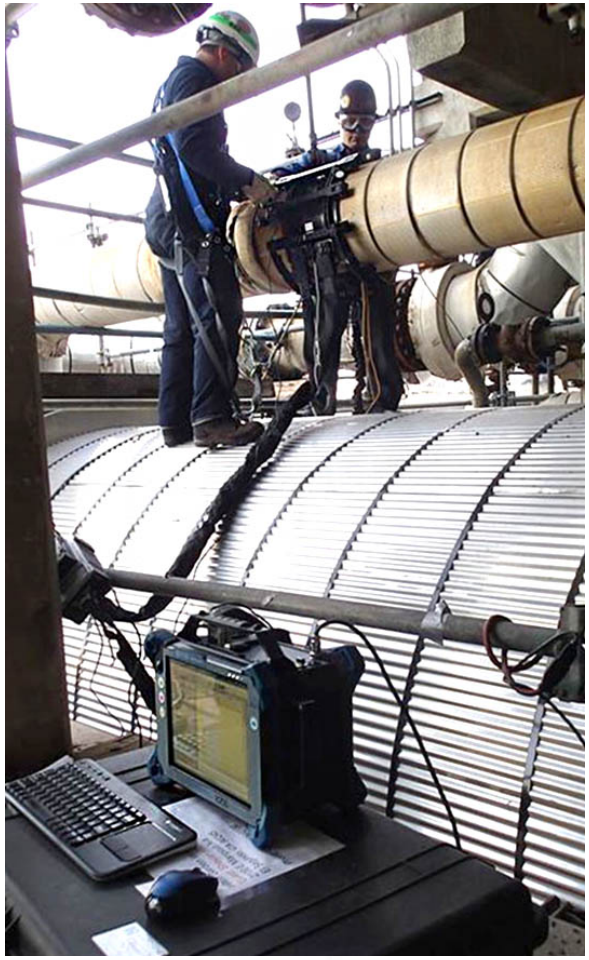




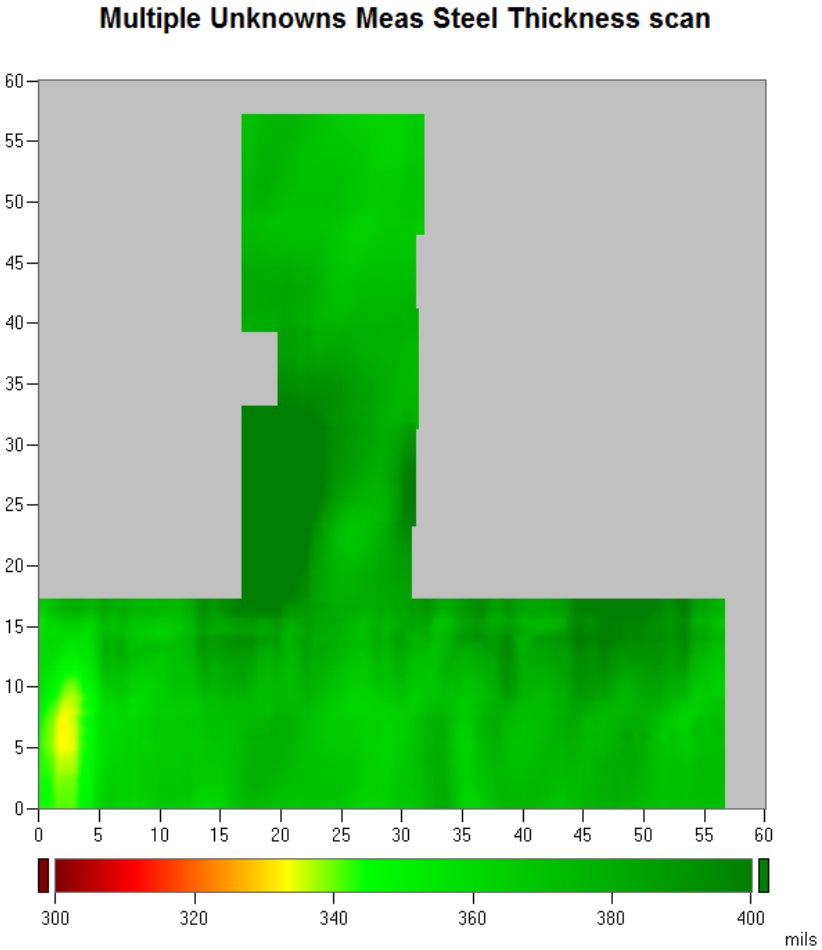
Inspection was performed with the pipe in production at high temperature

