Corrosion Imaging through Insulation using MR-MWM-Arrays

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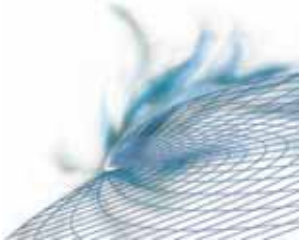
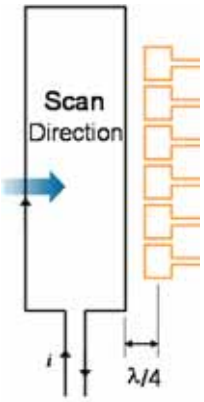


Technology Description

1. Sensors: MWM®-Arrays

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



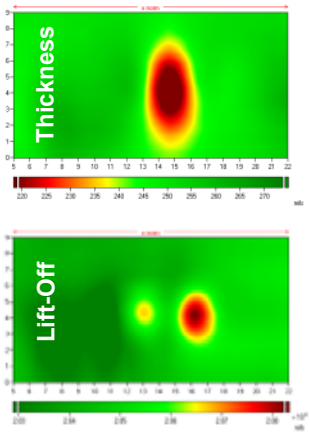
2. Next Generation 8200 GridStation® Electronics

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

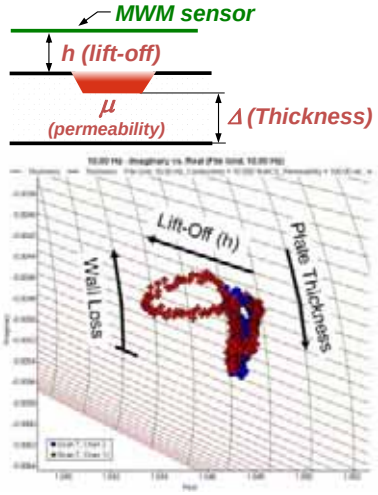
3. GridStation Software using Hyperlattices®

