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Imaging Corrosion under Insulation and under Fireproofing, using MR-MWM-Arrays

Neil Goldfine, Brian Manning, Zachary Thomas, Yanko Sheiretov, Scott Denenberg, Todd Dunford, and Shayan Haque
JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013

Rasheed Al Rushaid, Frederick Haught
Al Rushaid Technologies Co., Al Turki Business Park, Office Villa #4; 7244 King Saud Road, Ad Doha Al Janubiyah, Dhahran 34455, Kingdom of Saudi Arabia

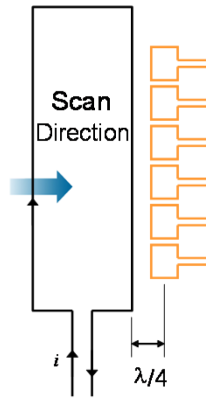
Outline

- **MWM-Array Technology Overview**
- **Detection and Characterization of Corrosion Under Insulation**
  - Problem Definition
  - Sensor Selection
  - 3-Unknown Lattices
- **Performance Evaluation Results**
- **Next Generation Technology for Corrosion Imaging Tool**
  - System Configurations
  - Performance Capability
- **Case Studies of Field Service Support**
- **Ongoing Efforts**

Technology Overview

1. Sensors: MWM®-Arrays

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



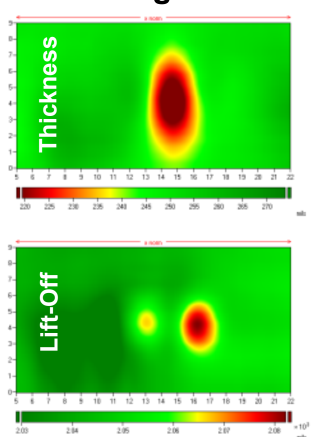
2. Next Generation Electronics

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

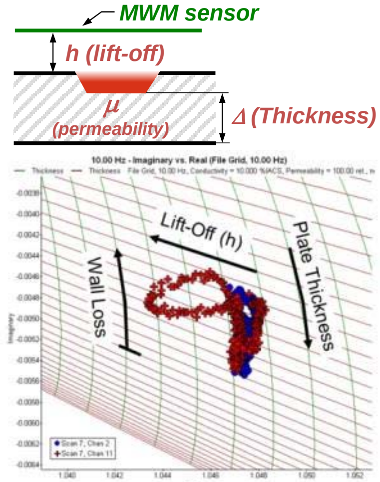
3. GridStation Software using Hyperlattices®

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

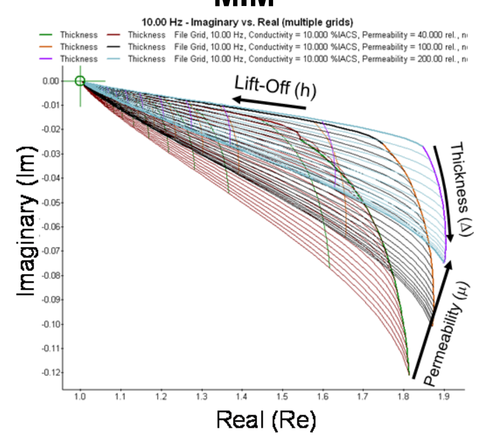
Images



Analysis

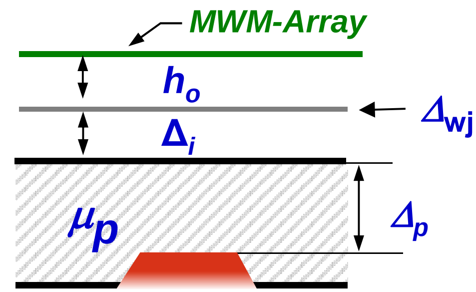


Solve Multiple Unknown Problems MIM



Detection & Characterization of CUI

Problem Definition



h, Δ_{wj}, Δ_i , Δ_p, μ_p

h_o = distance between sensor & external surface of weather jacket

Δ_{wj} = weather jacket thickness

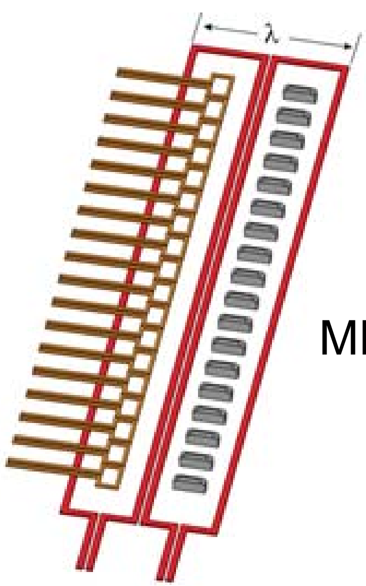
Δ_i = insulation thickness + external metal loss