Case Study II - Corrosion Imaging Tool on Refinery Piping

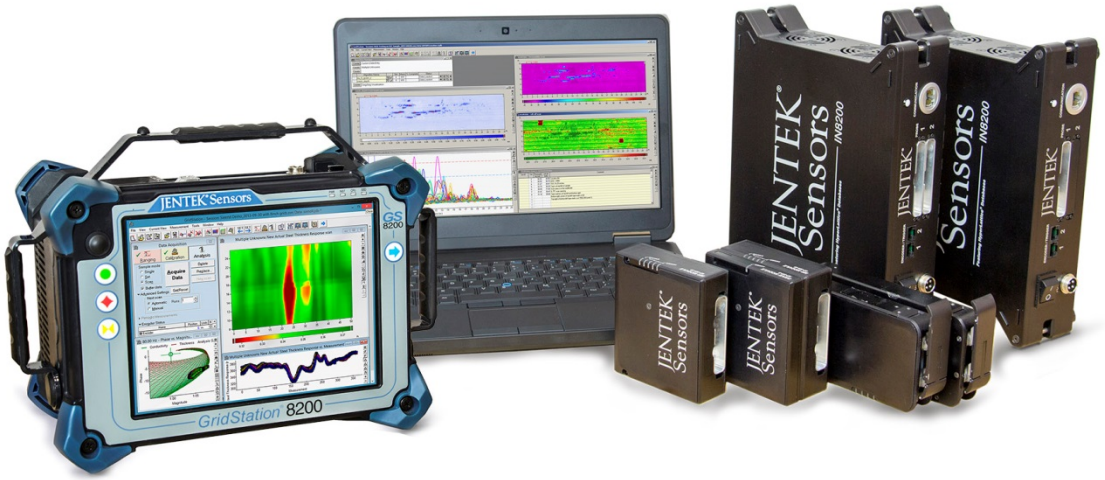




Case Study II - Corrosion Imaging Tool on Refinery Piping



Summary



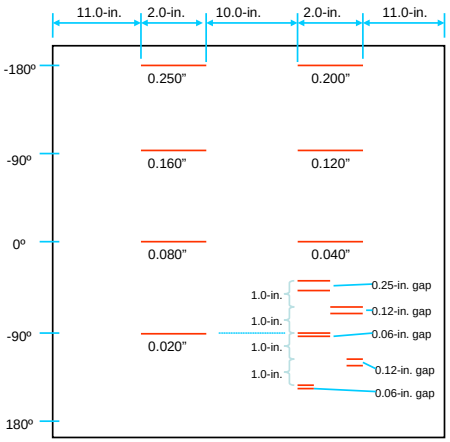
- Transitioning of the technology for field deployment is ongoing
- A comprehensive training and service support program has been developed for approved NDT service providers
- Several field service technicians have undergone JENTEK coursework and training and currently performing field services
- Software and hardware enhancements are ongoing to improve system capabilities

