Inspection of Pipelines using High-Resolution MWM® and MR-MWM-Arrays

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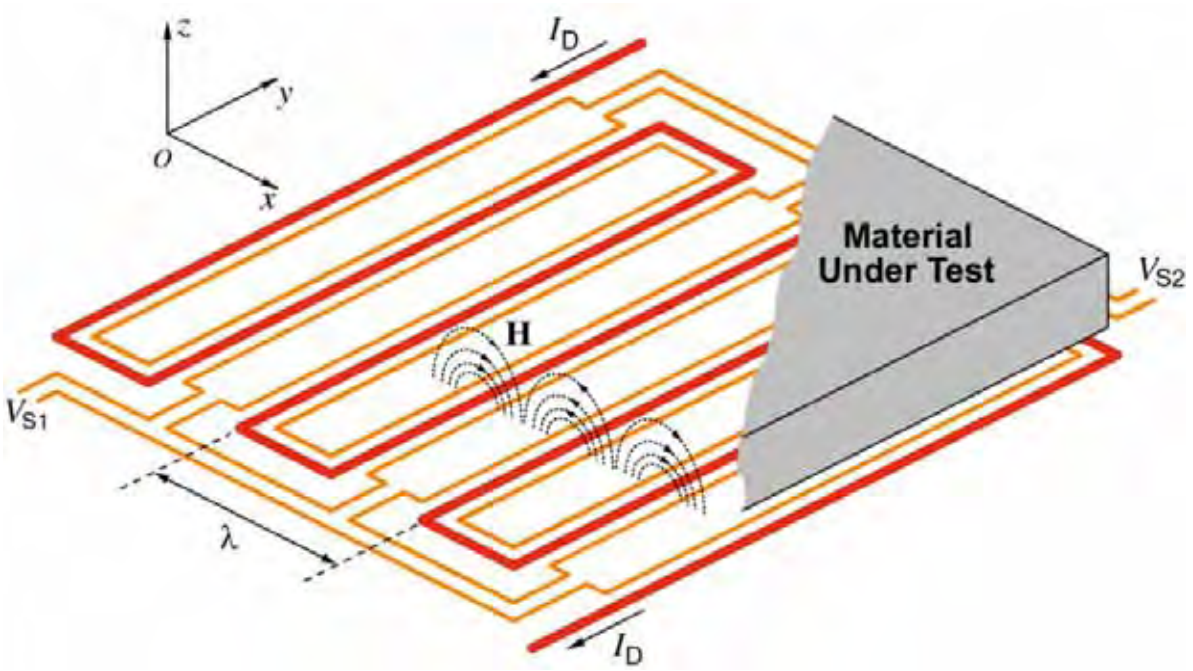
Outline

- **MWM-Array Technology overview**
- **Oil & Gas Applications**
  - Pipe wall thickness measurement through coatings/insulation
  - Underwater inspections (shallow water and deepsea) for pipe wall thickness measurement
  - SCC mapping and crack depth estimation
  - Characterization of pitting in stainless steel tubing
  - Permanently mounted sensors for continuous monitoring
  - In-line inspection (ILI)

