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Advancements in Imaging Corrosion Under Insulation (CUI) for Piping and Vessels

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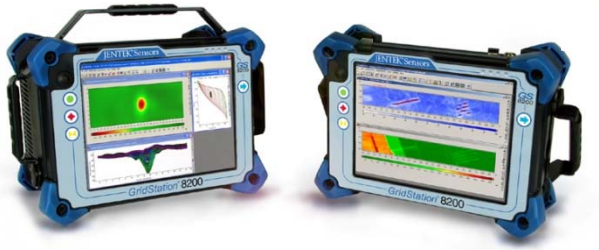
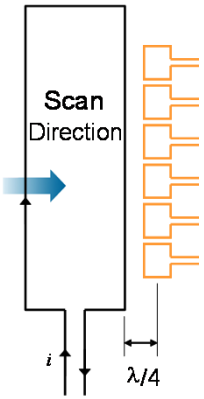


Technology Summary / Overview

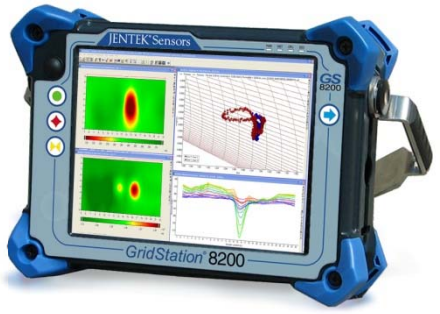
1. Sensors: MR-MWM®-Arrays

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



2. Next Generation 8200α GridStation® Electronics

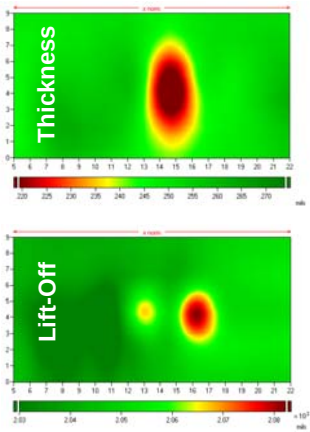
- **10x signal-to-noise improvement**
- **Very low frequencies (deep penetration)**
- **Crack detection through up to 0.5 inches of material**
- **Reduced drift**



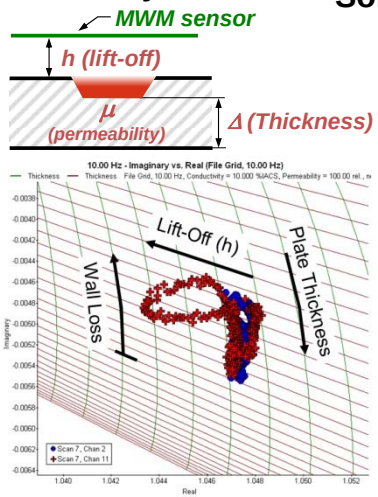
3. GridStation® Software using Hyperlattices™

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

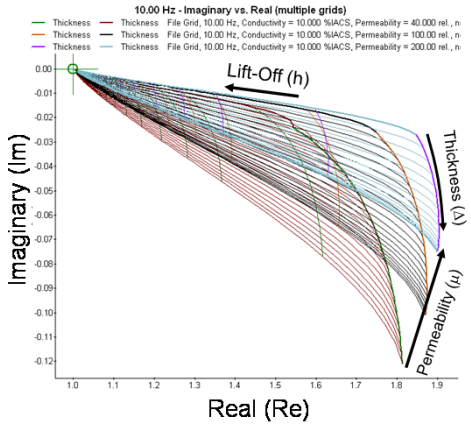
Images



Analysis



Solve Multiple Unknown Problems MIM



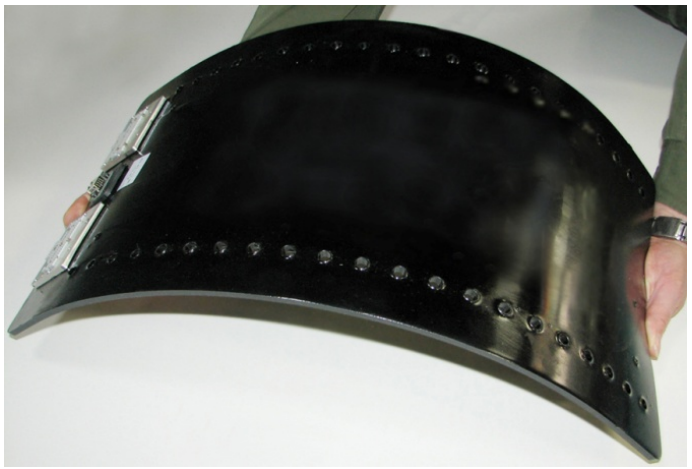
Flat Plate Demonstration

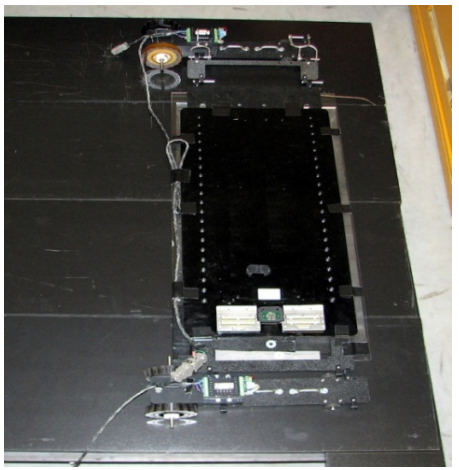
For External and Internal Corrosion

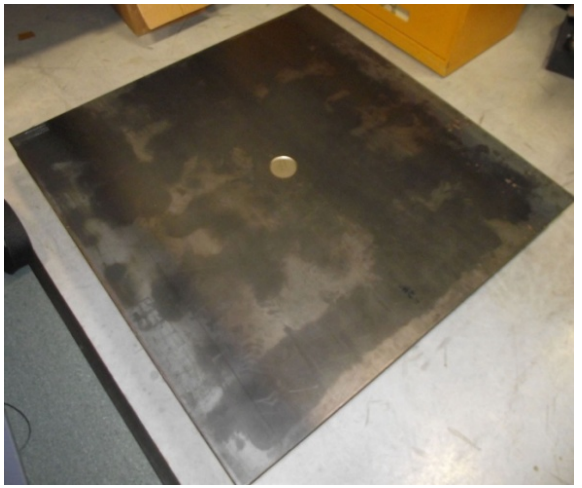
Sensor

- 18-channel sensor
- Motorized scanning vehicle
- External and internal wall loss imaging

MR-MWM-Array
(Curved or Flat surfaces)





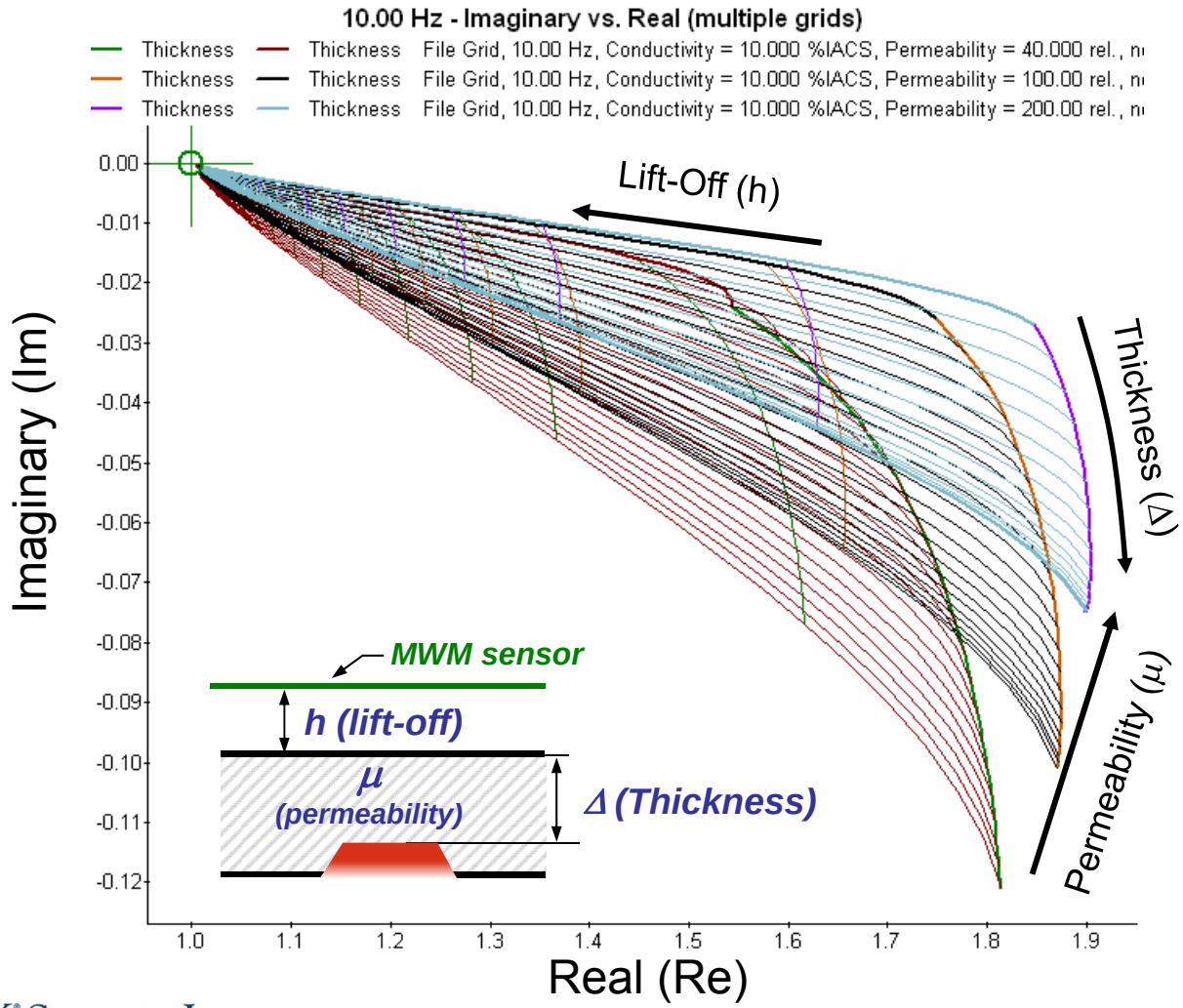


Flat Plate
Dimensions: 4 ft. x 4 ft.
Thickness: 0.25 in.