Summary of Project Results

Stress Corrosion Crack (SCC) Imaging and Depth Sizing

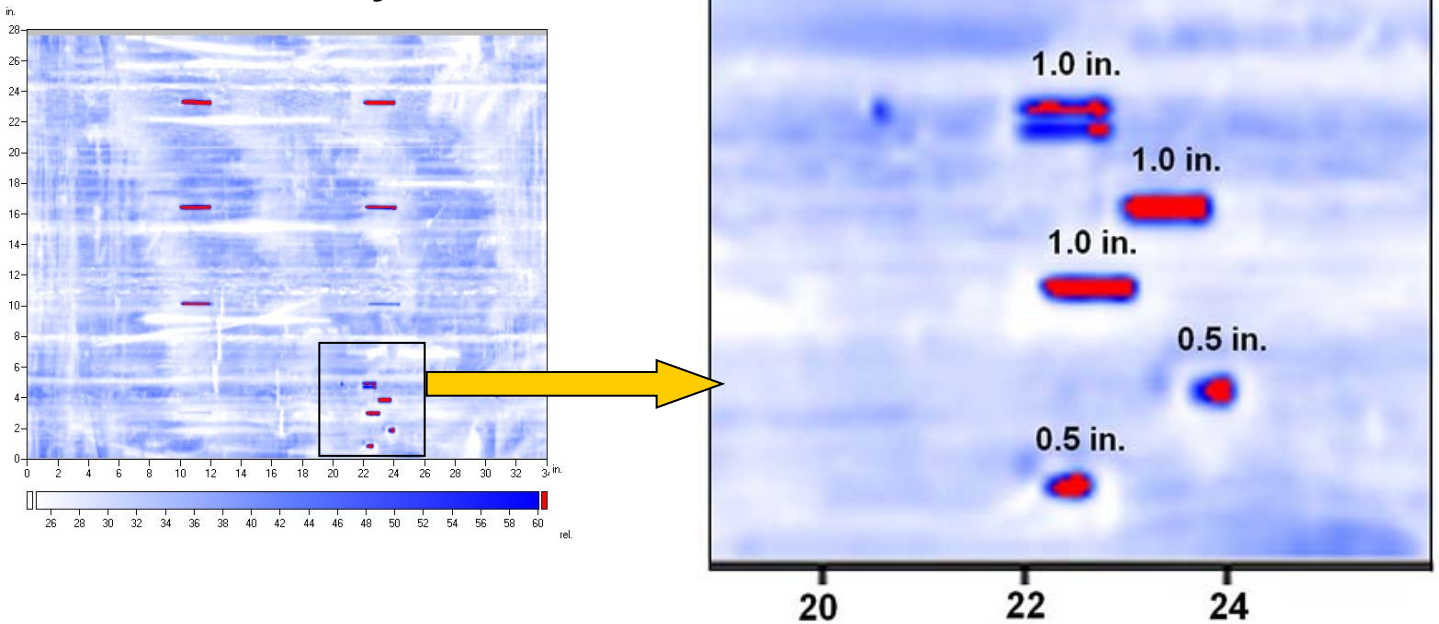
Crack Imaging and Depth Sizing

- **Representative FA24 data at 100 kHz on EDM notch pipe sample**
- **Notches clearly indicated as increase in permeability**
- **Pairs of notches show resolution capability**



Permeability

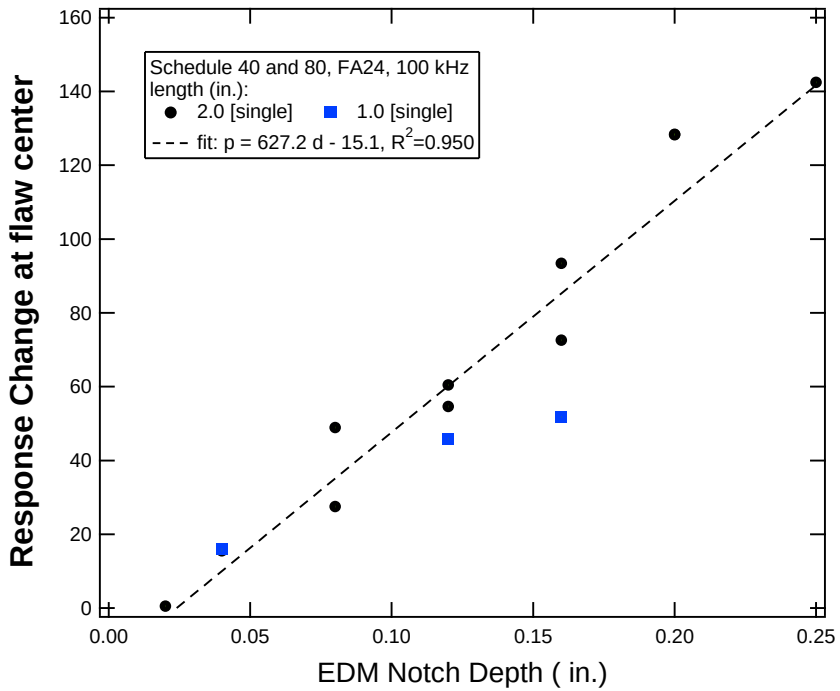
Post-EDM



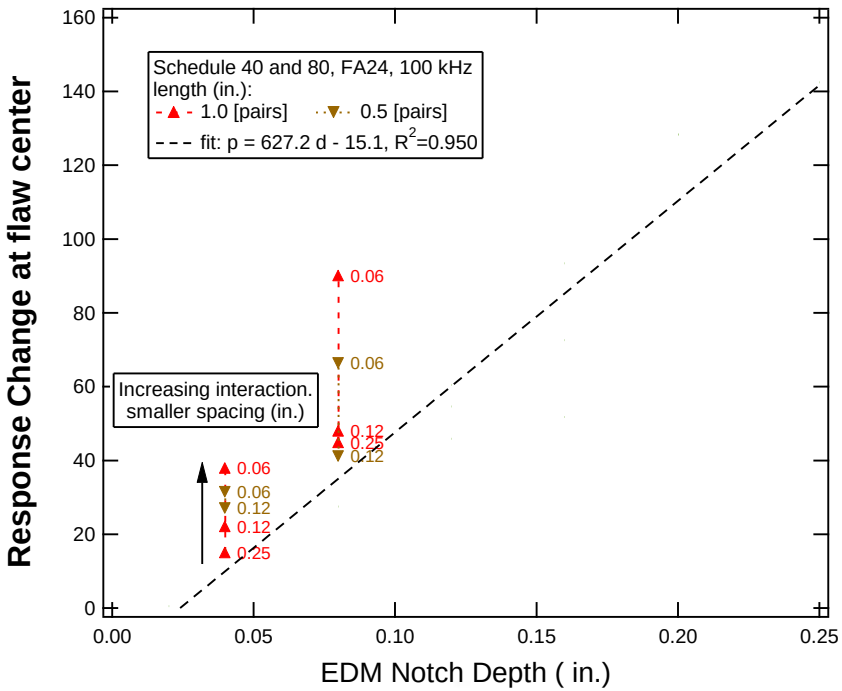
Crack Imaging and Depth Sizing

- **Reasonable measurement correlation between depth and effective permeability change**
- **Sensitive to notch depth over this range**