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

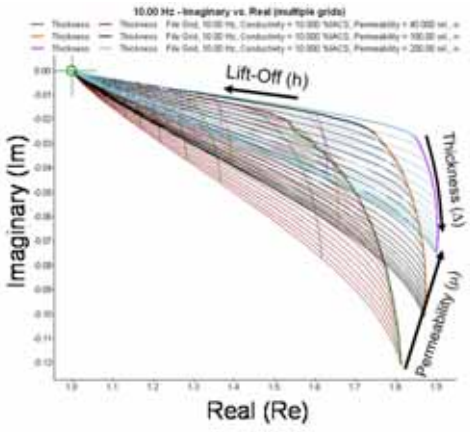
Images



Analysis

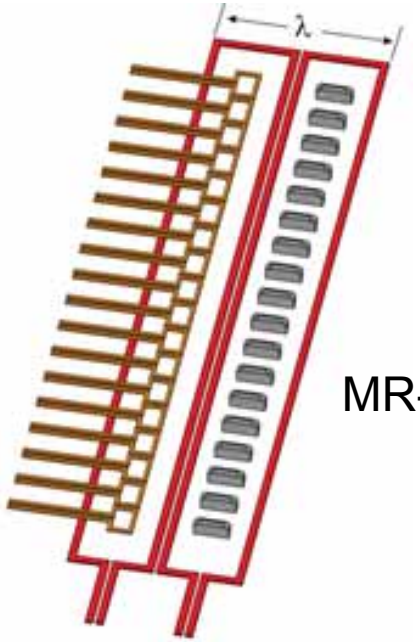


Solve Multiple Unknown Problems MIM



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



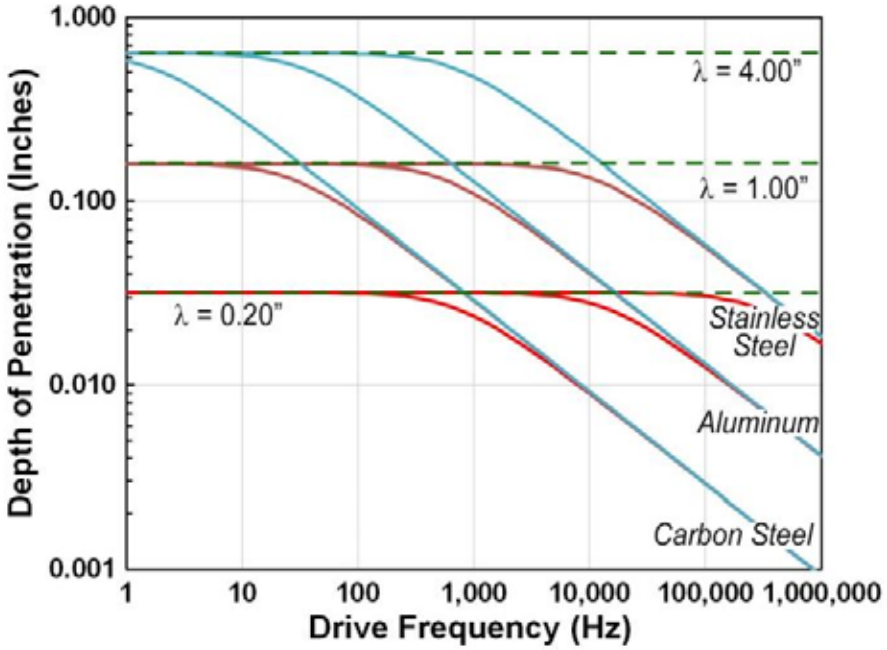
MR-MWM-Array

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

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

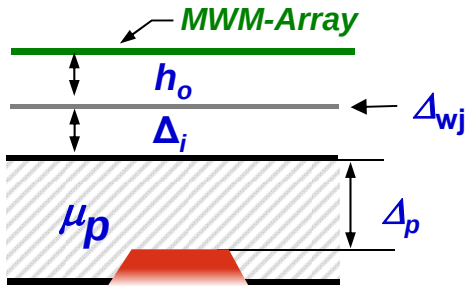
$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

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



1 inch = 25.4 mm

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

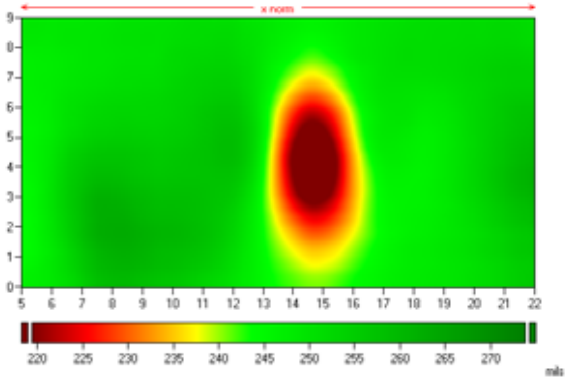
μ_p = pipe magnetic permeability

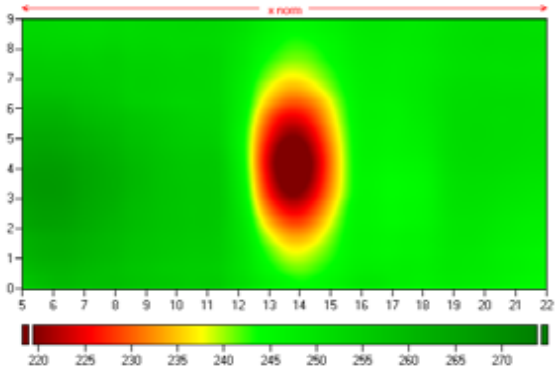
Lab Demonstration of ID/OD Discrimination