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

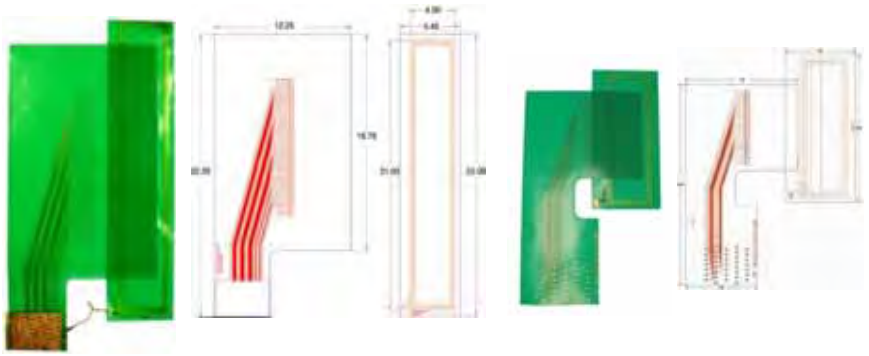


MWM-Array Examples

MWM-Array dimensions can be adjusted for the application

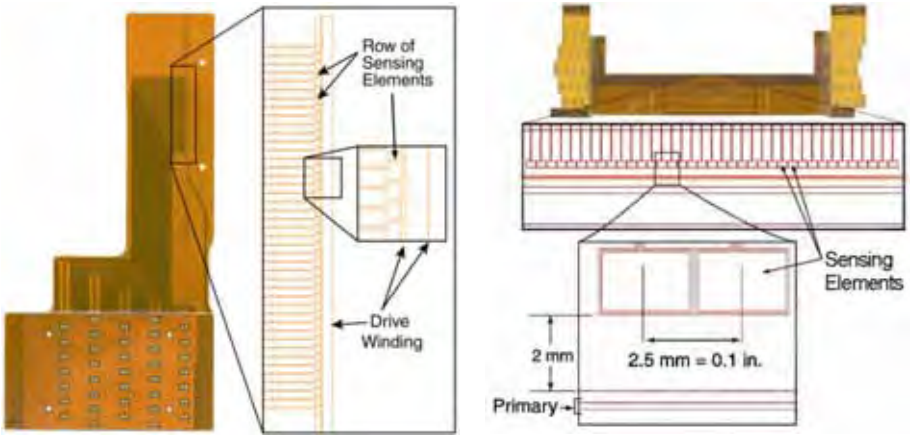
e.g., high spatial resolution or imaging through thick coatings

VWA001 **VWA003**



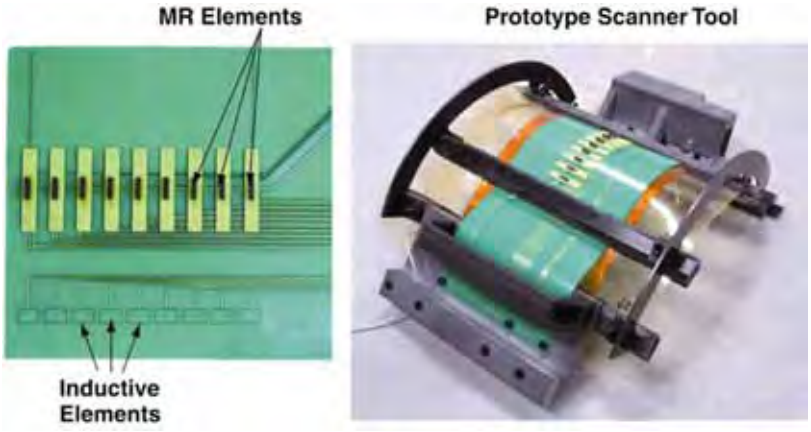
Thin insulation, external corrosion

FA28 **FA24**



High resolution, no insulation

Generation 3 MR-MWM-Arrays

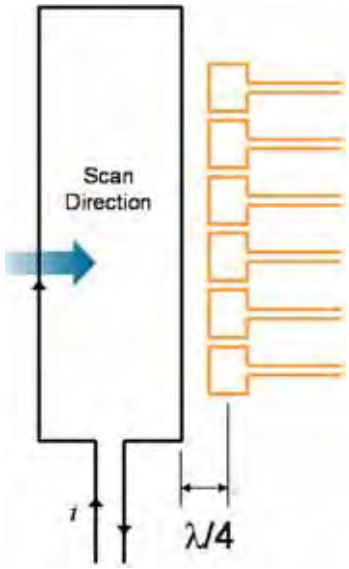


Thick insulation, internal & external corrosion

MWM-Array Sensor Selection

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

VWA001 MWM-Array

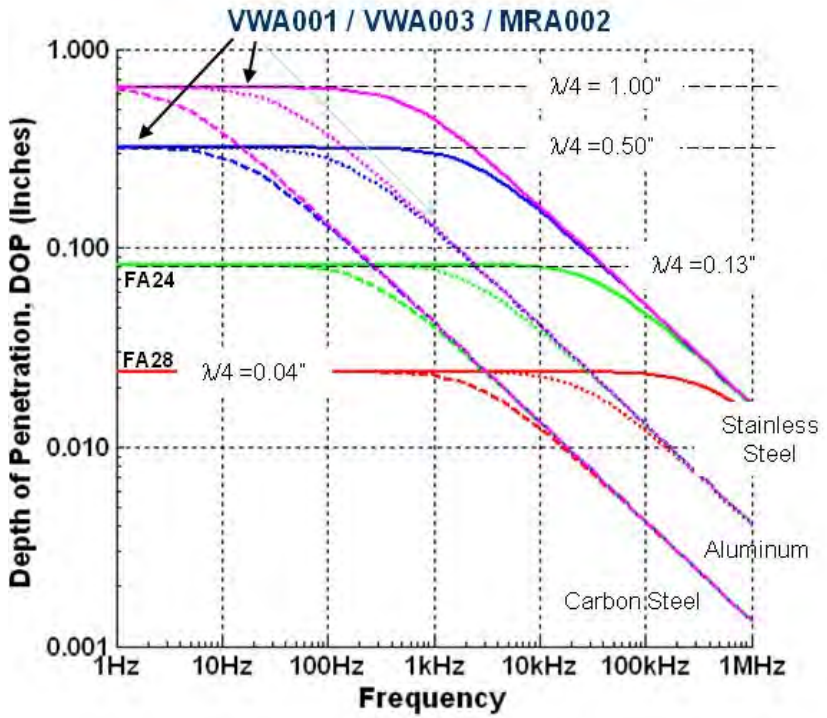


Depth of Penetration = 1/Re(Γ_n)