Δ_p = remaining pipe wall thickness

μ_p = pipe magnetic permeability

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**



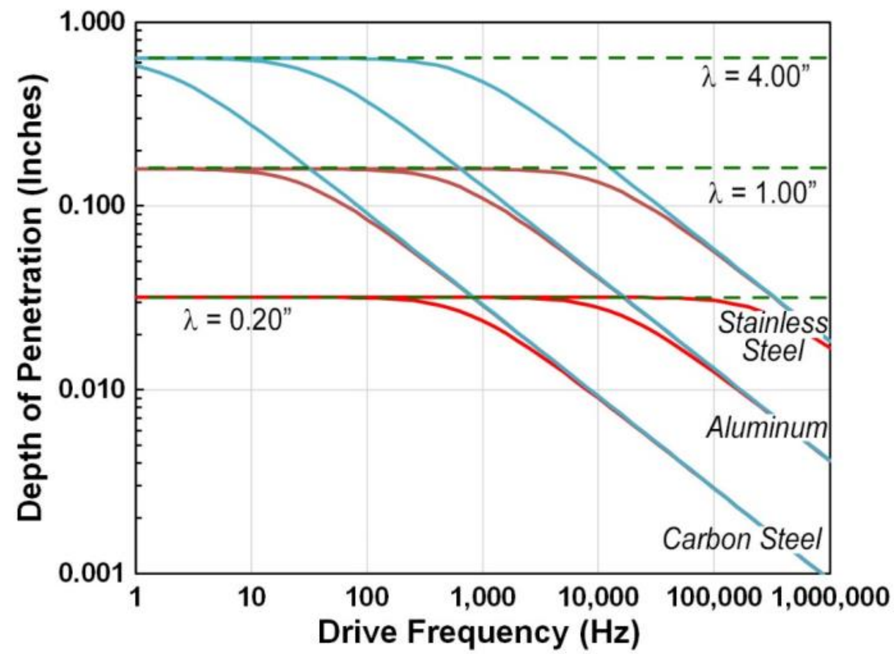
MR-MWM-Array

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

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

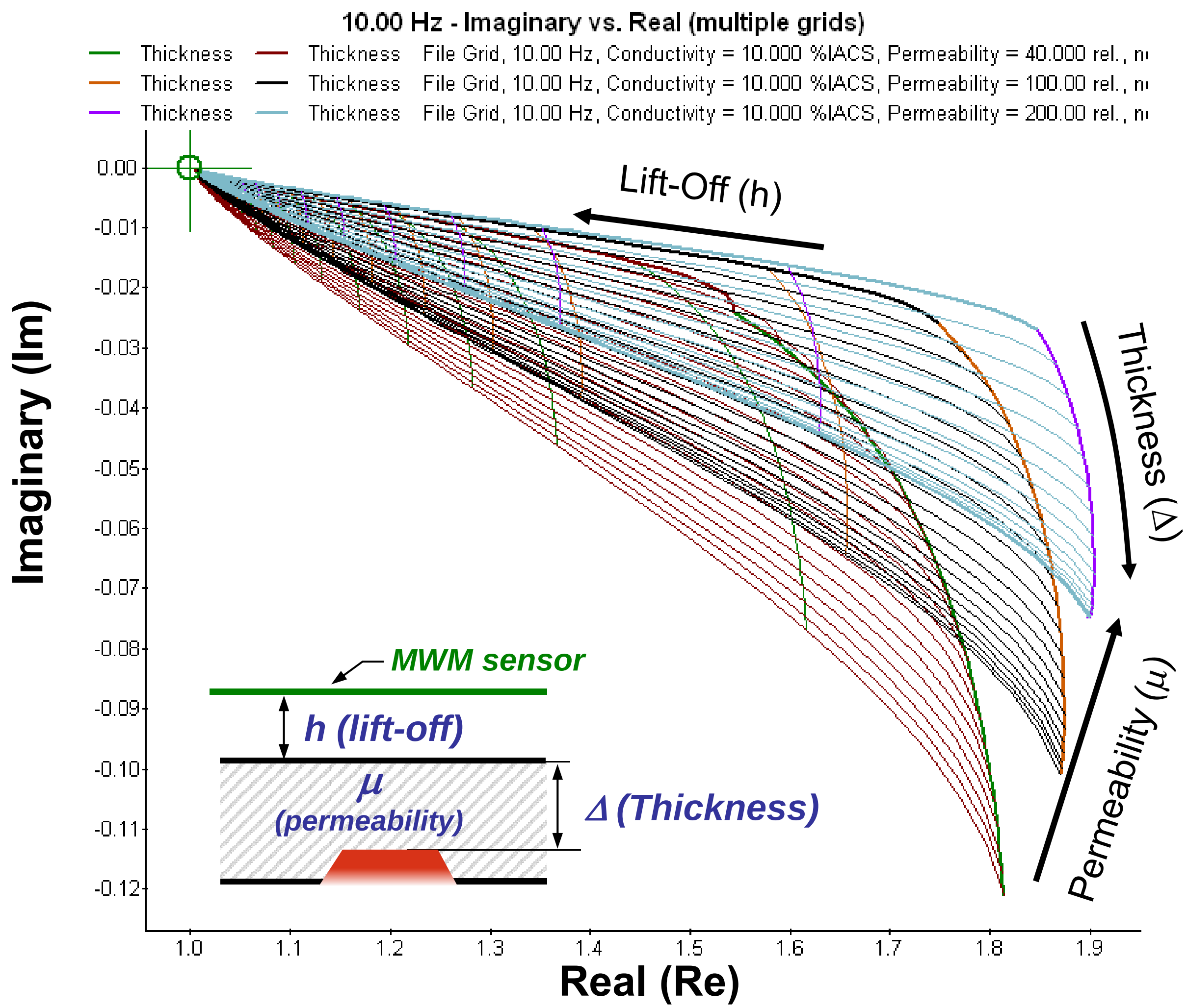
$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

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



1 inch = 25.4 mm