Flaw
Diameter: 2.25 in.
Depth: 0.150 in.

3-Unknown Lattices

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



$|Z|$ = Magnitude

θ = Phase

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

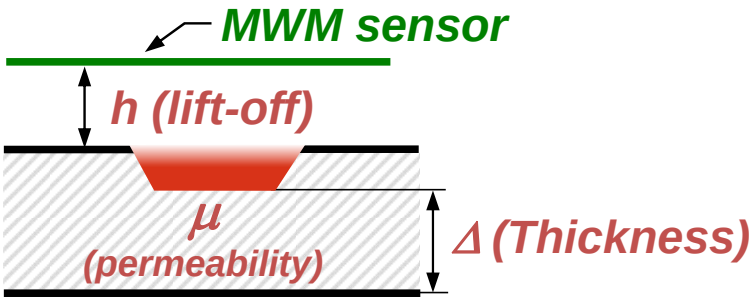
$$\theta = \arctan(Im/Re)$$

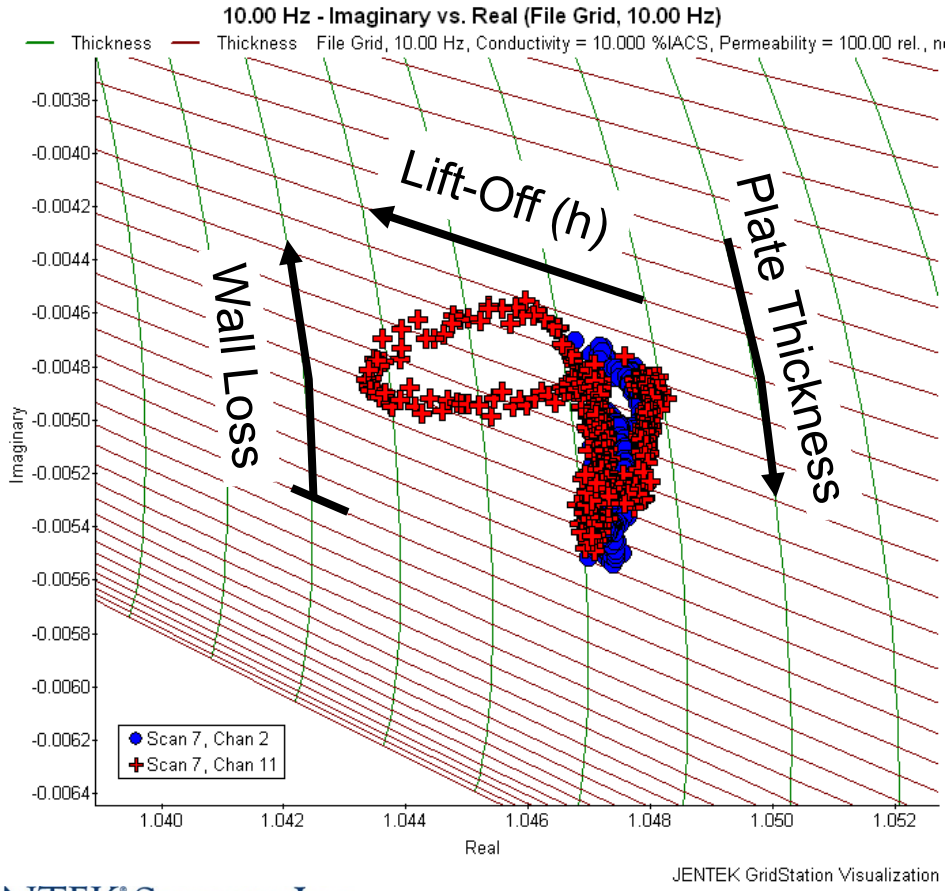
$$Re = |Z|\sin(\theta)$$

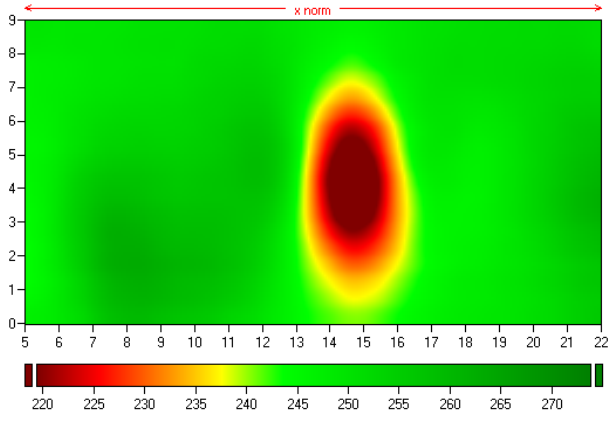
$$Im = |Z|\cos(\theta)$$

Independent Plate thickness and lift-off imaging

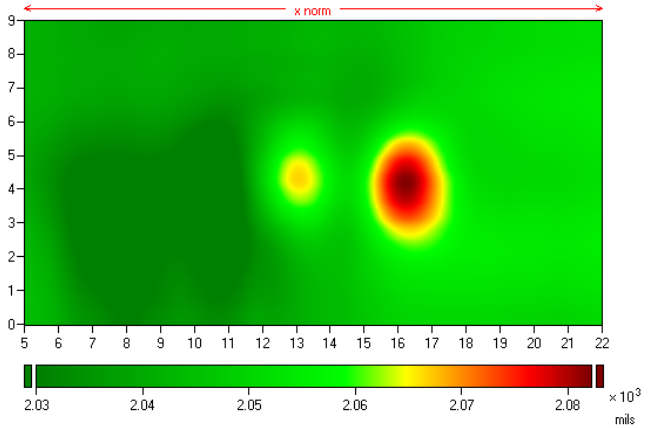
- Channel over defect shows defect signature as thickness reduction and lift-off increase







Thickness

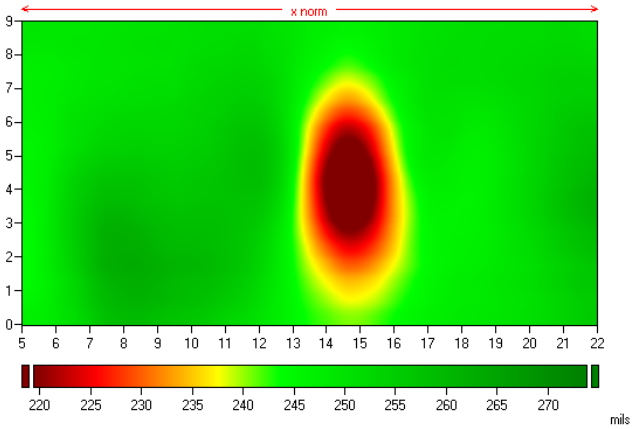


Lift-Off

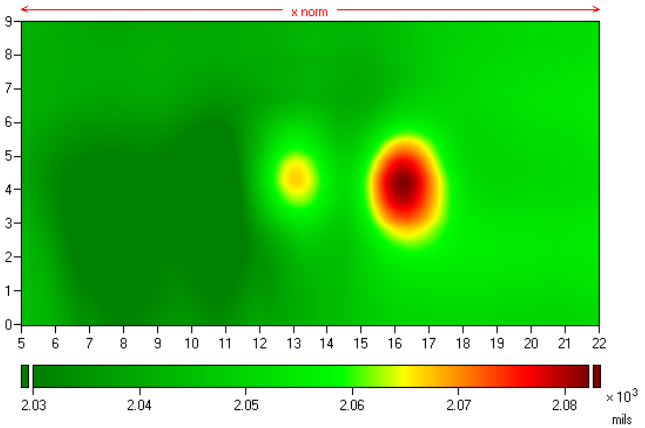
Discrimination Between External and Internal Wall Loss