External Wall Loss

Internal Wall Loss

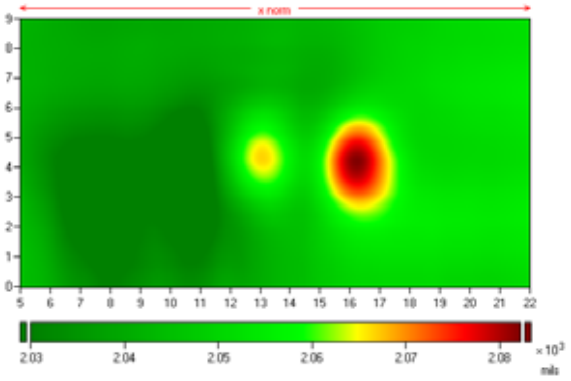
Thickness

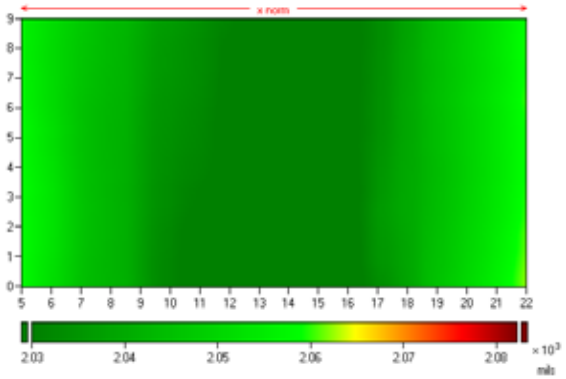




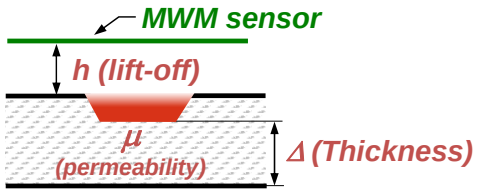
Thickness

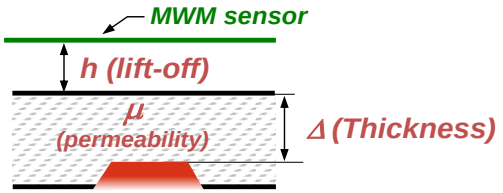
Lift-Off





Lift-Off





Performance Evaluation of Corrosion Imaging System

Results comparison with known natural corrosion defects on the OD (CUI)

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

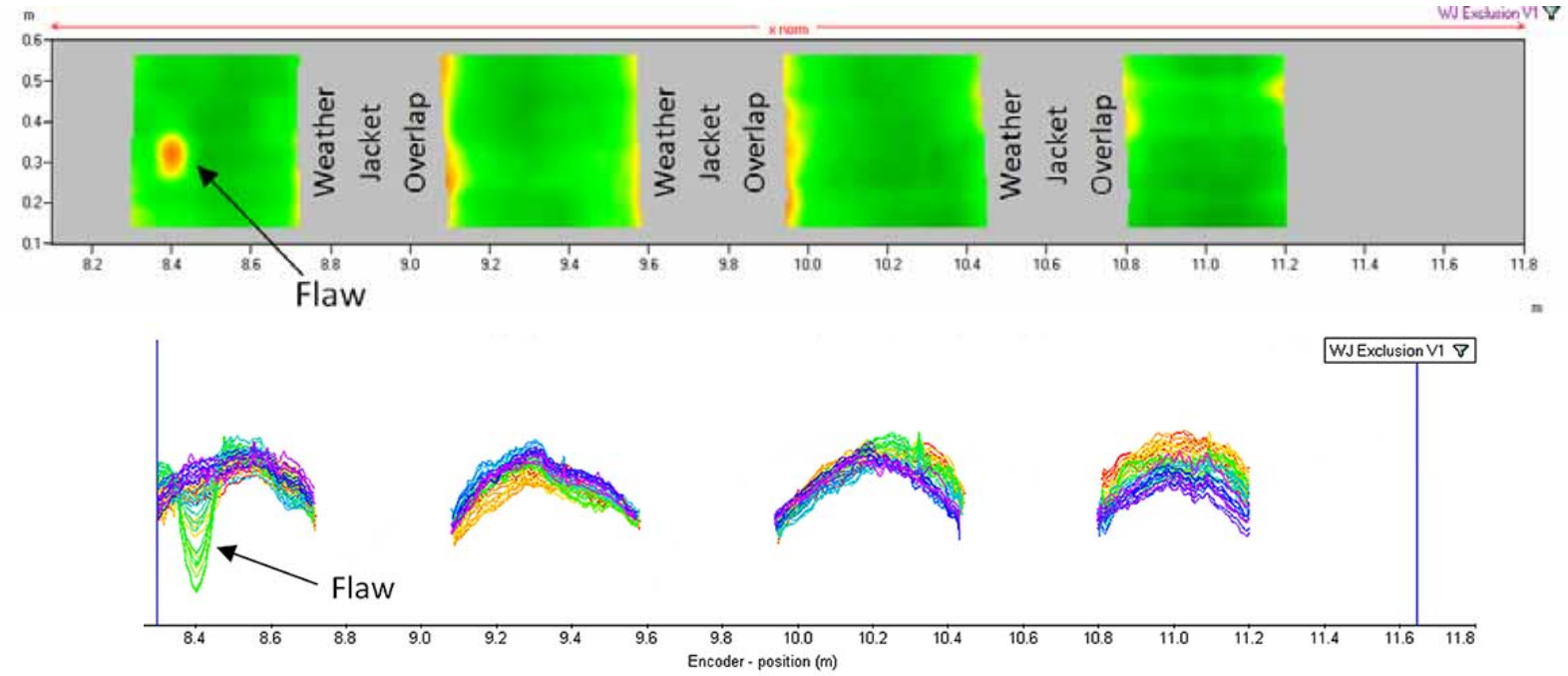
*The defect produced two distinct indications in the scan data that were responsible for the indications were identified on a best-effort basis.