Single Crack

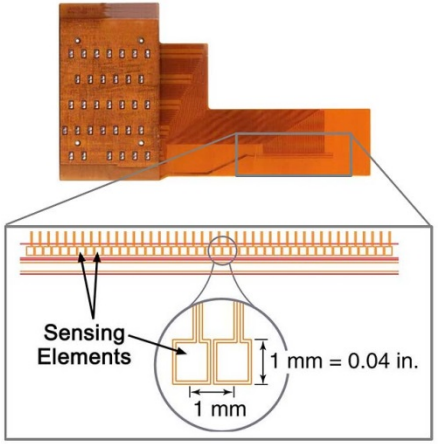


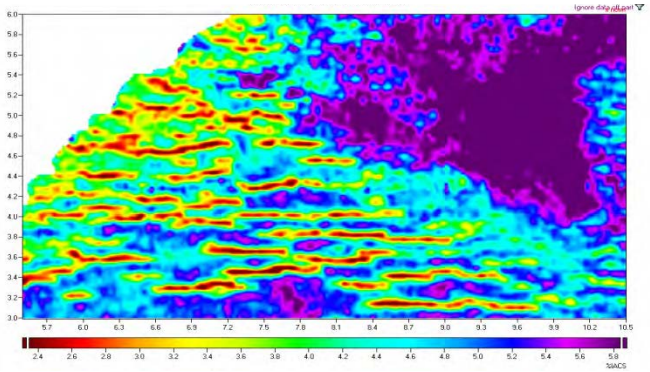
Crack Pairs



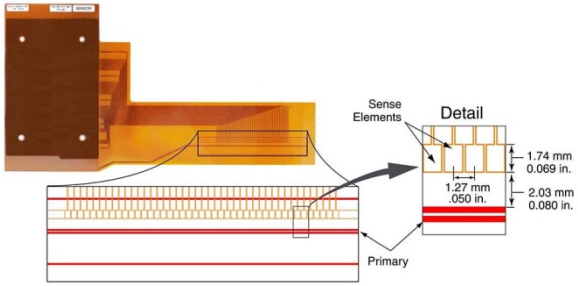
Crack Imaging and Depth Sizing: Sensors

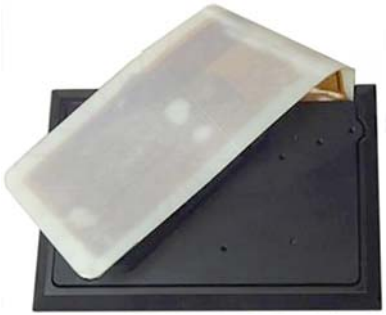
FA28 MWM-Array for Very High Resolution Imaging