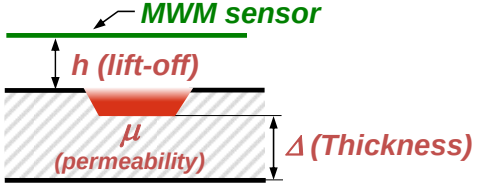
External Wall Loss

Thickness



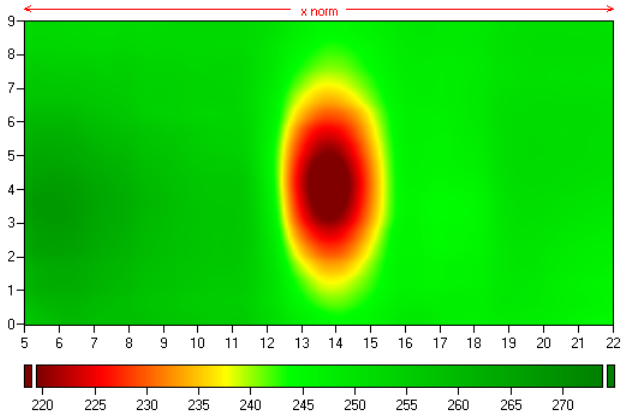
Lift-Off



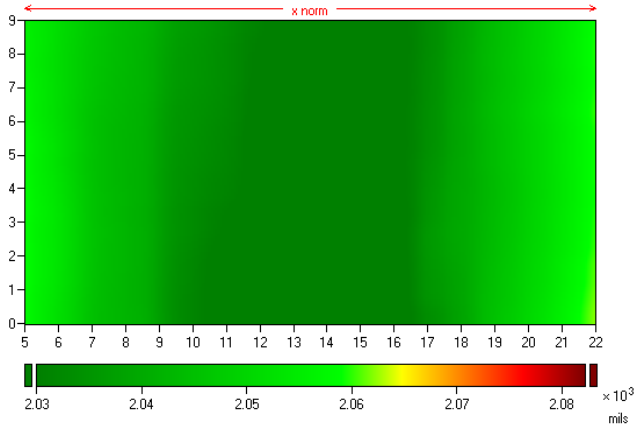


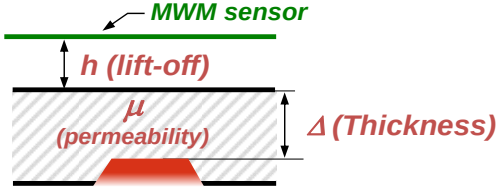
Internal Wall Loss

Thickness



Lift-Off



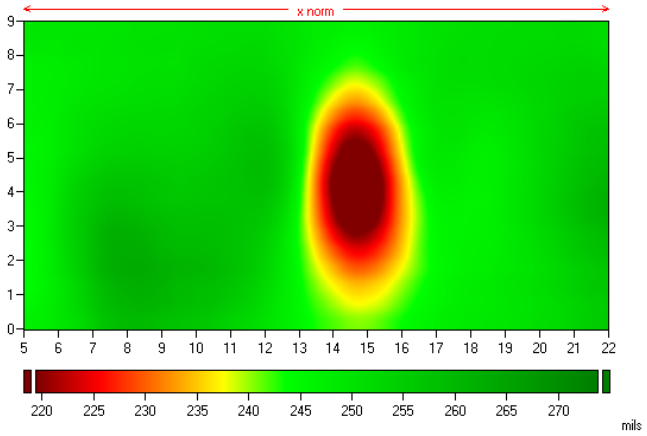


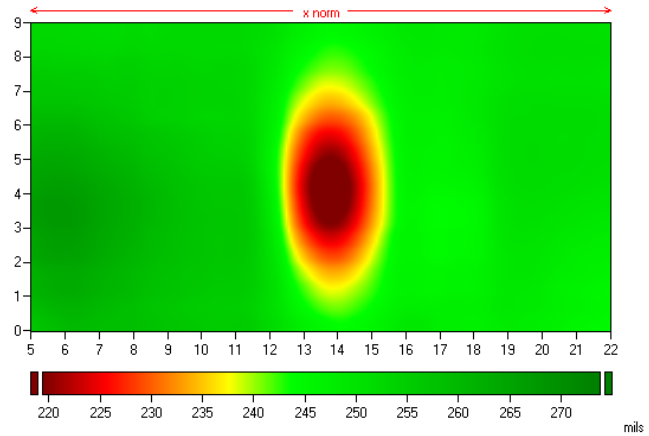
Independent Wall Thickness and Permeability (Longitudinal Stress) Imaging

External Wall Loss

Internal Wall Loss

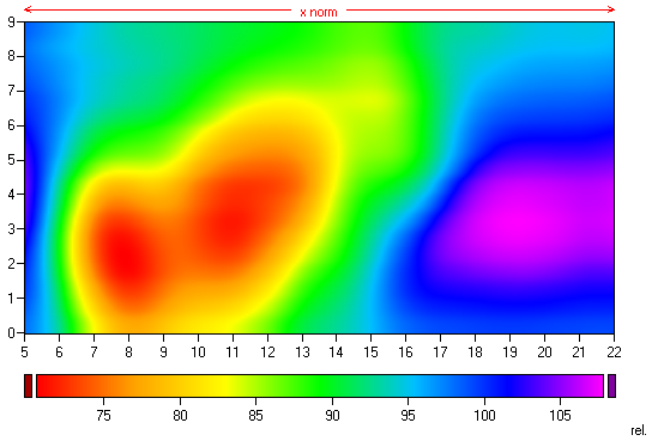
Thickness

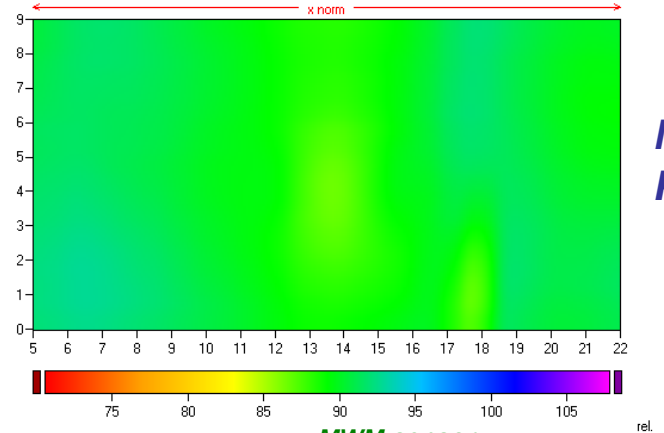




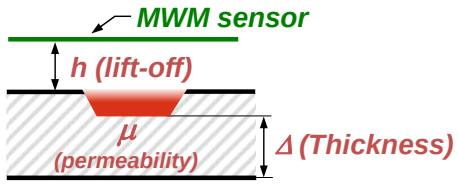
Thickness

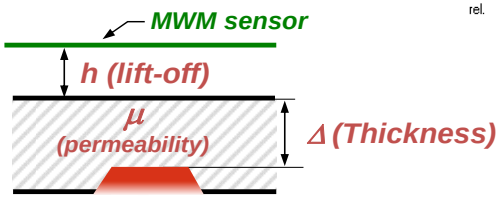
Permeability





Magnetic Permeability

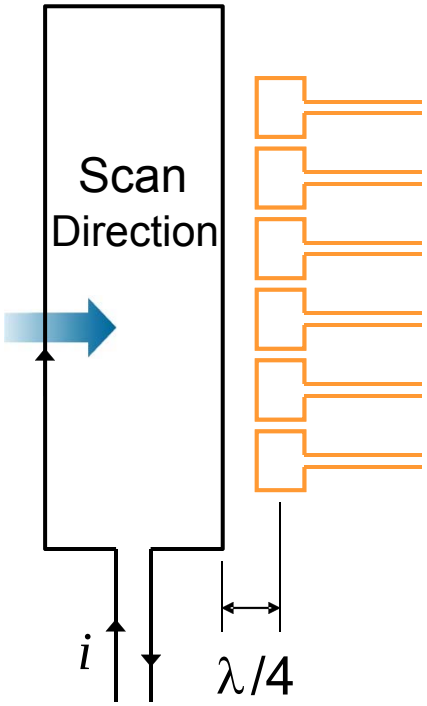




- Need to add correction for sensor construct effects
- Longitudinal permeability is related to stress

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

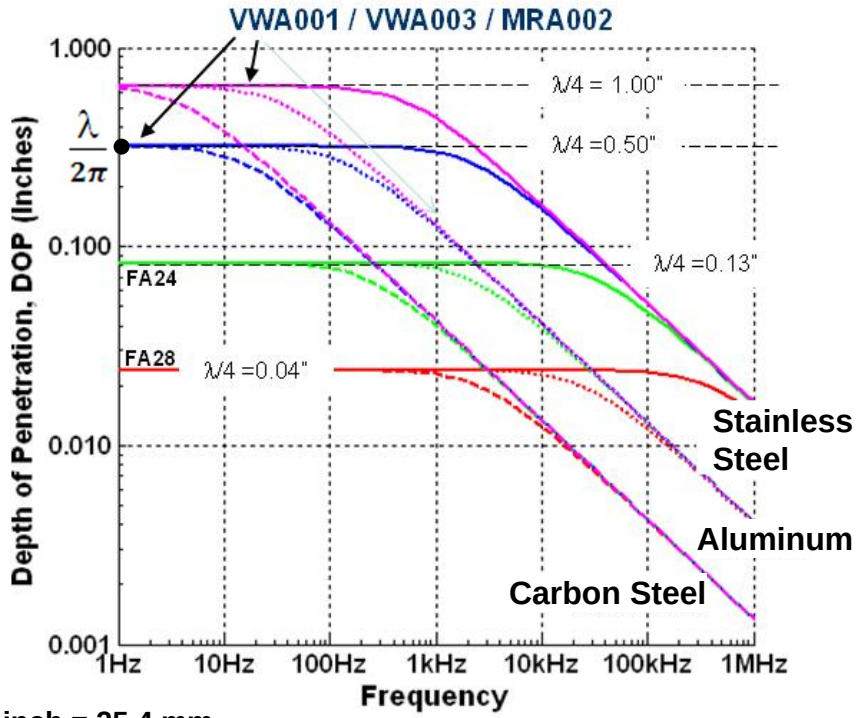


Depth of Penetration = $1/\mathrm{Re}(\Gamma_n)$

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

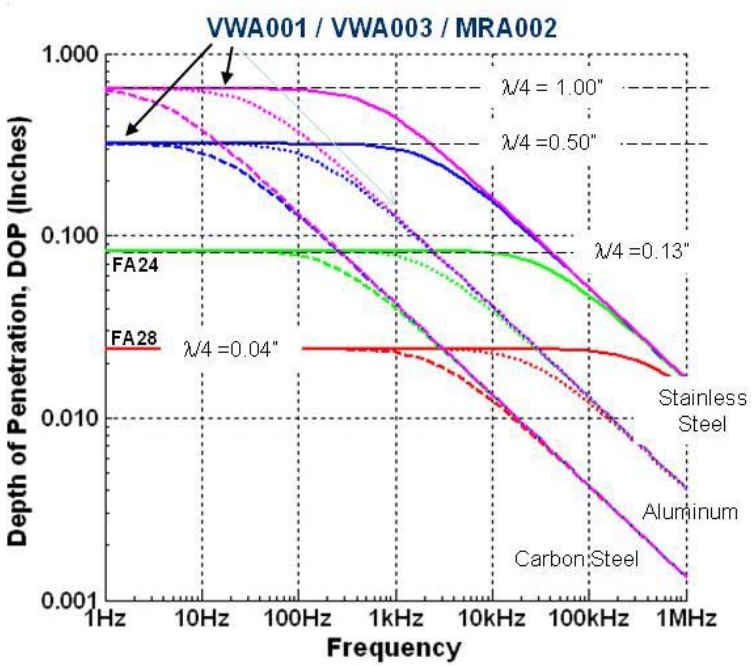
$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