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

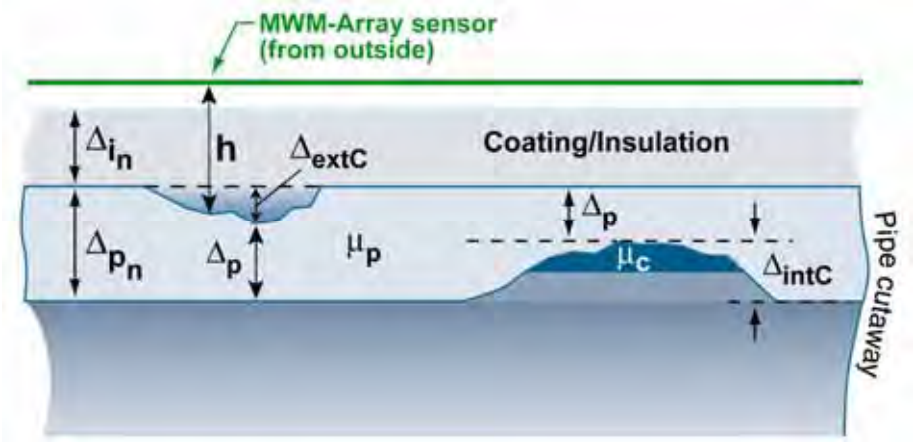
$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

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

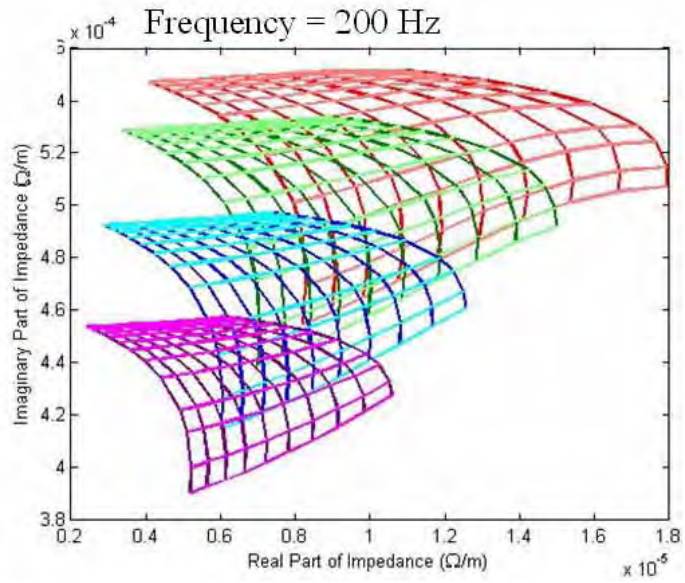


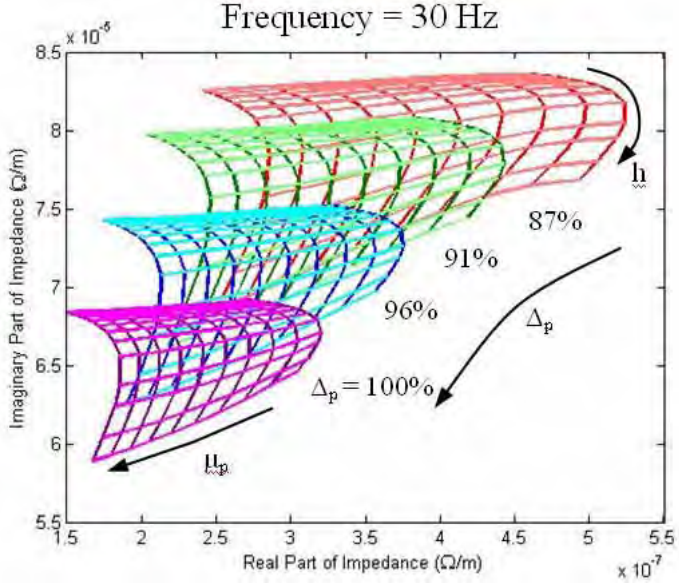
HyperLattices:
Precomputed Sensor Response Databases