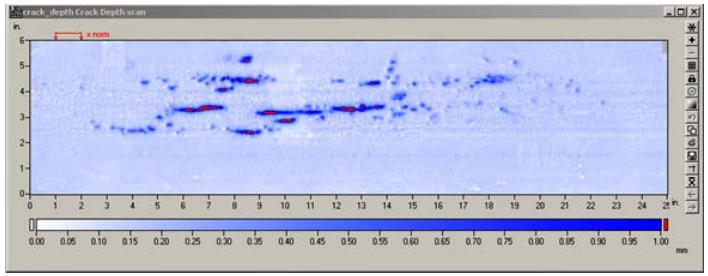




FA214 MWM-Array for High Resolution Depth Sizing



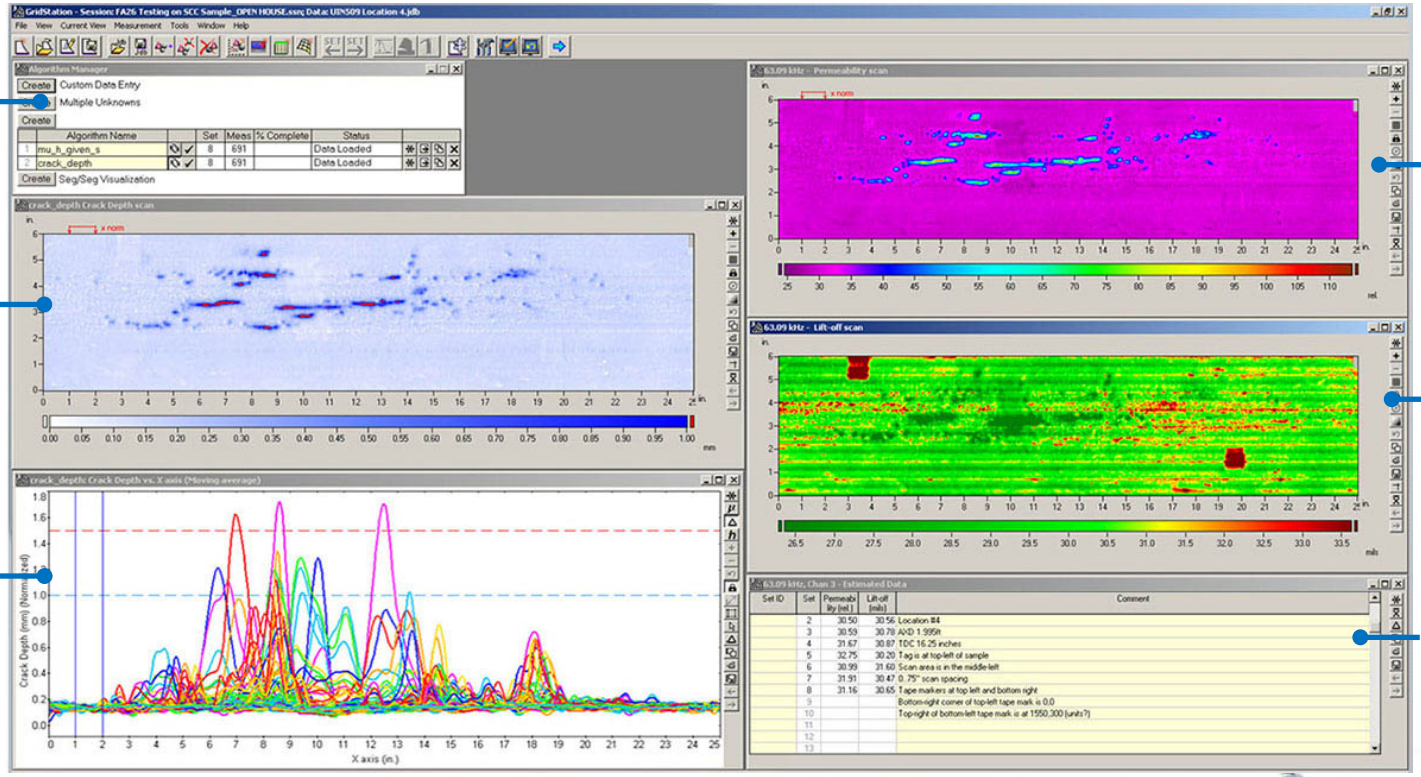




Crack Imaging and Depth Sizing

MWM-Array Mapping of SCC Crack Depth:

- Crack detection through coatings (screening capability)
- Mapping of crack location with digital record (MPI replacement)
- Crack depth estimation (single cracks or SCC colonies)
- Not affected by coatings, surface prep, moisture, or dirt



Summary of Project Results

Mechanical Damage Imaging and Characterization

Crack Detection in Welds and Weld Characterization

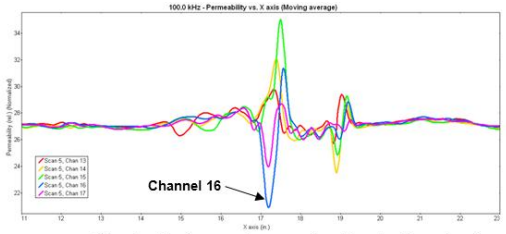
Mechanical Damage Imaging and Characterization

Completed development of a mechanical damage imaging capability

- Magnetic Profilometry
- Crack Detection
- Stress Mapping
- Crack Growth and Stress Monitoring

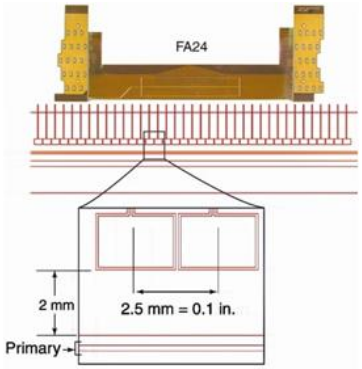
Completed preliminary capability demonstrations