Performance Evaluation Results (December 2013)

External Corrosion – Sample B

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

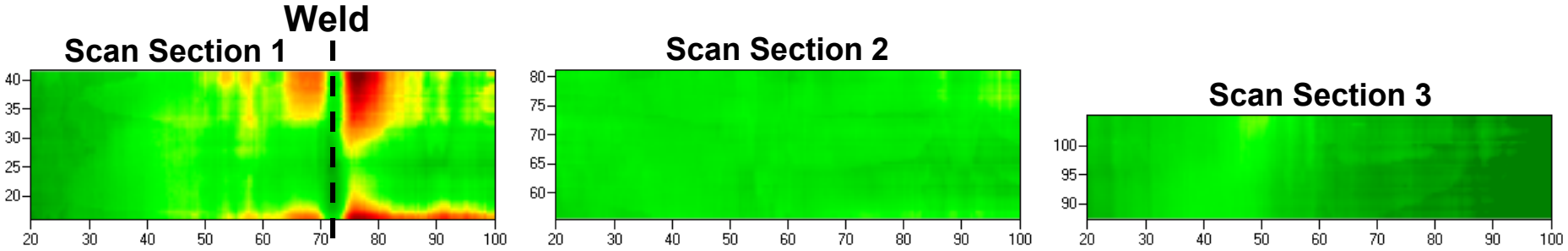
Flaw Data:
2.75” (Axial), 2.50” (Circumferential), 0.12 Deep (48%)



Performance Evaluation Results (July 2013)