- Rapid means for converting multiple frequency array data into material and geometric properties
- Grids (two-unknown databases), Lattices (3-unknowns), Hyperlattices (4+ unknowns) are generated and stored in advance



Example Lattices

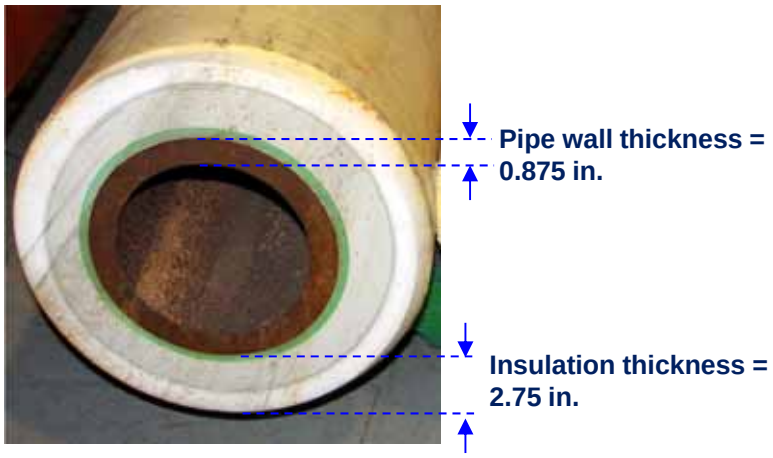


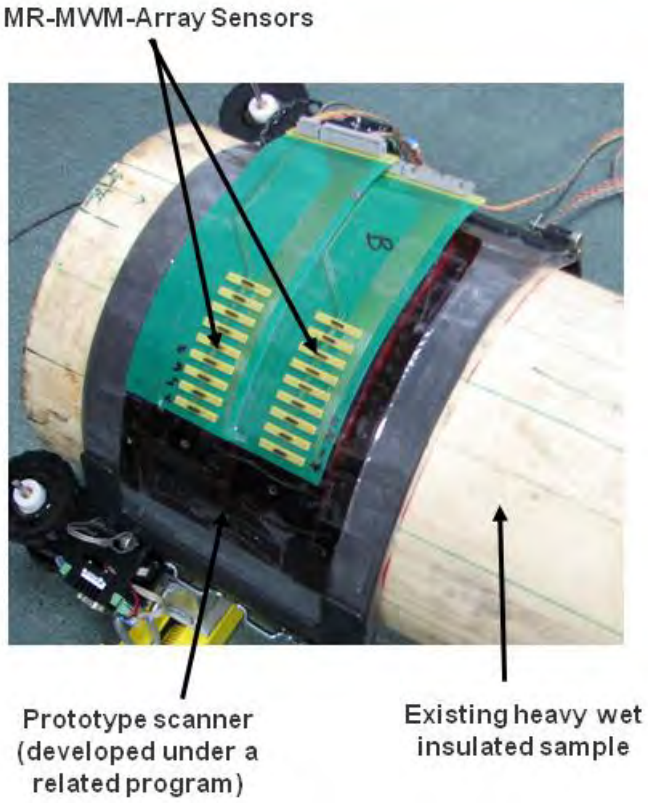


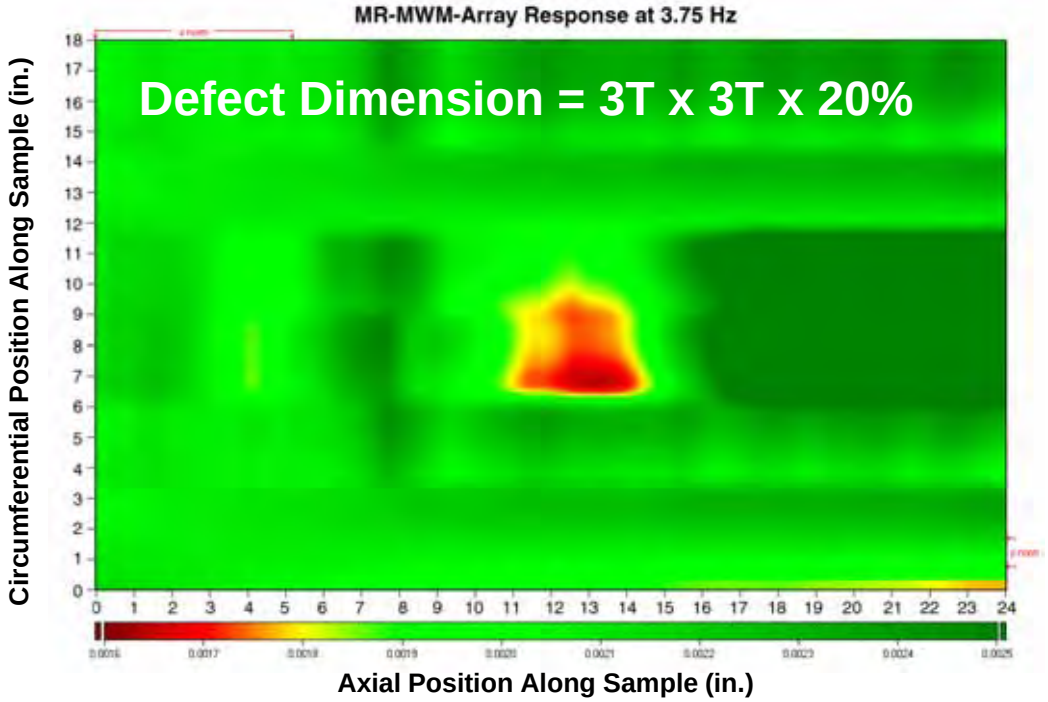
Internal Corrosion Imaging

MR-MWM-Array Imaging of Heavy Wet Insulated Risers

- **Performed measurements under a related effort on heavy wet insulated riser samples**
- **Detection of internal corrosion through *2.75 inch* insulation and *0.875 inch* pipe wall**