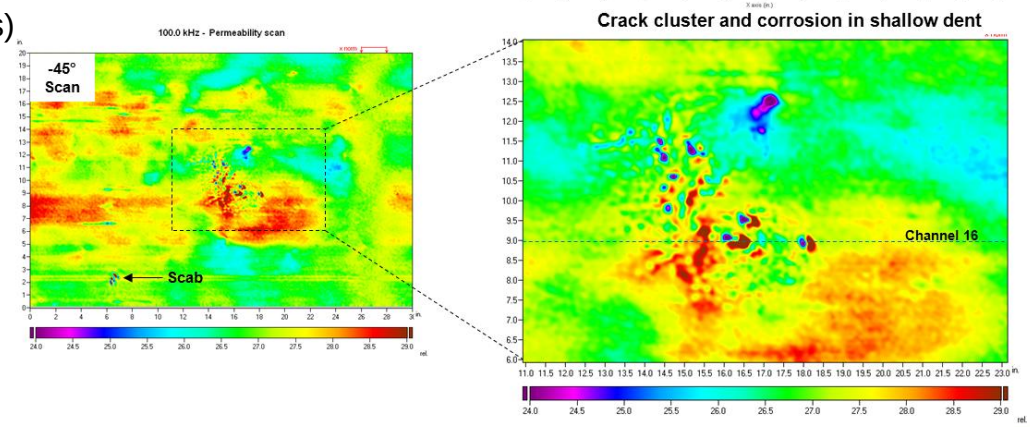
- PRCI Repository in Houston, TX (PRCI matching funds)
  - Magnetic profilometry, crack detection, and stress mapping
- GDF-Suez in Saint Denis, France (PRCI matching funds)
  - Crack detection, crack growth monitoring, stress monitoring
  - Successfully stopped the test before pipe failure



Completed enhanced capability demonstrations

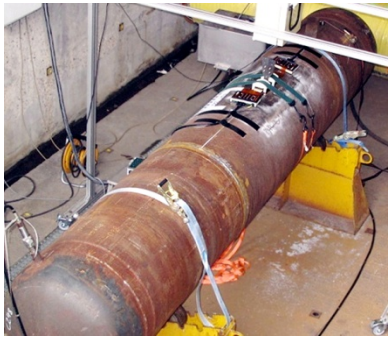
- PRCI Repository in Houston, TX (PRCI matching funds)
  - Crack detection, stress mapping

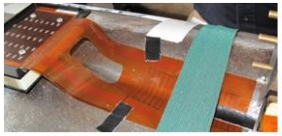


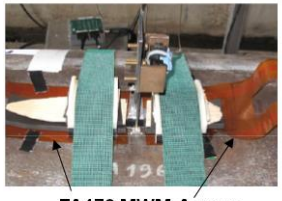


SHM for Crack Growth Monitoring in Dents & Gouges

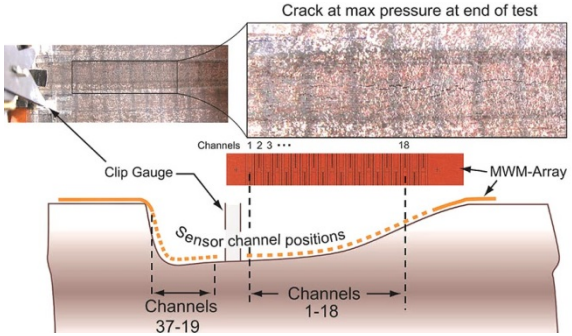
Under DOT and PRCI Funding with GDF Suez