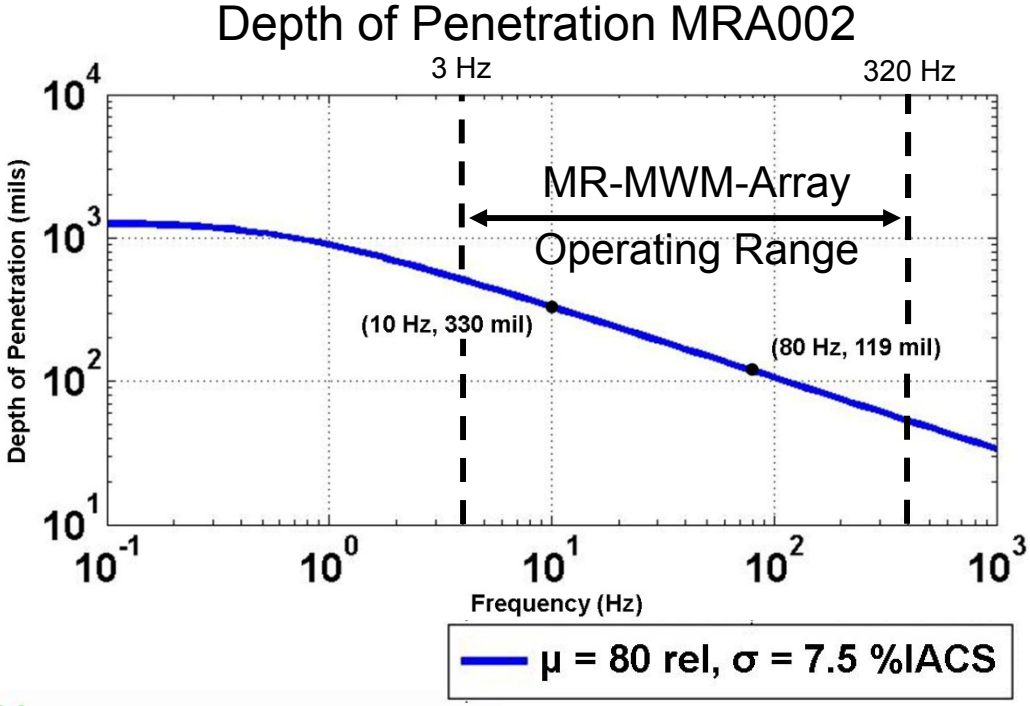
Skin depth: $\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}$

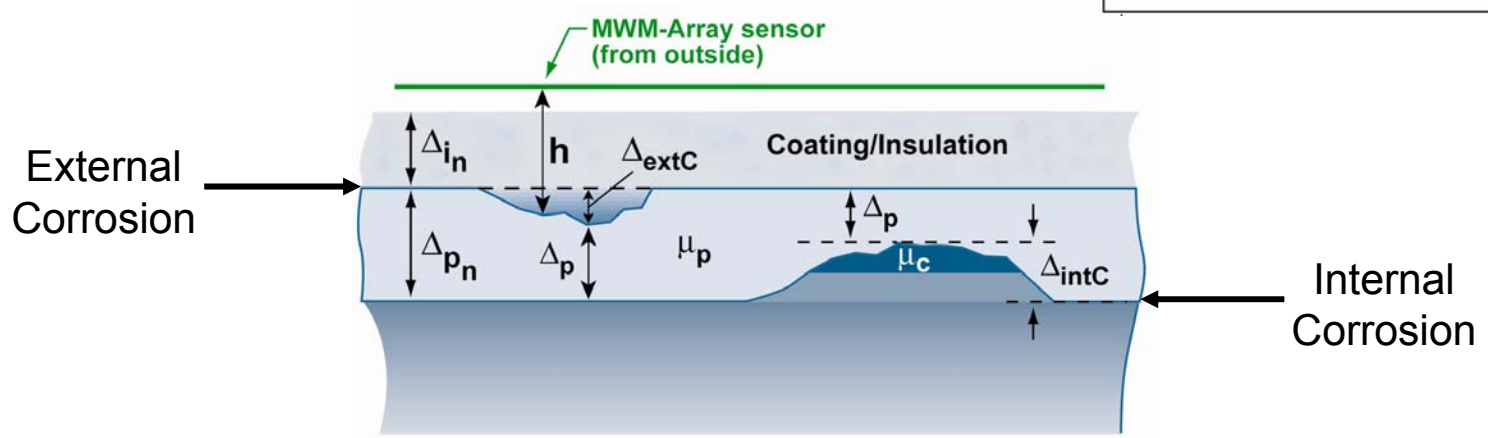


1 inch = 25.4 mm

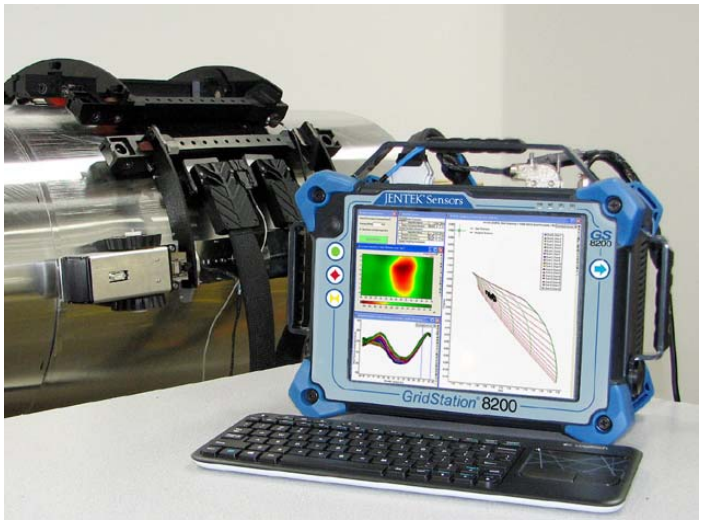
MWM-Array Sensor Selection



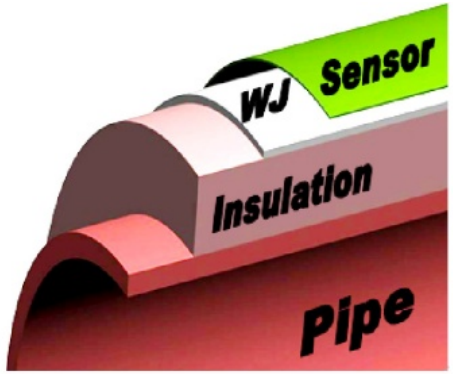


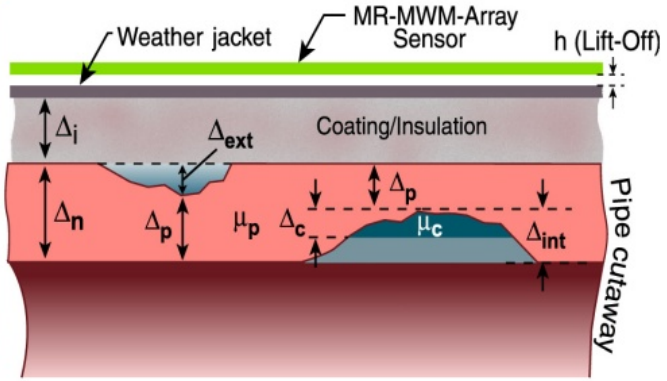


MWM-Array Imaging of External and Internal Corrosion through Insulation with Weather Jacket



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

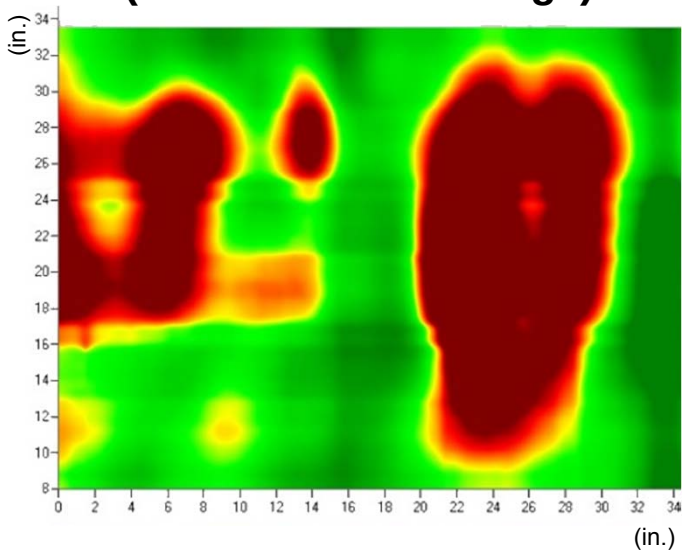
μ_c = Permeability of internal corrosion product layer