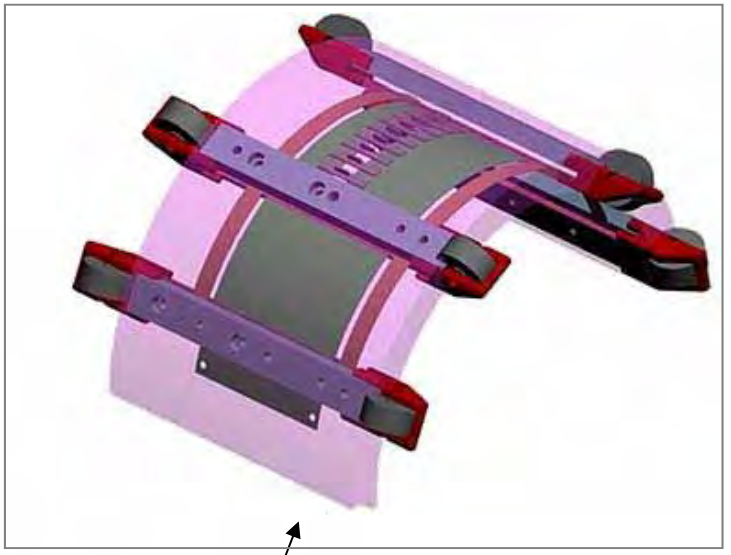


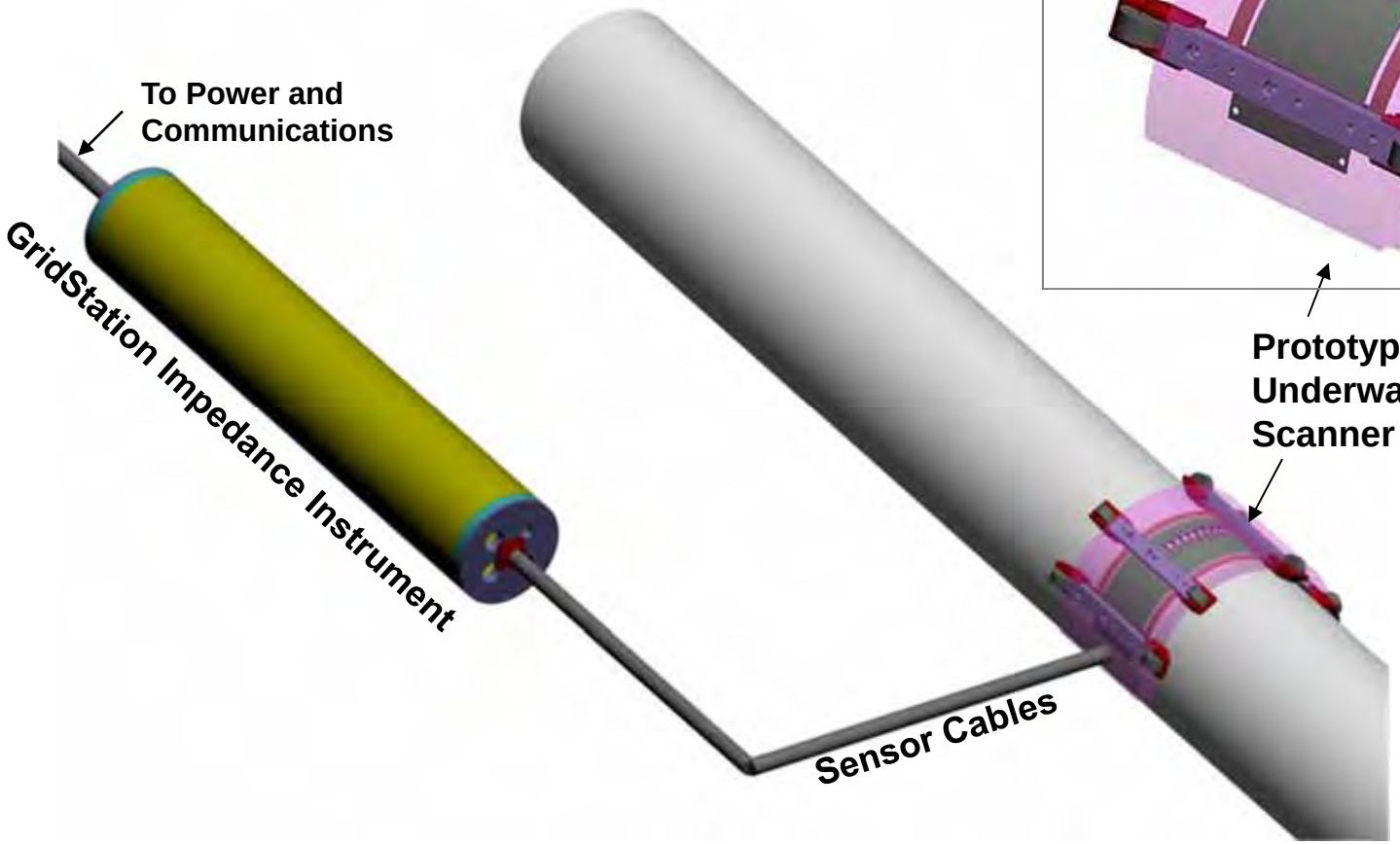




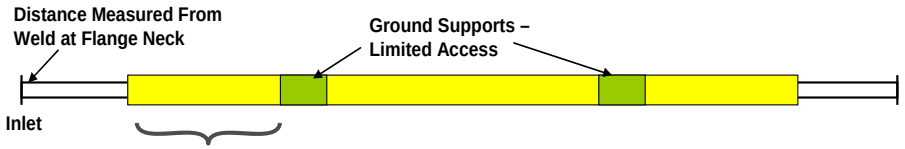
Underwater Scanning System

Under Development



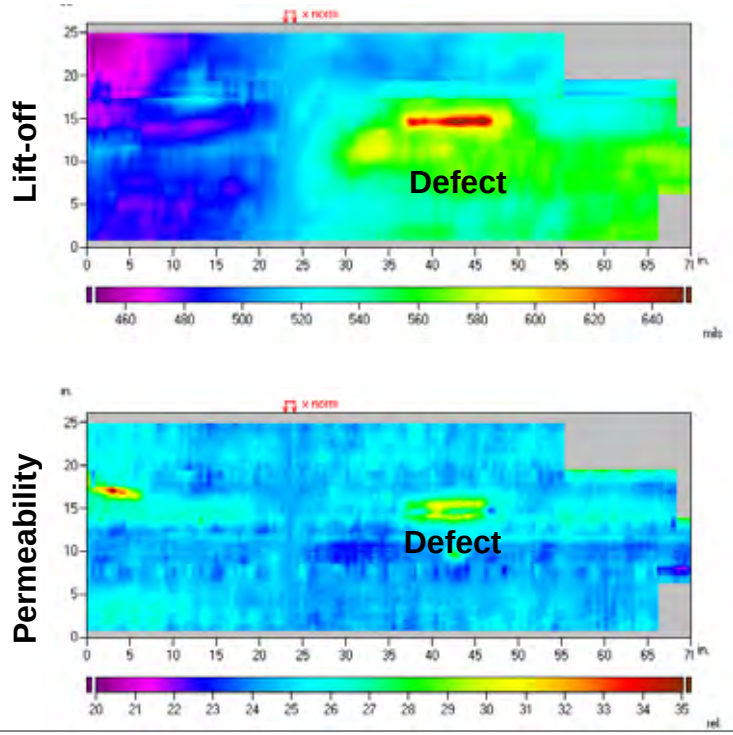


Previous CUI Results
Using VWA001 MWM-Arrays

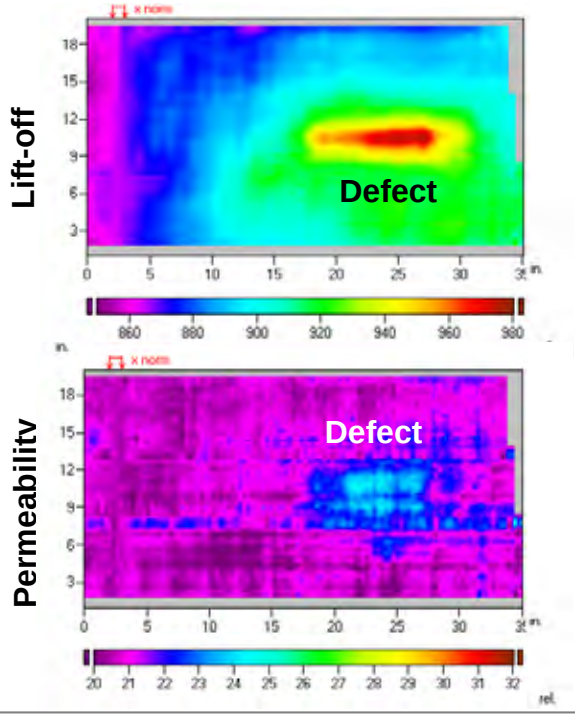