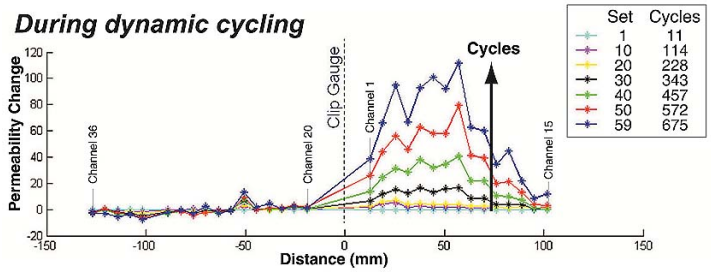


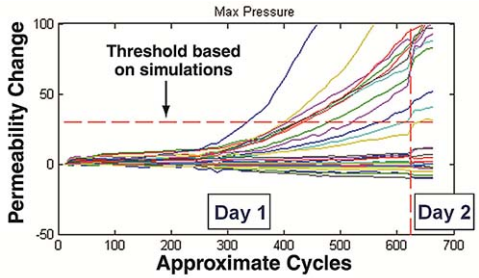


FA178 MWM-Arrays



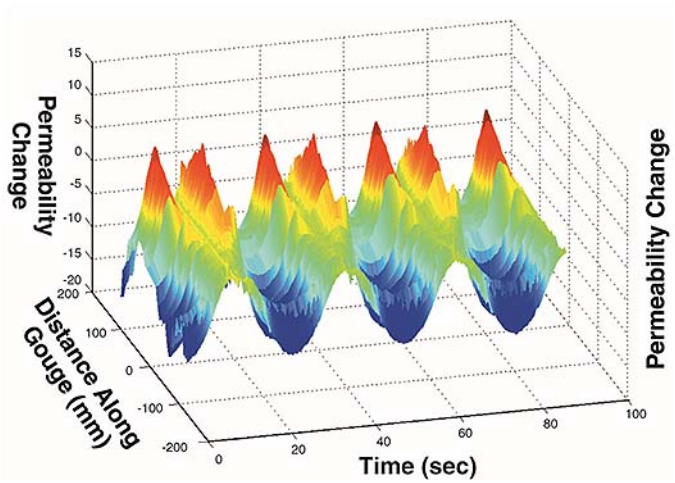
Damage Monitoring



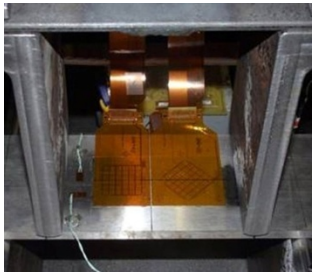


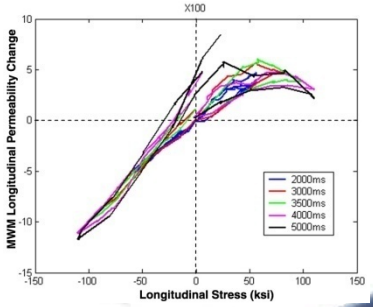
Stress Monitoring

Dynamic pipeline pressure testing



4-pt static load testing of coupon





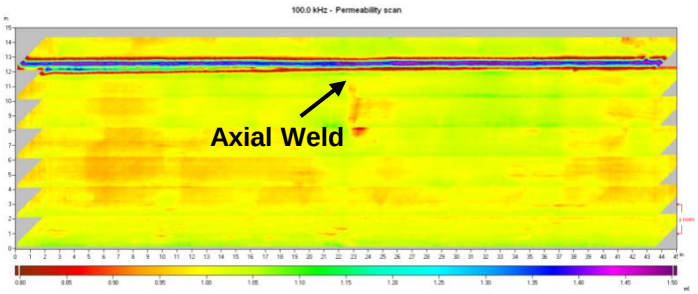
Crack Detection in Welds And Weld Characterization

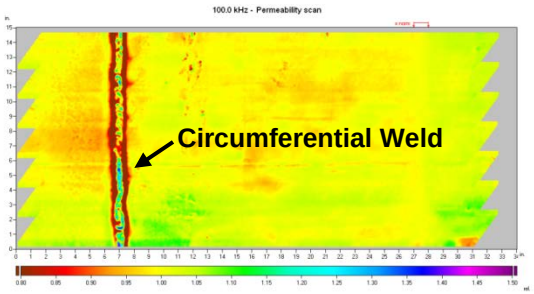
Completed investigating inspection methods for cracks in welds

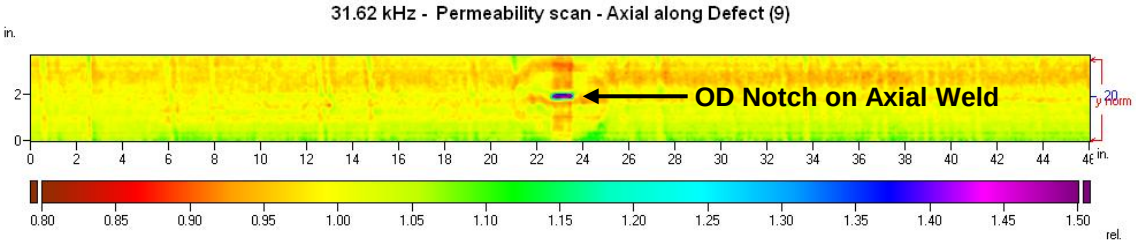
- A limited effort under this program, with the goal to develop:
  - Algorithms that can suppress the inconsequential weld property variations and
  - Enhance responses associated with defects that can degrade weld and neighboring pipe material integrity

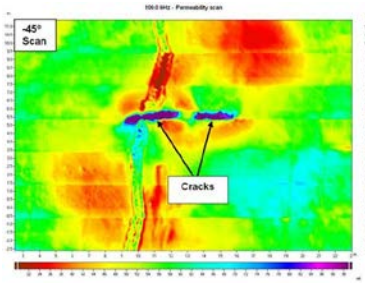
Completed preliminary capability demonstration of weld imaging and characterization