Δ_c = Thickness of internal corrosion product layer

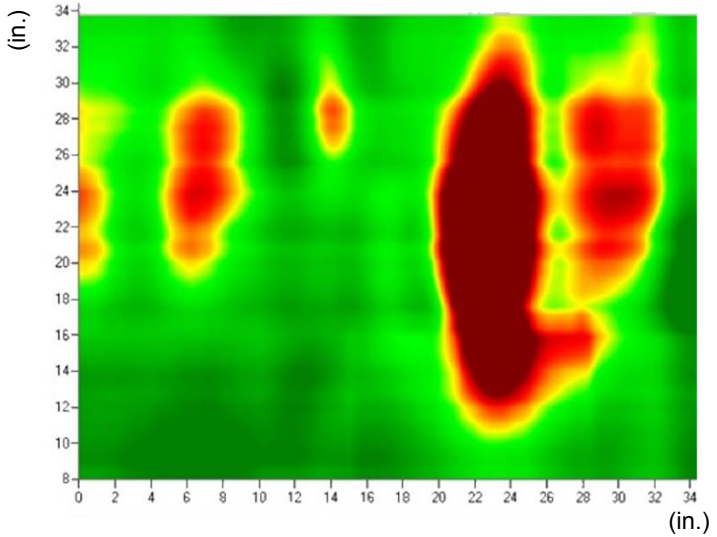
Δ_i = Coating/insulation thickness

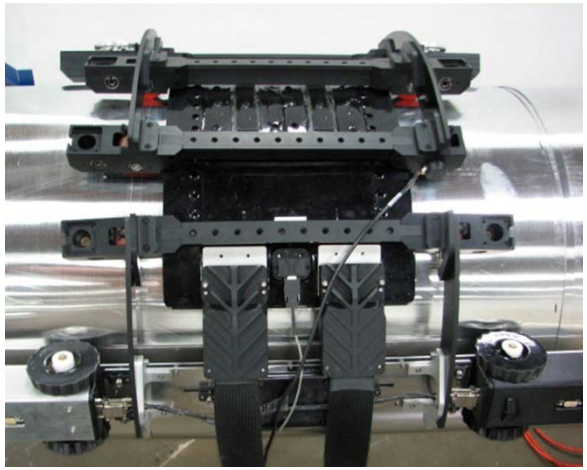
MWM-Array Inspection for CUI

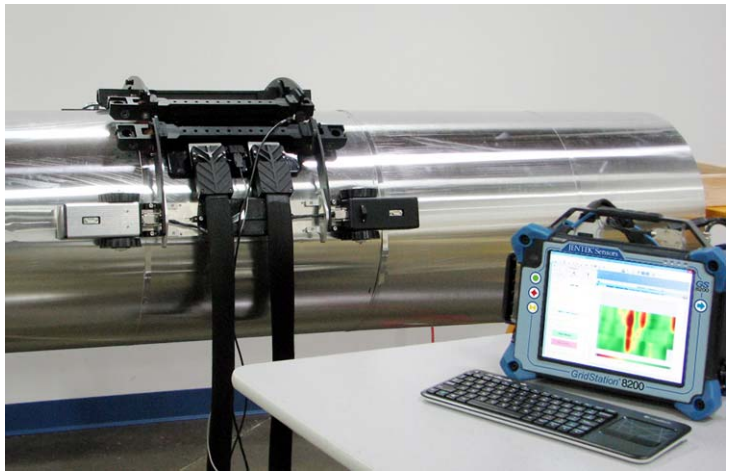
Pre-Alpha System Performance (Wall Thickness Image)



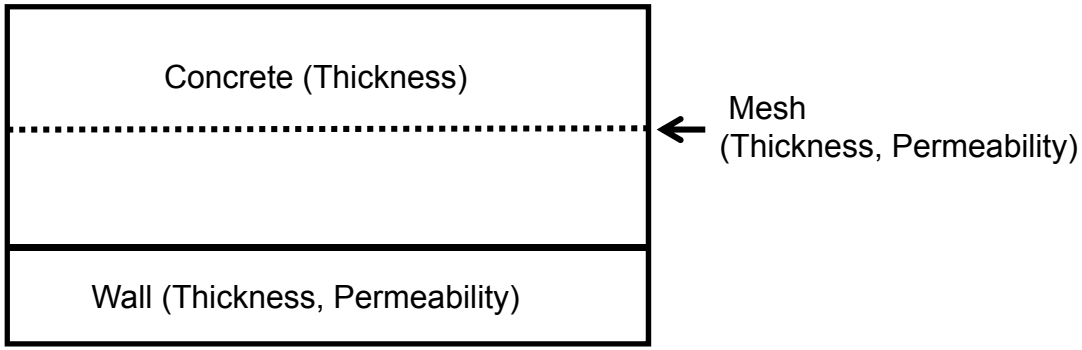
Improved Resolution with Alpha System (Wall Thickness Image)