Riser section of interest

0.5 in. coating



1.0 in. coating



Capability Demonstrations

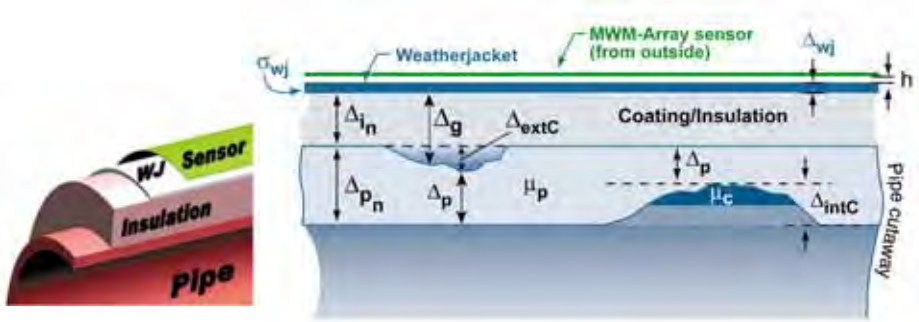
MR-MWM-Arrays through weather jacket

- Performed field trials in 2011 and 2012
- 4 field trials completed to date, more planned for 2013
- Trials designed to guide future development
- Successfully demonstrated a flexible scanner on multiple locations and pipe diameters

MWM-Array Inspection for CUI

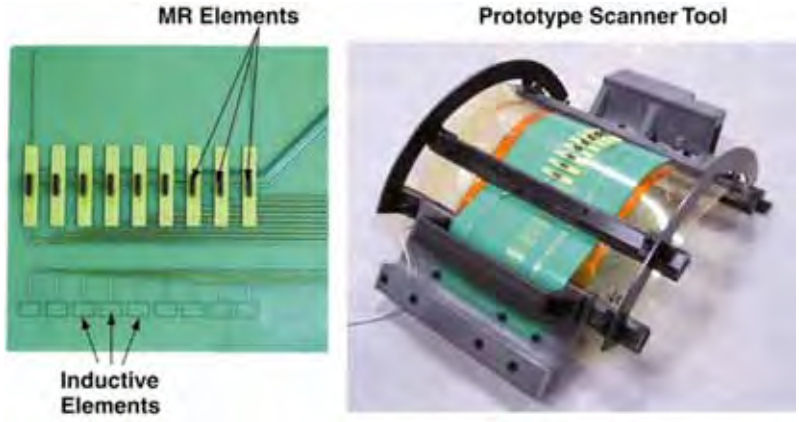
Through weather jacket

Problem Definition



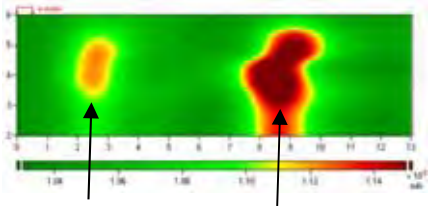
$\Delta_g = \Delta_{in} + \Delta_{extC}$, Δ_p = wall thickness