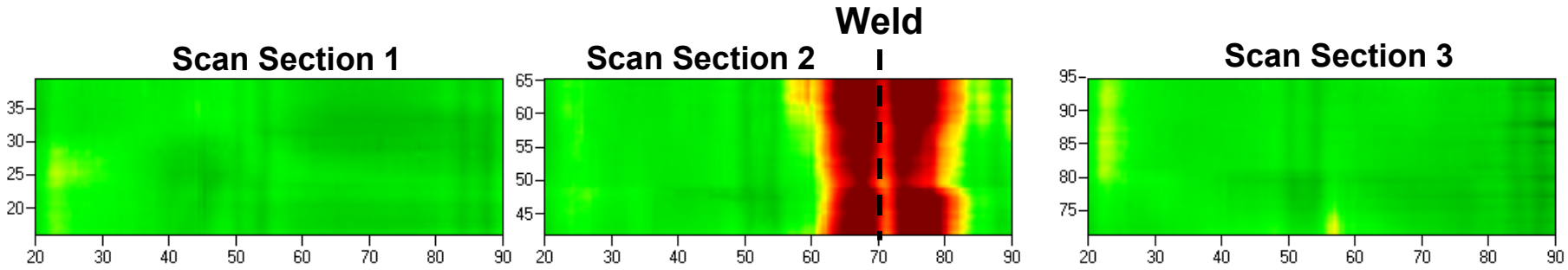
Internal Corrosion Sample A

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



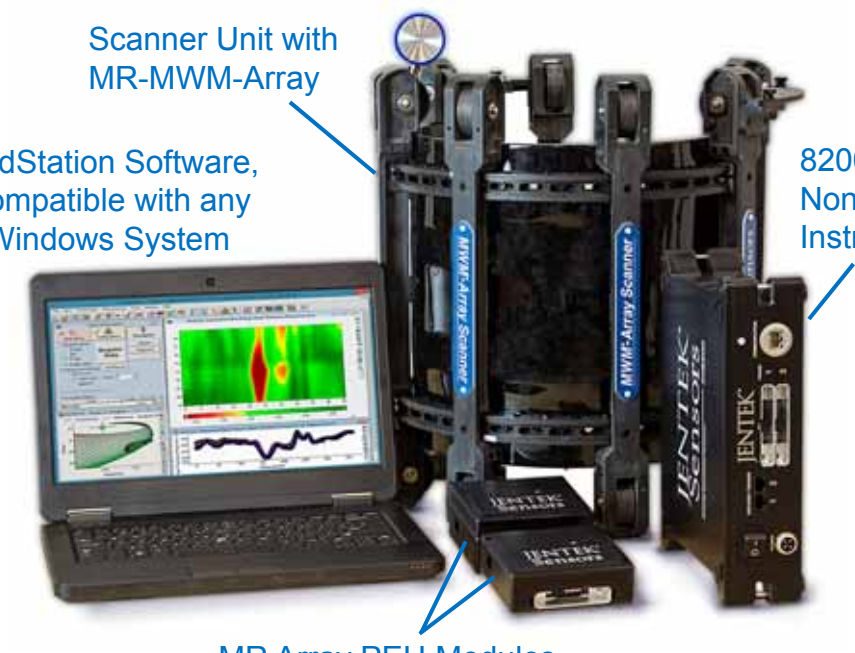
Internal Corrosion Sample B

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



Solution: Corrosion Imaging System

8200 Non-Integrated System



8200 Integrated System

- Longer, light-weight cables for increased operator ease-of-use
- More compact cable/PEU configuration
- Improved positioning encoder module

Corrosion Imaging Tool – Current Capability (1)

System capabilities:

- Carbon steel pipelines and piping (straight sections only) for a minimum of 8.5 in. total diameter (including insulation) and above
- Up to 0.5 in. thick pipe walls for internal and external corrosion imaging
- Up to 0.040 in. Aluminum and Stainless Steel weather jackets **(not suitable for galvanized weather jackets)**
- All (non-conducting) insulation materials, up to 3 in. thick
- Current focus is on pipelines and piping, but **method can be adapted for vessels or other carbon steel structures**

Corrosion Imaging Tool – Current Capability (2)

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

- **1 in. diameter @ 65% wall loss (average)**
- **2 in. diameter @ 50% wall loss (average)**
- **3 in. diameter @ 30% wall loss (average)**

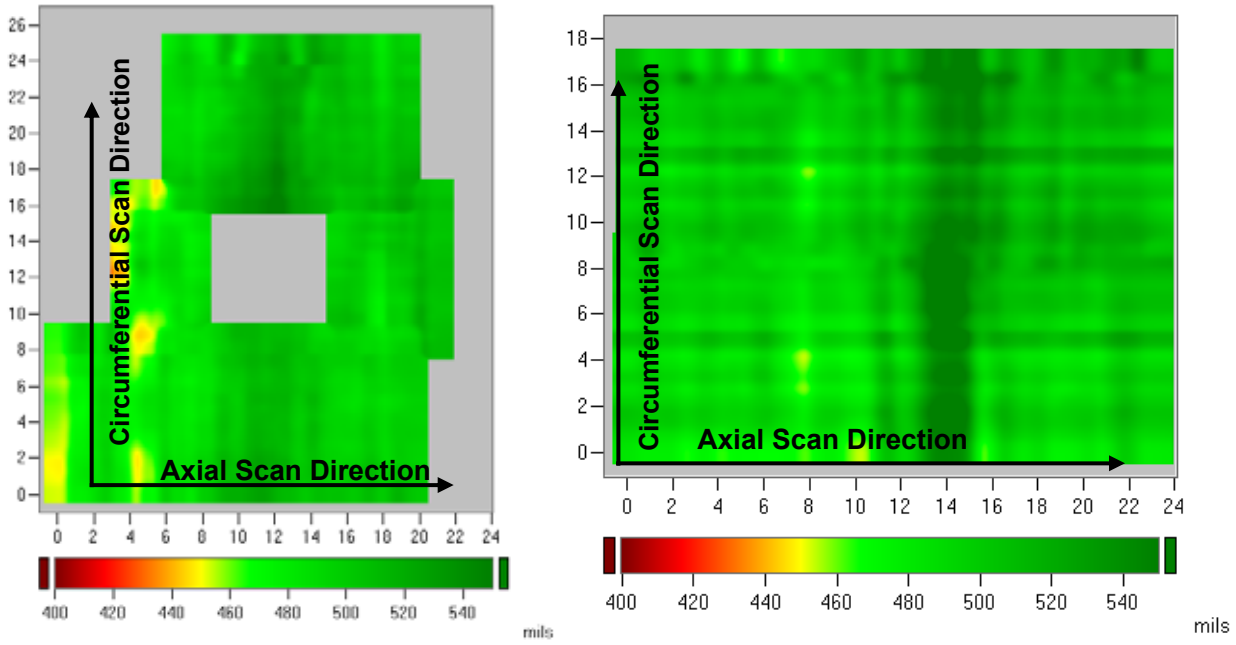
Note: This evaluation was performed on 20 in. pipes with natural corrosion, 0.250 in. wall, 2 in. insulation, and 0.020 in. aluminum weather jacket. The system performance is expected to vary with different pipe configurations.