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

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

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

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

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

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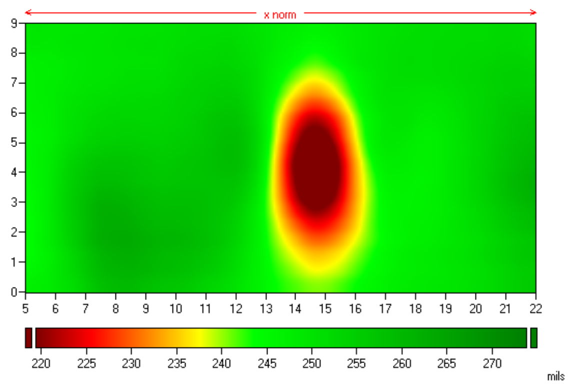
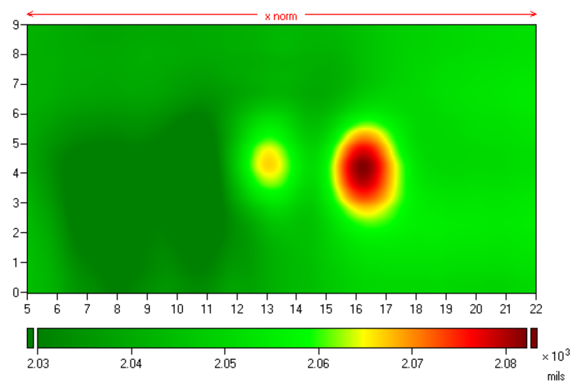
Lab Demonstration of ID/OD Discrimination