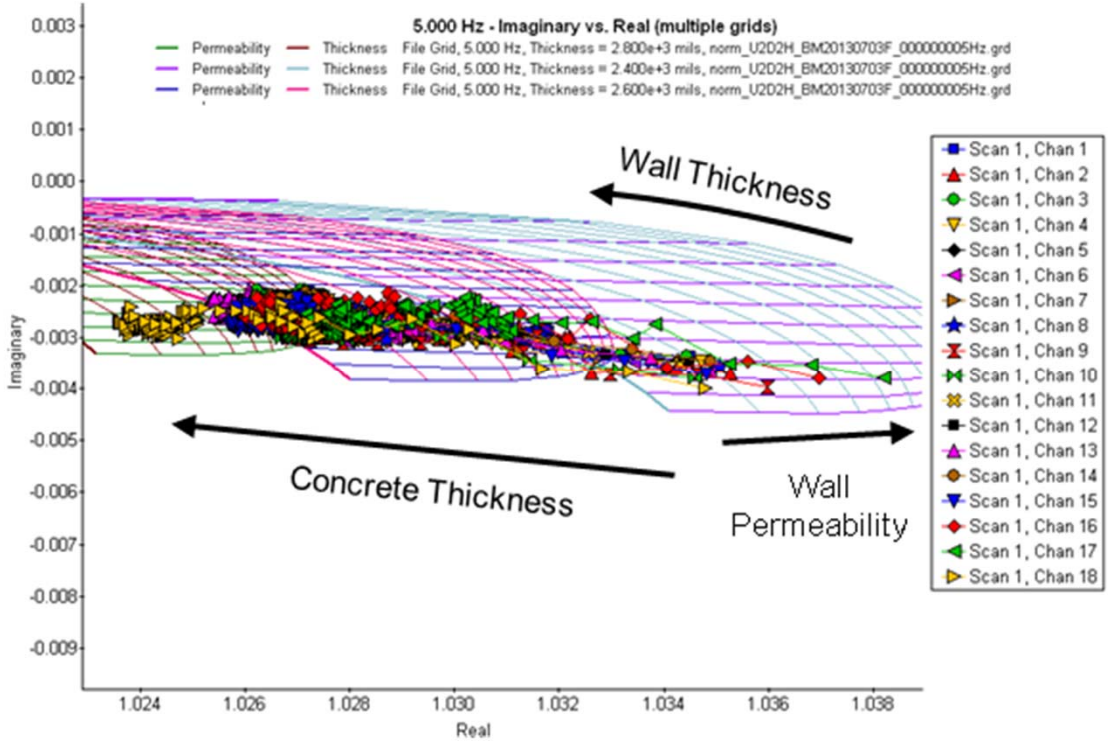






Corrosion Under Fireproofing (CUF) with Wire Mesh

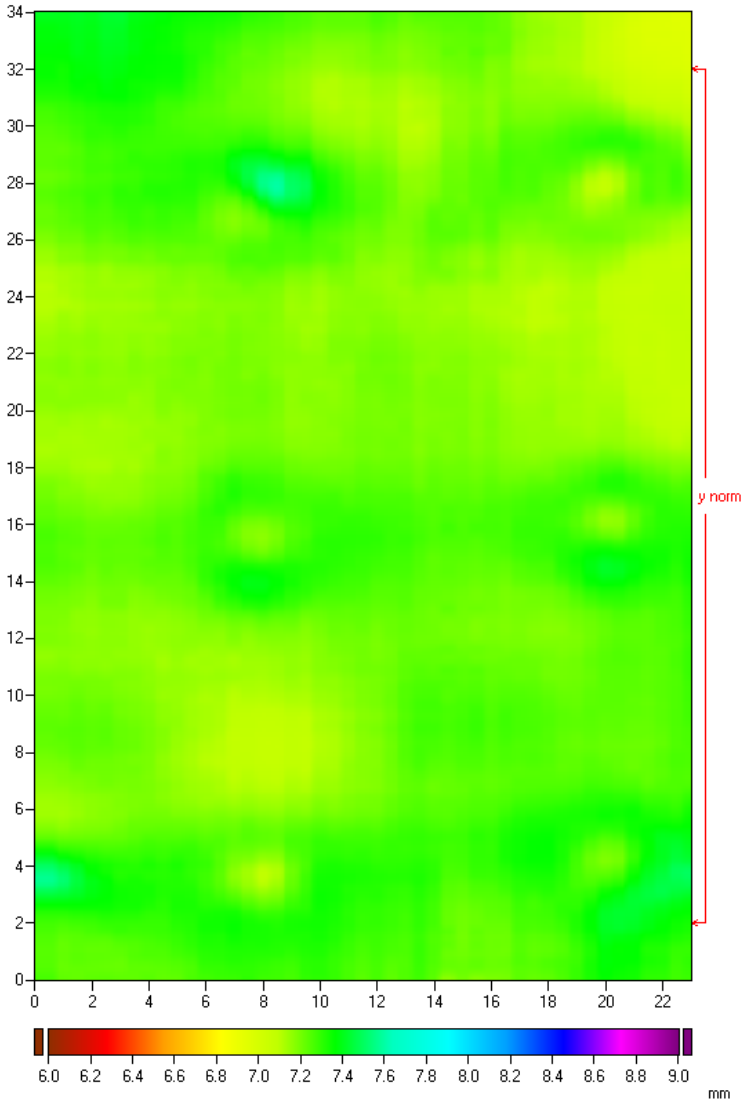




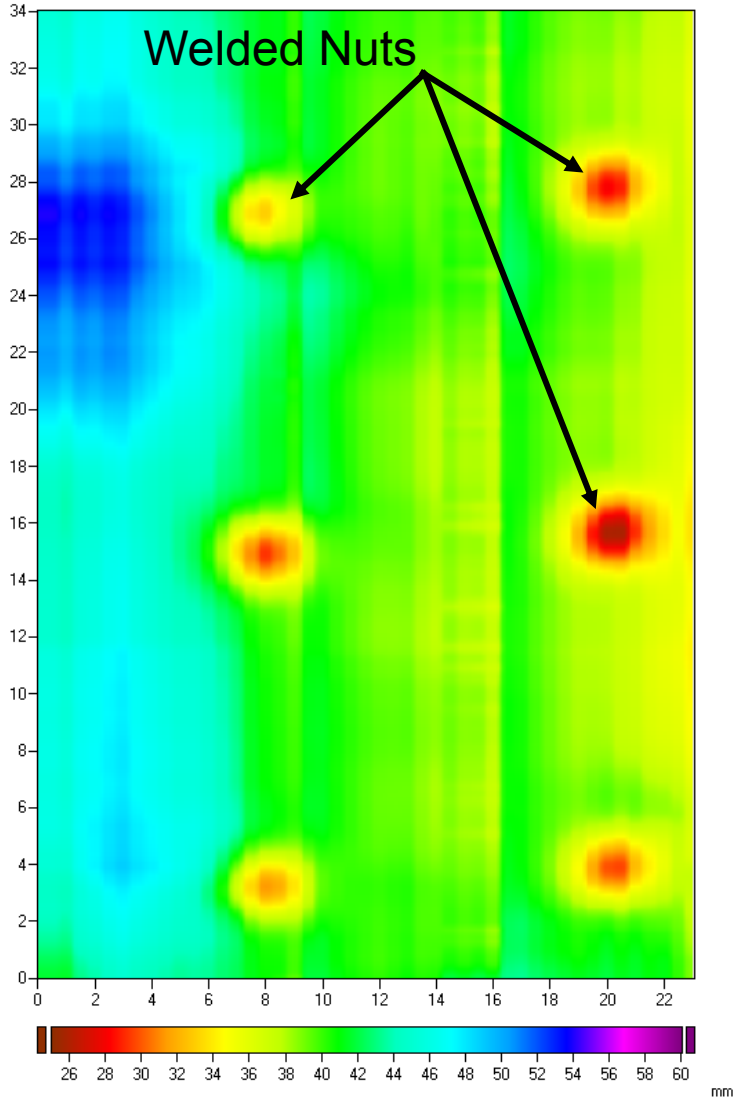
Vessel Scanner

Wall Thickness and Concrete Thickness

Wall Thickness

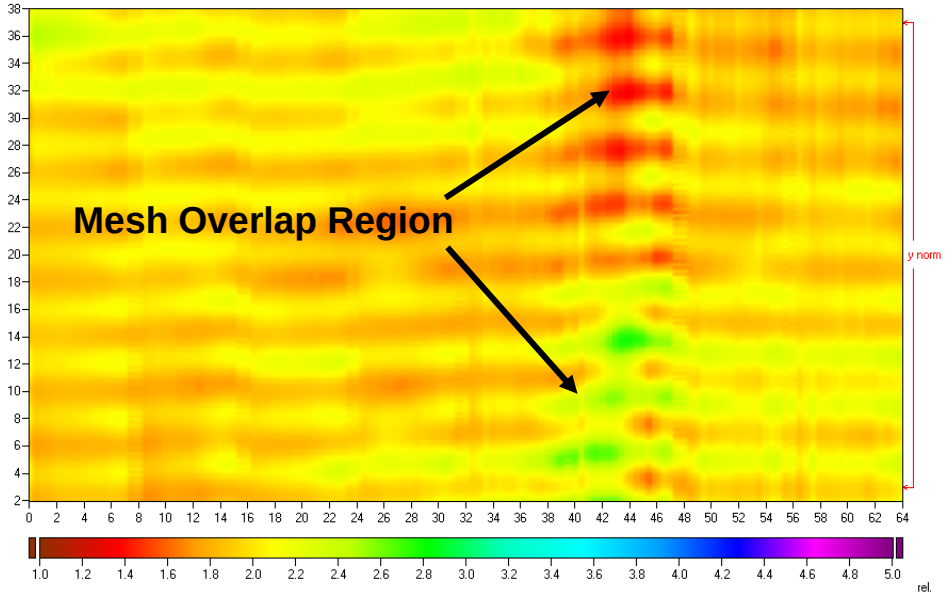


Concrete Thickness

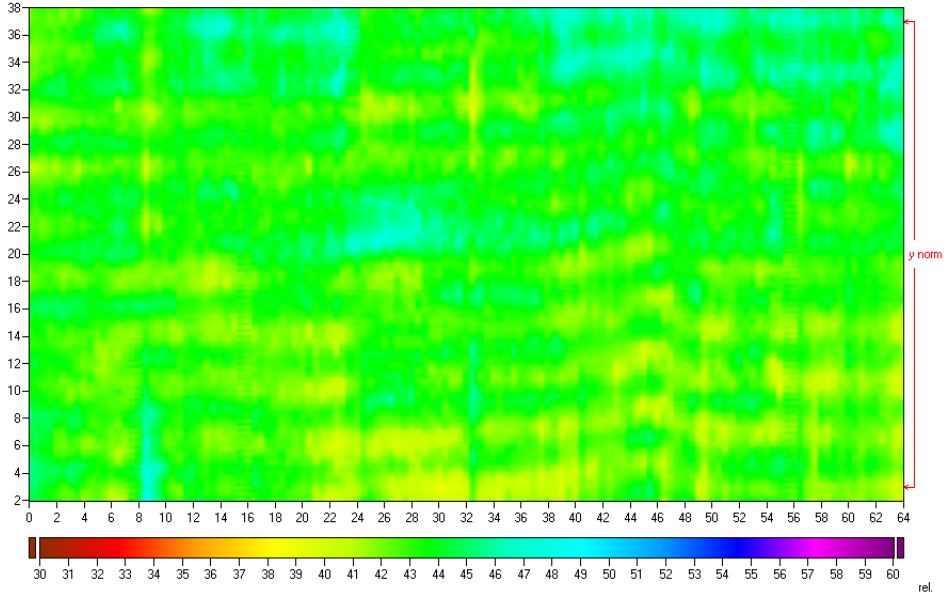


Removing Mesh Contribution

Mesh Permeability



Wall Permeability



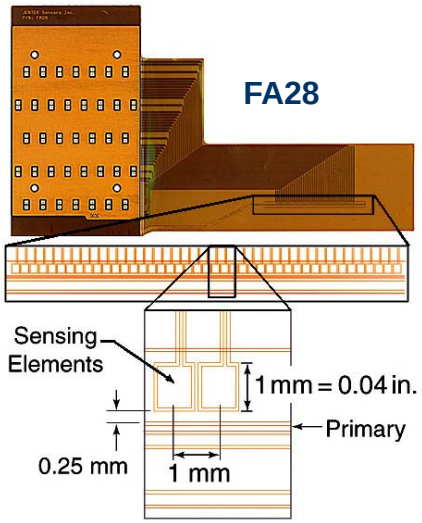
Mesh Models Still Under Development

Other Example Applications

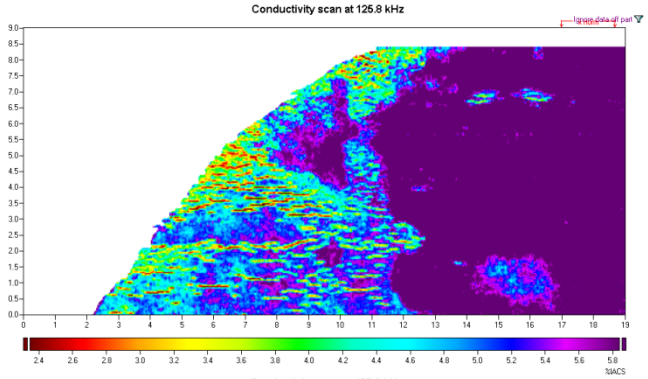
- SCC Mapping and Depth Measurement
- Post Weld Heat Treatment (PWHT) Assessment
- ILI (Internal Corrosion and Stress)
- Mechanical Damage Profile and Residual Stresses
- SHM for Crack Growth, Corrosion, and Stress