Case Study I - Corrosion Imaging on Refinery Piping

Inspection was performed with the pipe in production at high temperature

Case Study I - Corrosion Imaging on Refinery Piping

Multiple Unknowns Meas. Steel Thickness Scans



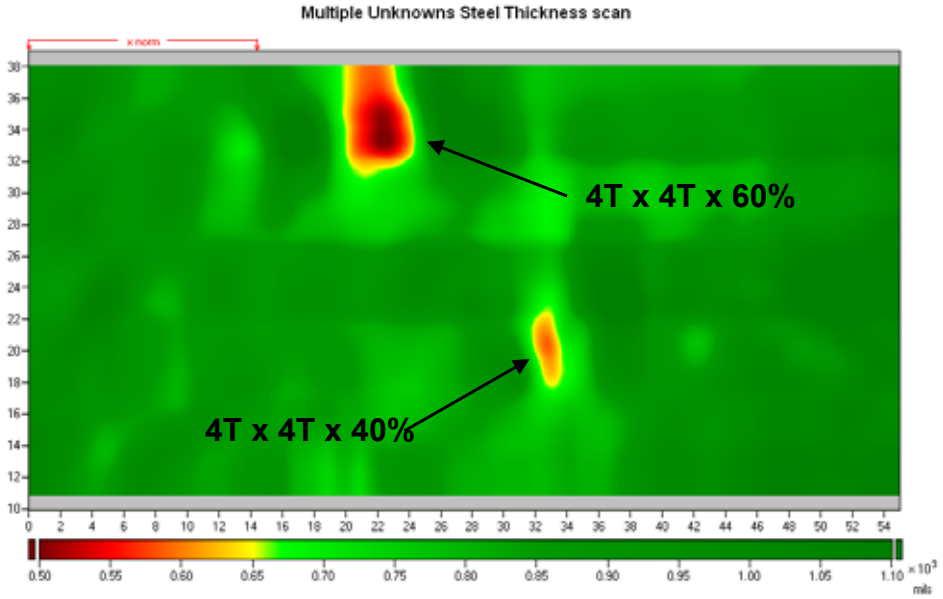
Inspection was performed with the pipe in production at high temperature

Case Study II - Corrosion Imaging on Refinery Piping

- JENTEK engineers provided service support to field service technicians performing inspection for internal and external corrosion on a pipe at a major U.S. refinery.
- Technicians are using system with magnetoresistive array sensing technology capable of imaging corrosion in weather jacketed pipe.

Internal Corrosion in Heavy Wall Pipe

- **Completed demonstration of MR-MWM-Array**
  - Performed scans with the 8200α prototype system and the low frequency MR-MWM-Array on the new sample (with fabricated internal defects) through 2-in. insulation
  - Performed measurement and calibration adaptation procedure and algorithm development (under JENTEK IR&D funding)
  - Completed evaluation of GridStation 8200α system (under JENTEK IR&D funding)
- **Completed fabrication and testing of the deep water scanner**
  - Fabrication of the scanner is complete
  - Integrated with our new GridStation 8200α system
  - Completed preliminary testing of the sensor
  - Addressed cabling and connectivity issues
  - Completed pressure testing of scanner components



Preliminary Results – Internal Corrosion through 2-in. insulation & 0.875-in. wall

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 coursework and training by JENTEK and are currently performing field services
- Software and hardware enhancements are ongoing to improve system capabilities