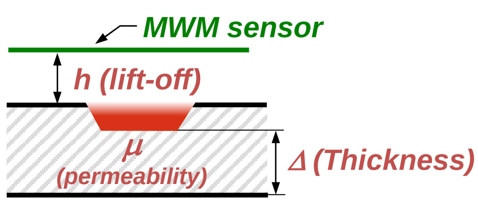
External Wall Loss

Thickness



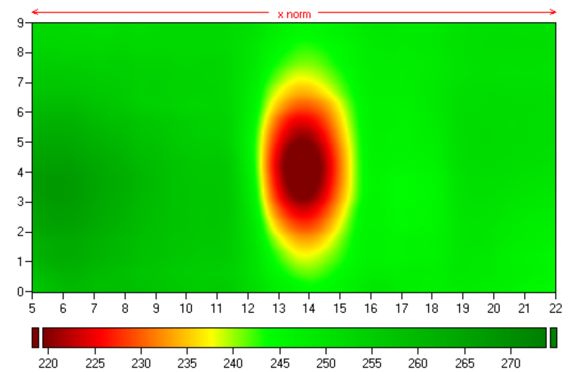
Lift-Off



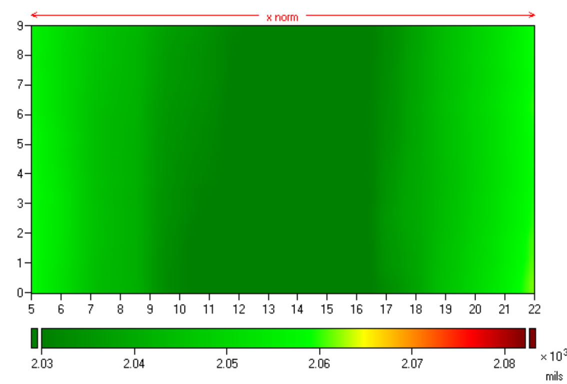


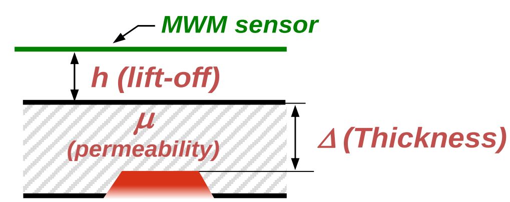
Internal Wall Loss

Thickness



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	1.50/38	0.12/3.0	Hit
9.0/228	1.50/38	0.06/1.5	Miss
2.0/50	1.50/38	0.08/2.0	Miss
4.0/101	1.25/32	0.12/3.0	Hit
4.0/101	4.00/101	0.08/2.0	Hit*
4.0/101	4.50/114	0.08/2.0	Hit*
1.75/44	2.75/70	0.10/2.5	Hit
2.75/69	2.50/63	0.12/3.0	Hit
1.0/25	0.75/19	0.16/4.0	Miss

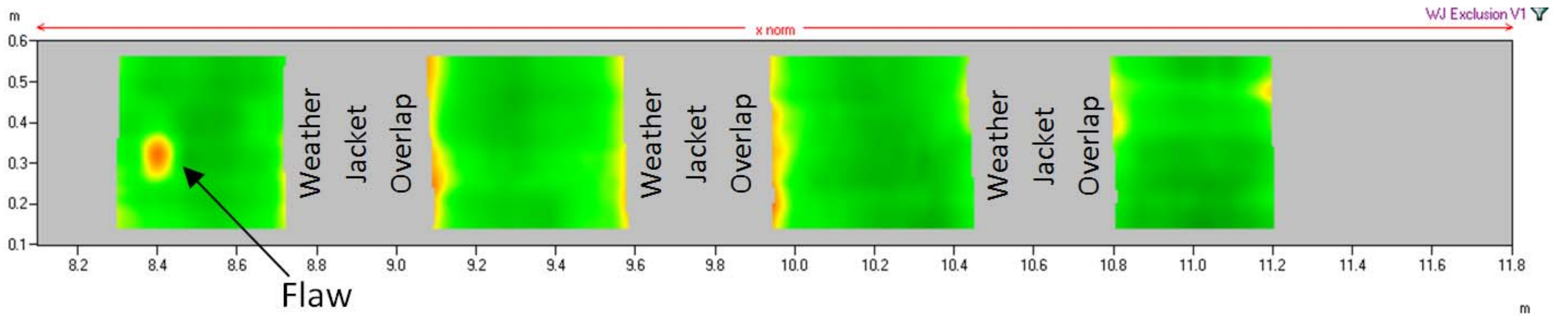
*The defect produced two distinct indications in the scan data that were responsible for the indications were identified on a best-effort basis.