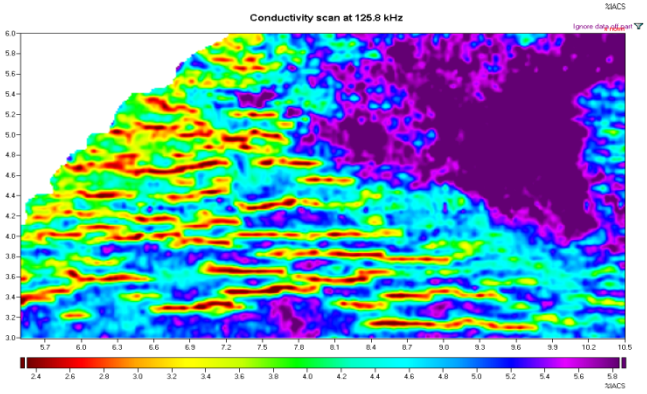
FA28 MWM-Array Imaging of SCC

Pipeline Sample Provided by Applus/RTD

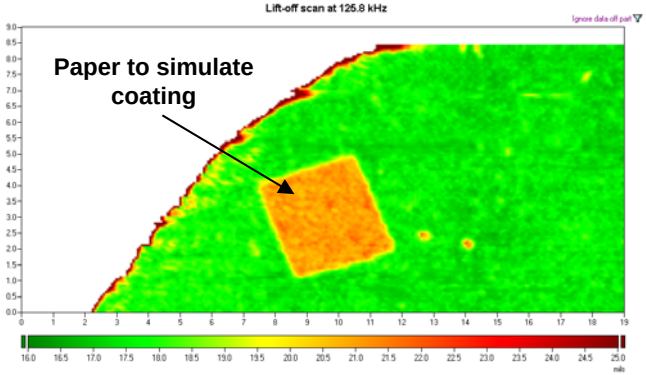


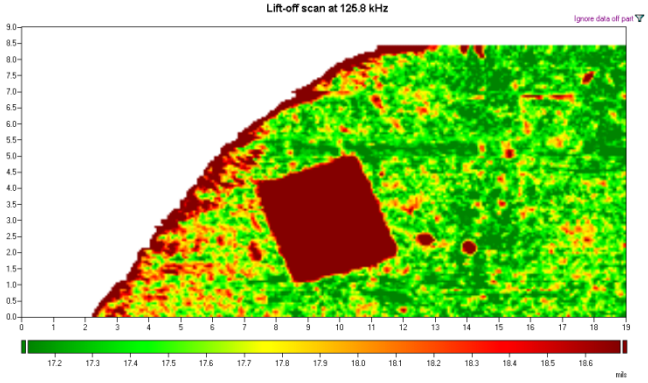
Crack Response Image





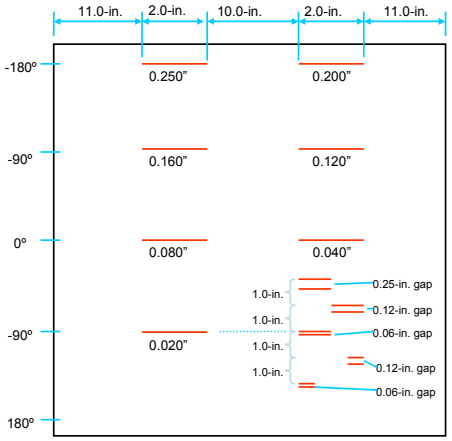
Lift-Off Image

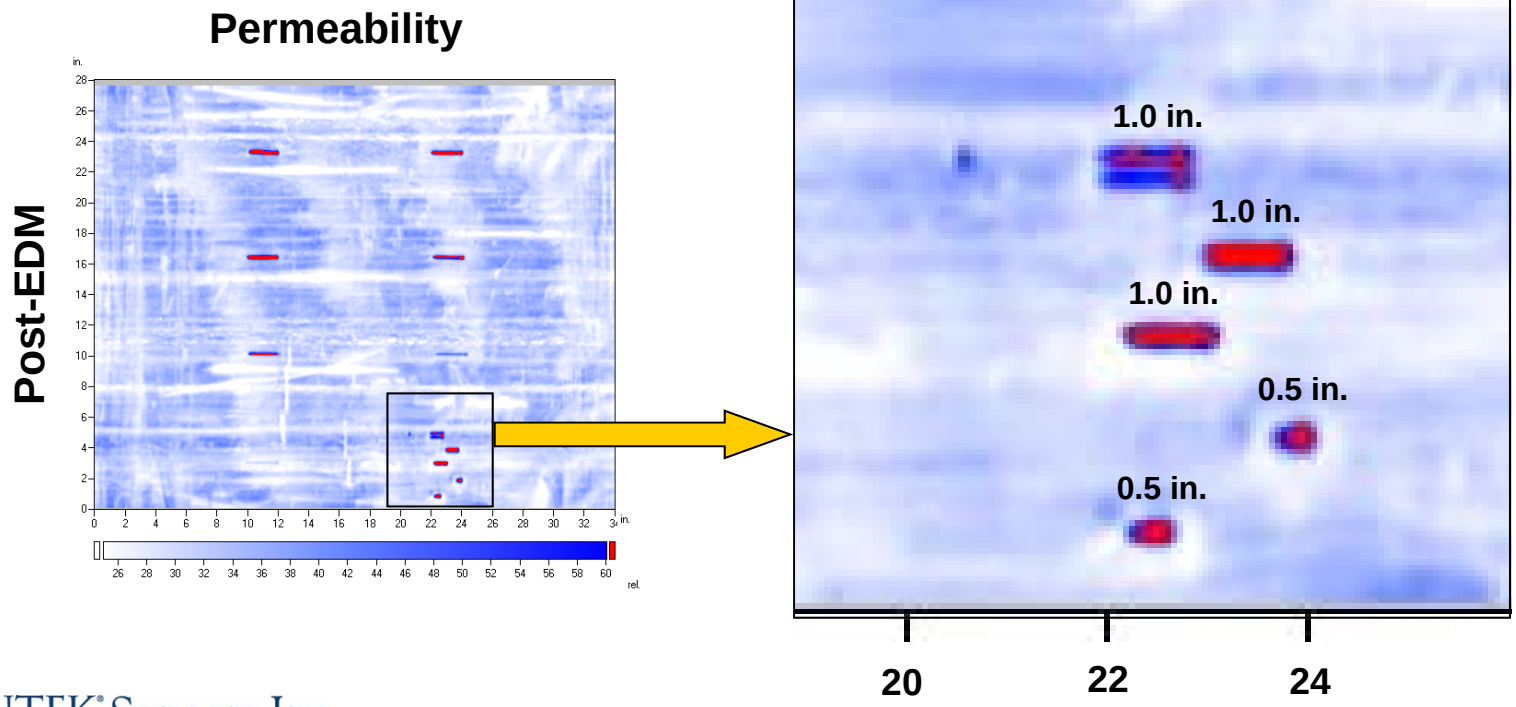




Crack Imaging & Depth Measurement Capability

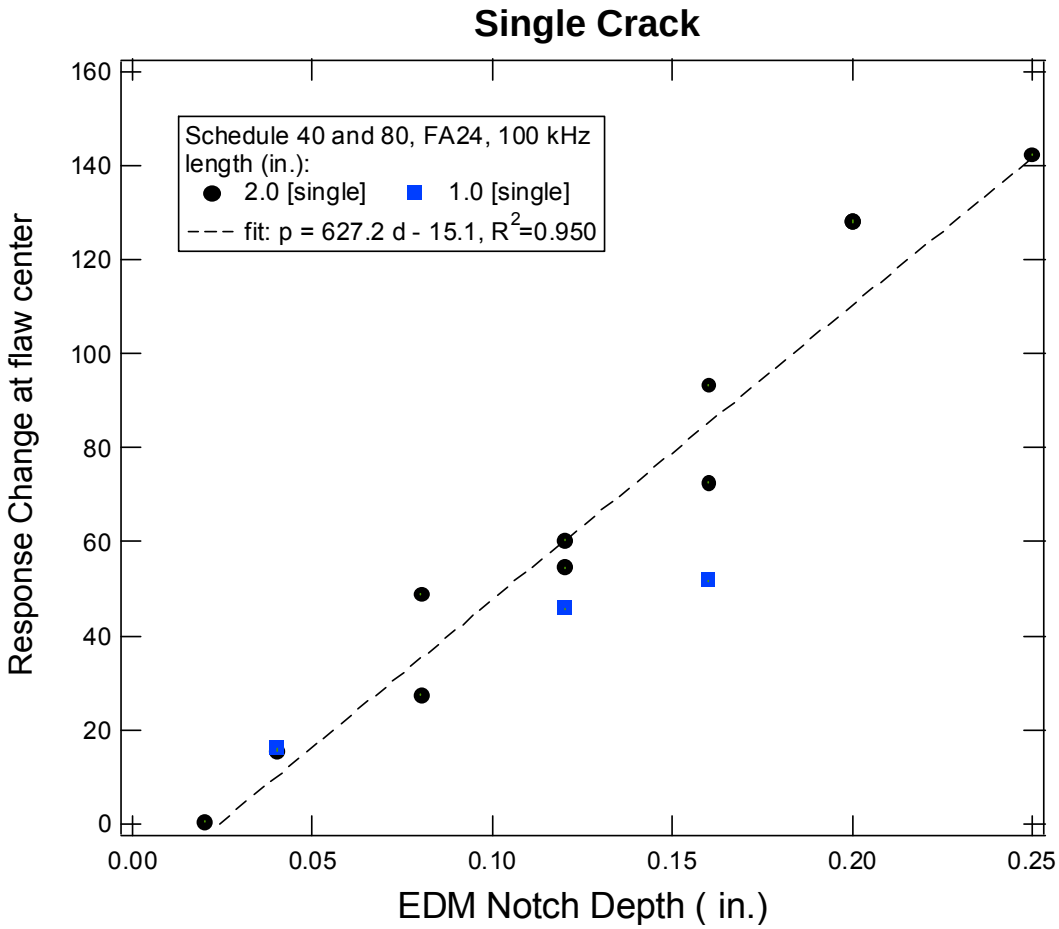
- Representative FA24 data at 100 kHz on EDM notch pipe sample
- Notches clearly indicated as increase in permeability
- Pairs of notches show resolution capability





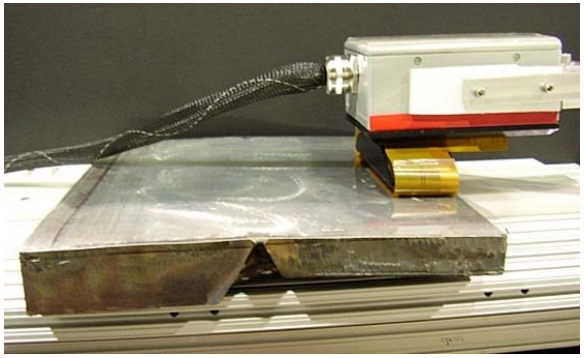
Crack Imaging & Depth Measurement Capability

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



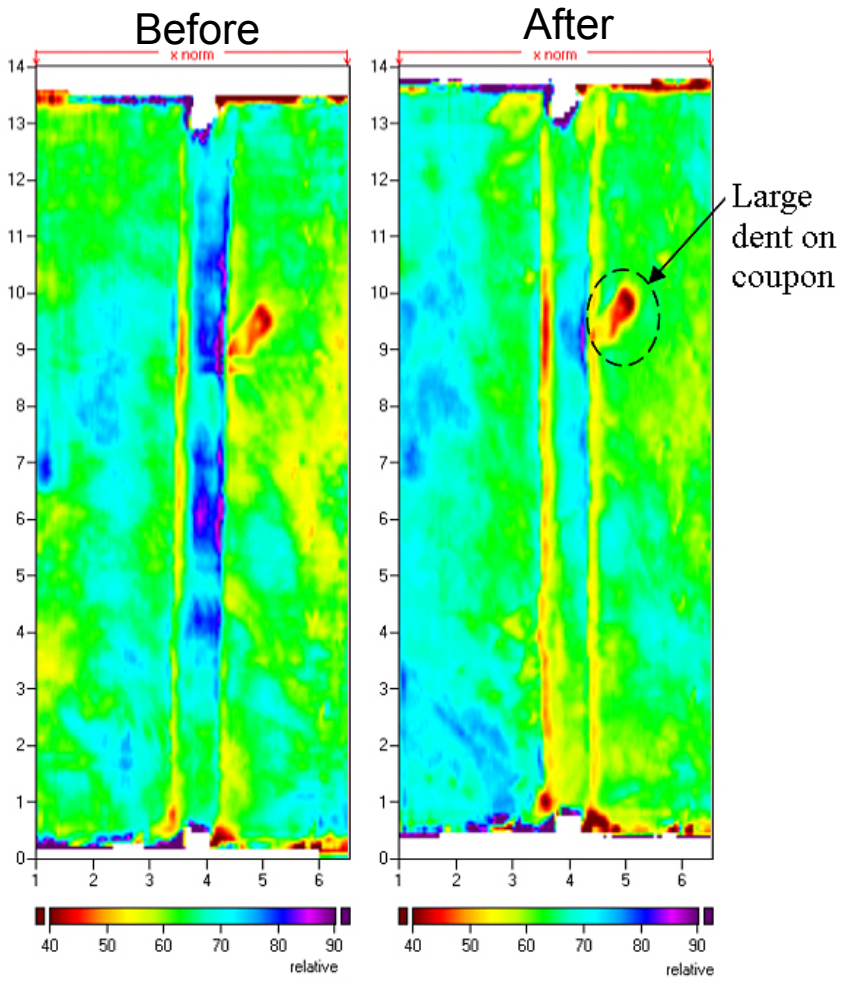
MWM-Array Residual Stress Imaging

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

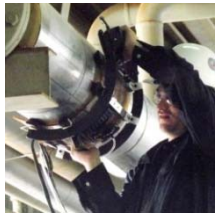


Developing solutions for through-thickness imaging of stresses in welds with crowns