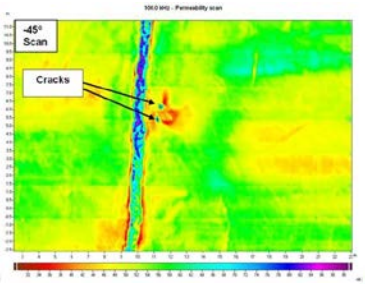
- Successful laboratory demonstrations in 2012 and 2013 for detection of weld defects
  - **2012 :** API 5L sample with ID and OD notches provided by industry partner
  - **2013 :** Samples provided by PRCI with dents & cracks in welds











ERW weld in an API 5L grade pipe section

Transition of Technology for Field Deployment

Performed field trials in 2013 and 2014 to evaluate corrosion imaging capability in the field

- Several field trials were conducted at oil major and petrochemical facilities
- Completed hardening and refinement of the CUI imaging system

Performed several performance evaluations of the defect characterization capability

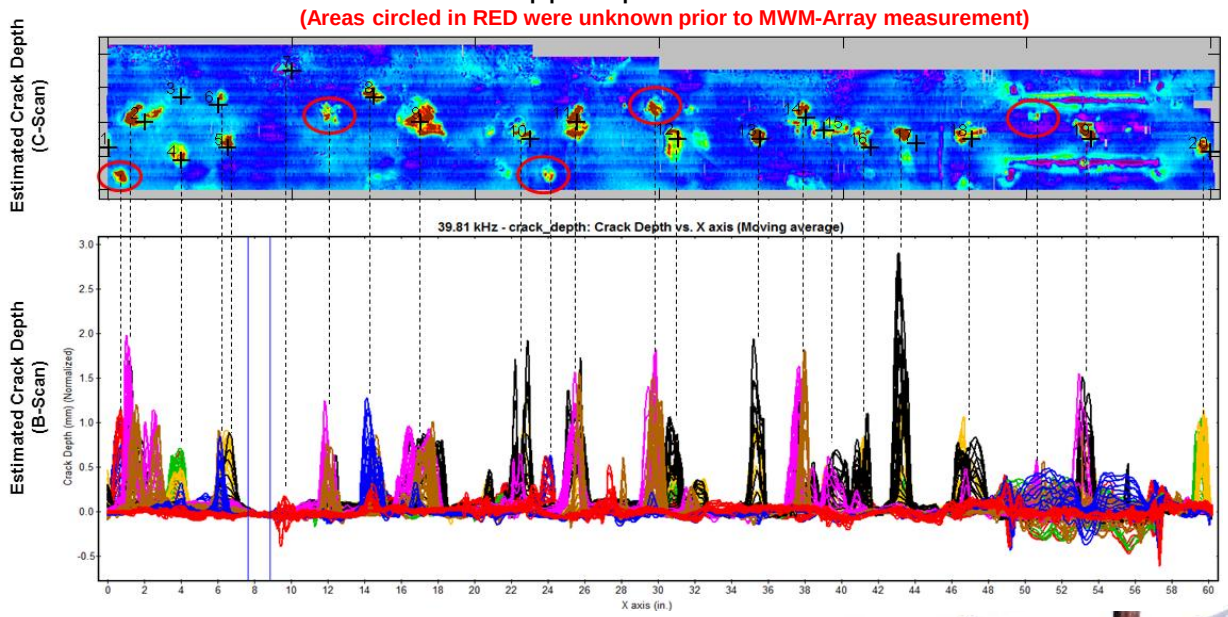
- Improved accuracy and sizing capability
- Improved algorithms and software interface

Performed testing of SCC crack depth imaging and sizing capability with PRCI and GDF-Suez

- Successful imaging and depth sizing of SCC crack clusters during cyclic fatiguing

FA26 Scans on a pipe sample with 20 identified SCC colonies

(Areas circled in RED were unknown prior to MWM-Array measurement)



Usefulness to End-Users

- Deliver a cost-effective, easy-to-use and reliable tool for “in-the-ditch” characterization of pipeline defects. The Corrosion Imaging Tool and the SCC Crack Mapping and Depth Sizing Tool are both commercially-available products.
- The systems developed under this program includes sensor arrays, impedance measurement instrumentation, and software for data acquisition and analysis.
- Output data is being displayed in a format suitable for end-users such as service providers and pipeline operators, providing **quantitative characterization in engineering units** (length, width, depth).
- Scan speed for CUI of approximately 4 inch per second combined with the capability to inspect without removing the weather jacket offers a substantial return on investment.
- The SCC crack mapping capability can detect SCC colonies through coatings, reducing the need to remove unnecessary insulation.
- All of this should lead to more comprehensive inspections and a resulting safety improvement.

Q&A and Discussions

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Call before you dig.

Thank You