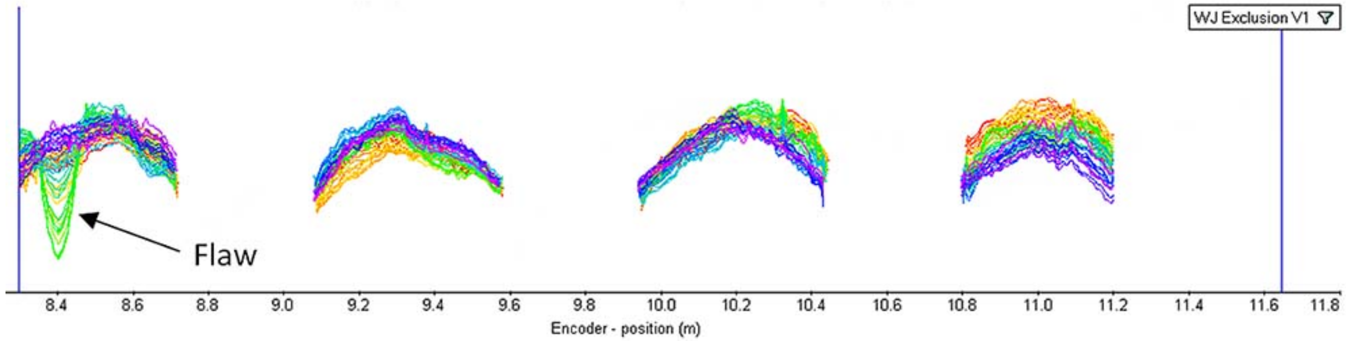
Performance Evaluation Results (December 2013)

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%)

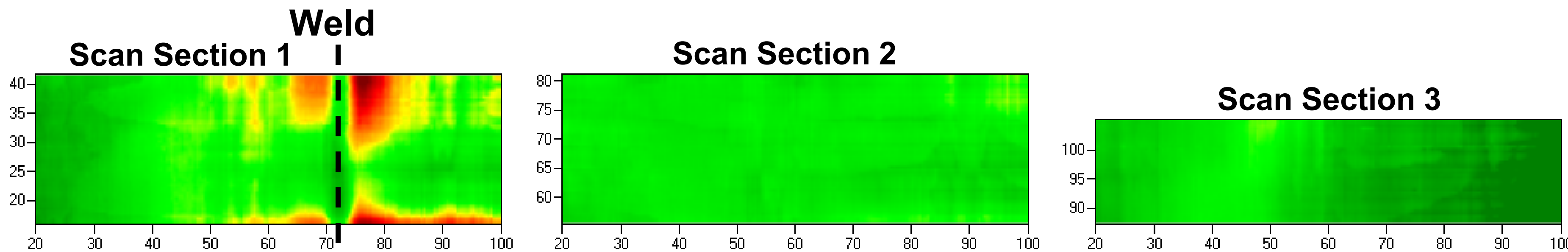




Performance Evaluation Results (July 2013)