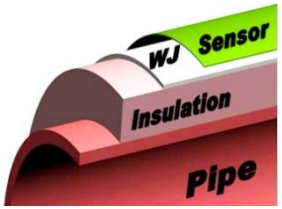
Oil & Gas Summary - Application Examples

CUI

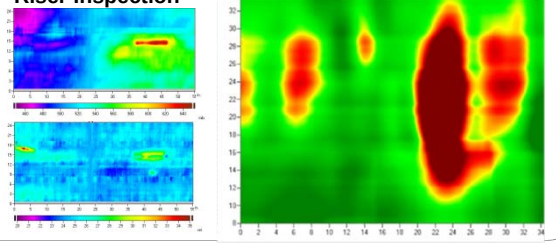
Corrosion Under Insulation



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

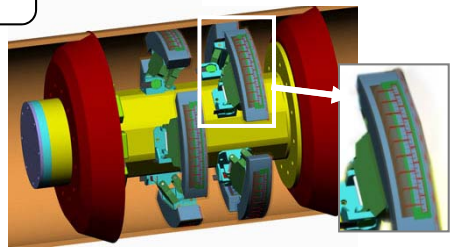


Riser Inspection



ILI

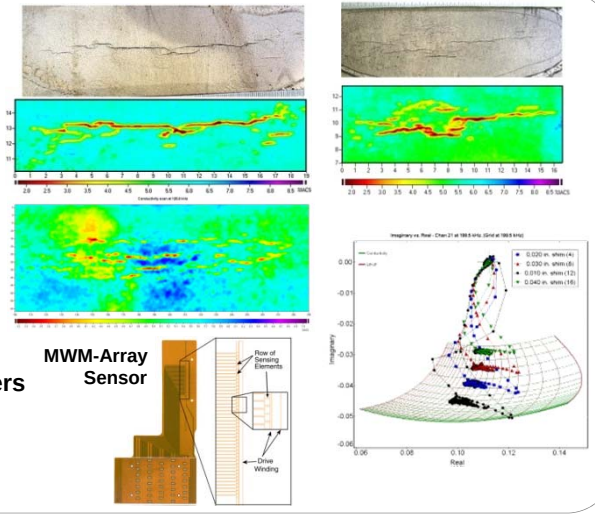
In-Line Inspection



- 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

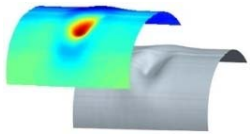


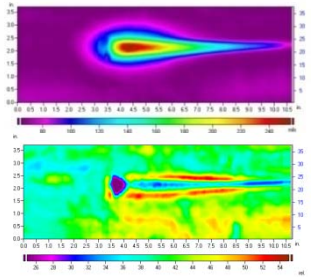
- Mapping of SCC clusters
- Developing depth screening capability
- MPI replacement

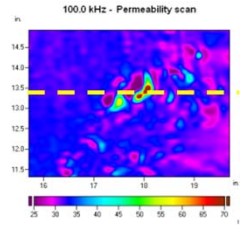
MWM-Array Sensor

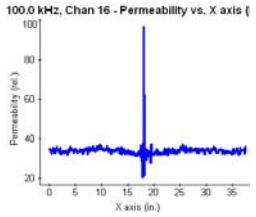
MD

Mechanical Damage





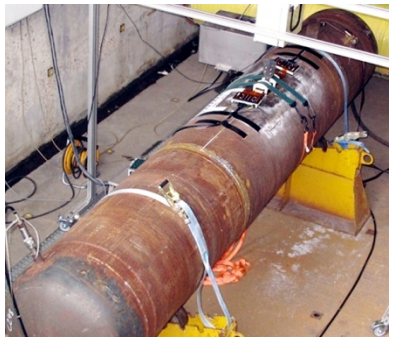


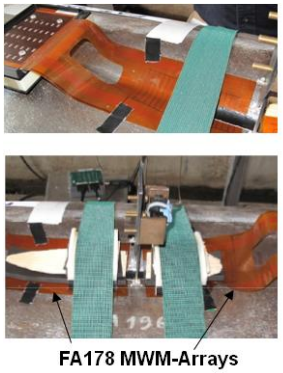


- Magnetic profilometry
- Crack Detection in Dents
- Developing residual stress mapping

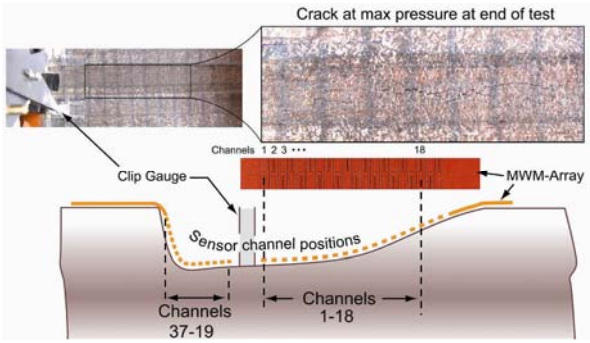
SHM for Crack Growth, Stress (and Corrosion Monitoring)

Under DOT and PRCI Funding with GDF Suez

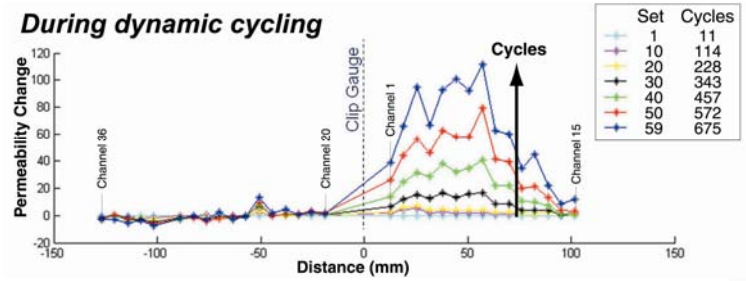


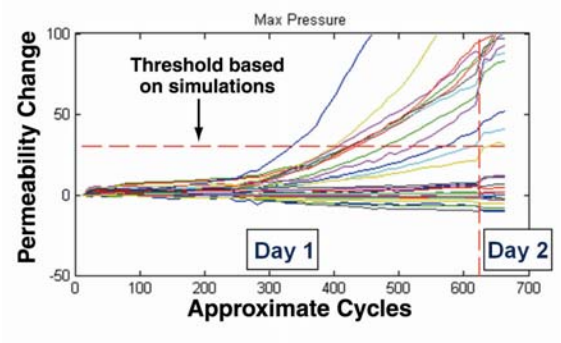


FA178 MWM-Arrays



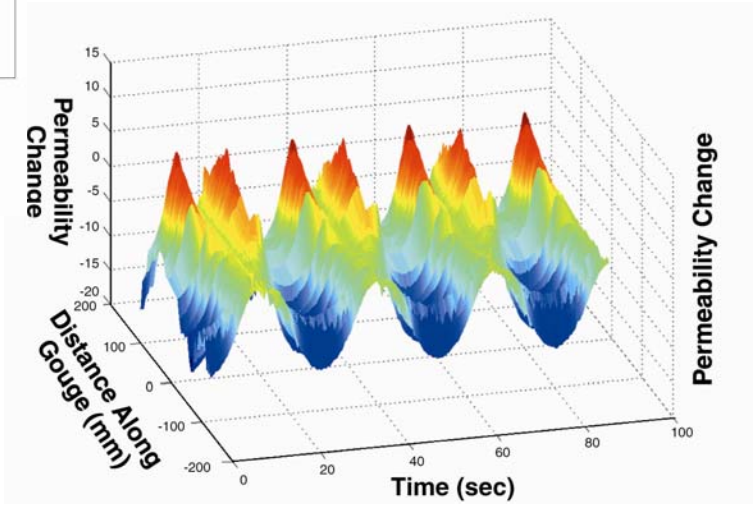
Damage Monitoring



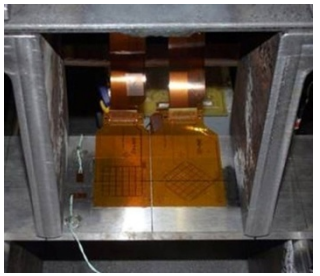


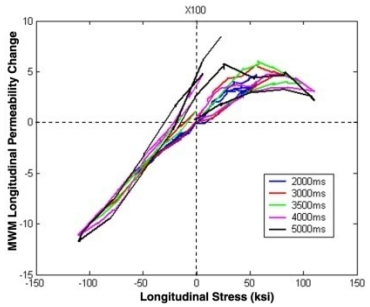
Stress Monitoring

Dynamic pipeline pressure testing



4-pt static load testing of coupon





Summary

Internal and External Corrosion

- CUI (Insulation or Insulation with Weather Jacket)
- CUF (Concrete with Wire Mesh)

Other Applications

- SCC Mapping and Depth Measurement
- Post Weld Heat Treatment (PWHT) Assessment
- ILI (Internal Corrosion and Stress)
- Mechanical Damage Profiling and Residual Stress
- SHM for Crack Growth, Corrosion, and Stress