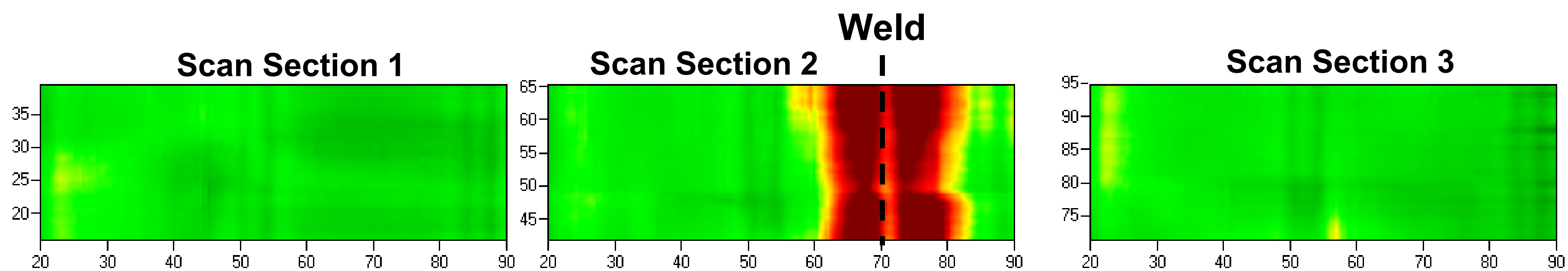
Internal Corrosion – Sample A

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



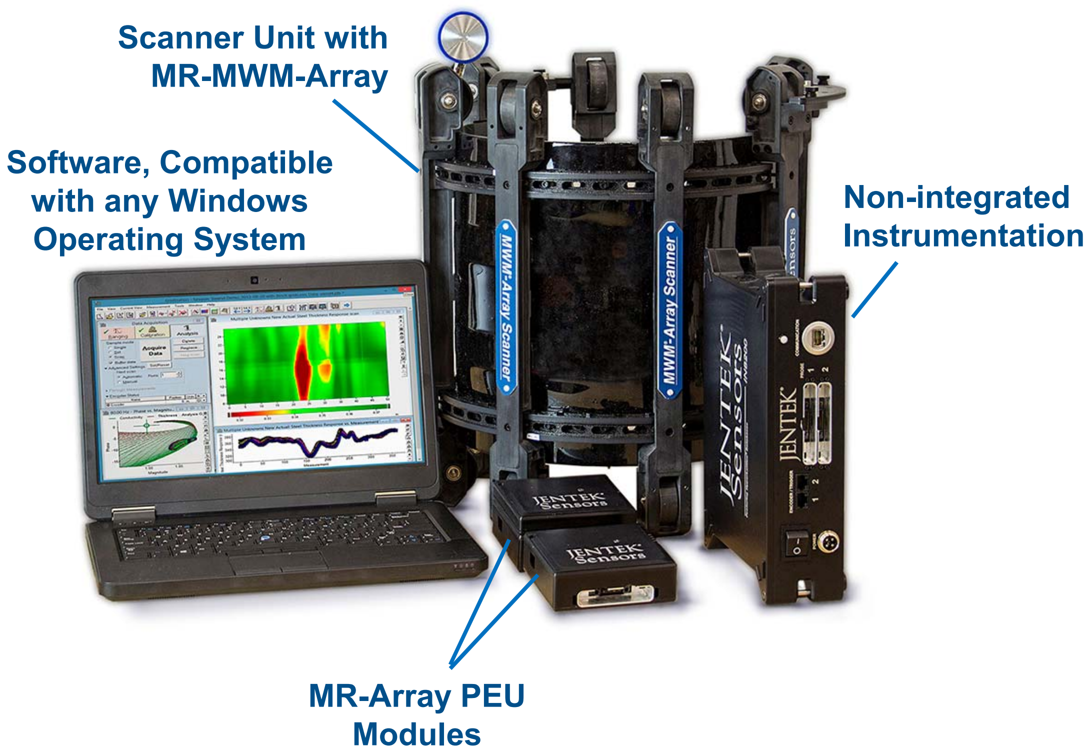
Internal Corrosion – Sample B

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

Non-Integrated System



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:

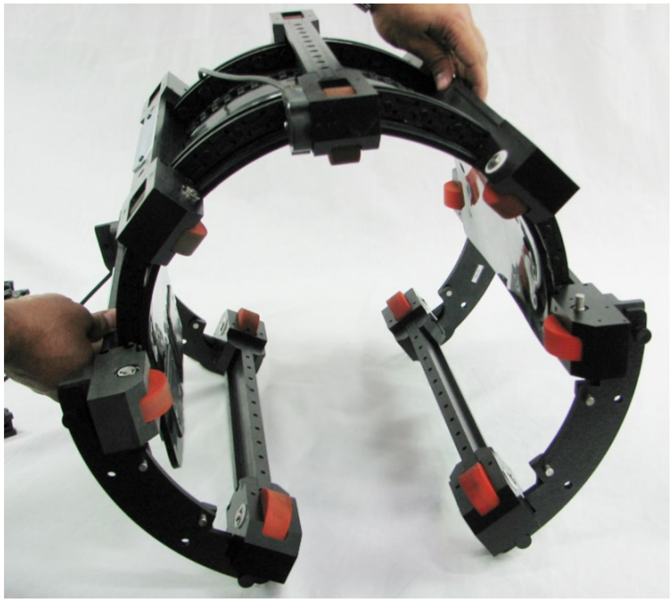
- Carbon steel pipelines and piping (straight sections only) for a minimum of 8.5 inch total diameter (including insulation) and above
- Up to 0.5 inch thick pipe walls for internal and external corrosion imaging
- Up to 0.040 inch Aluminum and Stainless Steel weather jackets **(not suitable for galvanized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

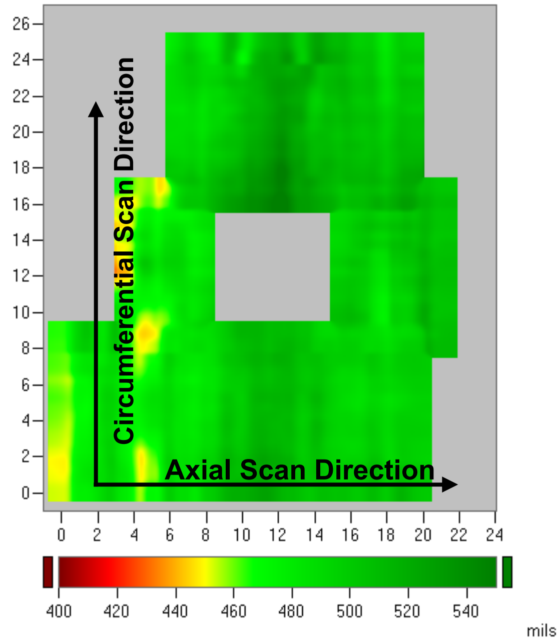


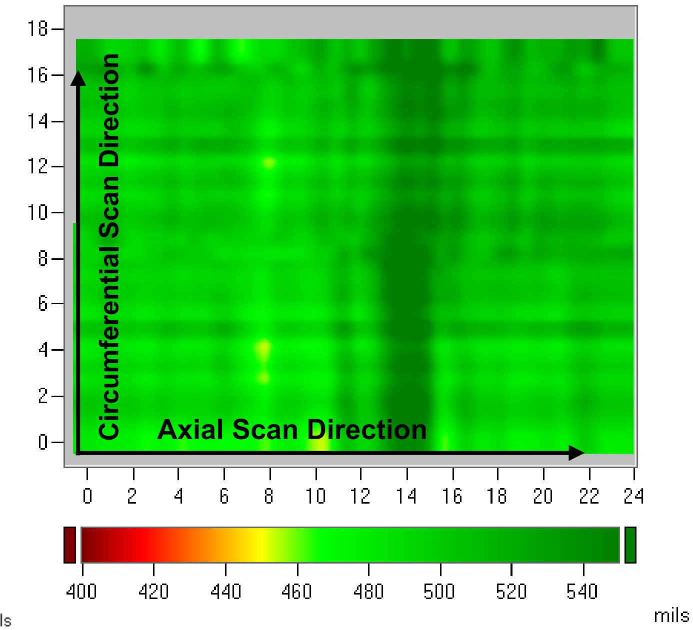
Case Study I - Corrosion Imaging on Refinery Piping


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

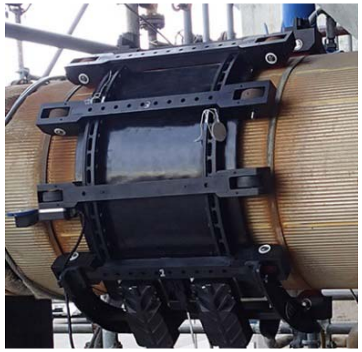




Inspection was performed with the pipe in production at high temperature

Case Study II - Corrosion Imaging on Refinery Piping

- 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.



Ongoing CUI Efforts

- Transitioning of the technology for field services
- Comprehensive training and service support program developed for approved NDT service providers
- Several field service technicians have undergone coursework and training and are currently performing field services
- Software and hardware enhancements are ongoing to improve system capabilities
- Related applications:
  - Corrosion under composite repair – using both magnetoresistive and inductive sensing elements
  - CUF enhancements
  - Subsea corrosion under weight-coat
  - New sensor development for thicker pipe wall