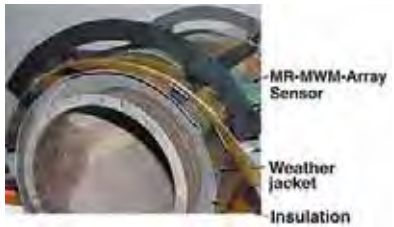
JENTEK MR-MWM-Array

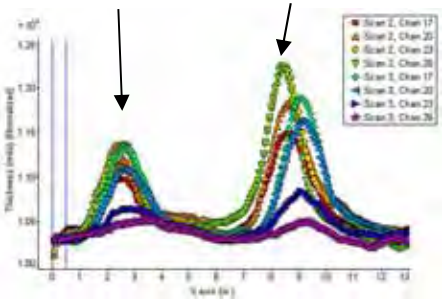


Detection of External Corrosion

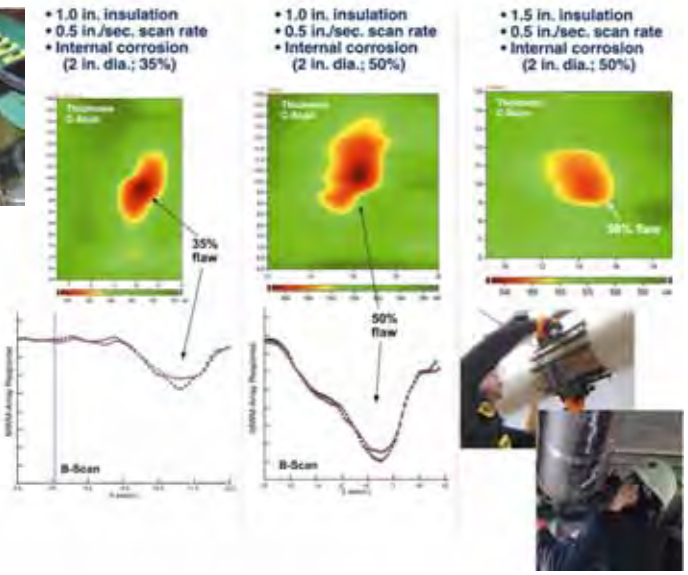
- 1.0 in. Insulation
- 0.025 in. aluminum weather jacket
- 0.5 in./sec. scan rate
- External corrosion
  (2 in. dia.; 20% and 35%)





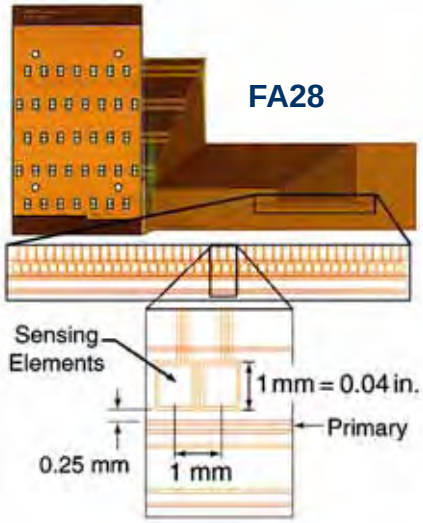


Detection of Internal Corrosion

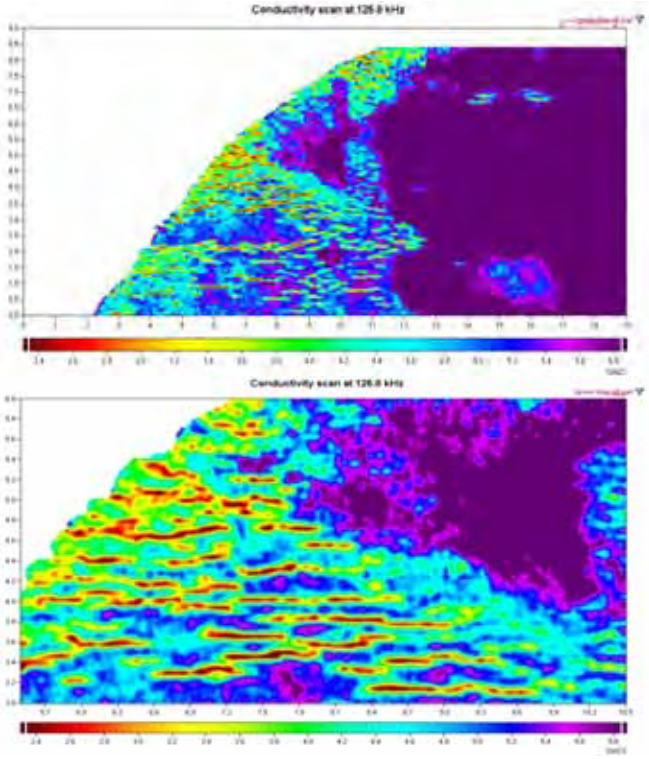


FA28 MWM-Array Imaging of SCC

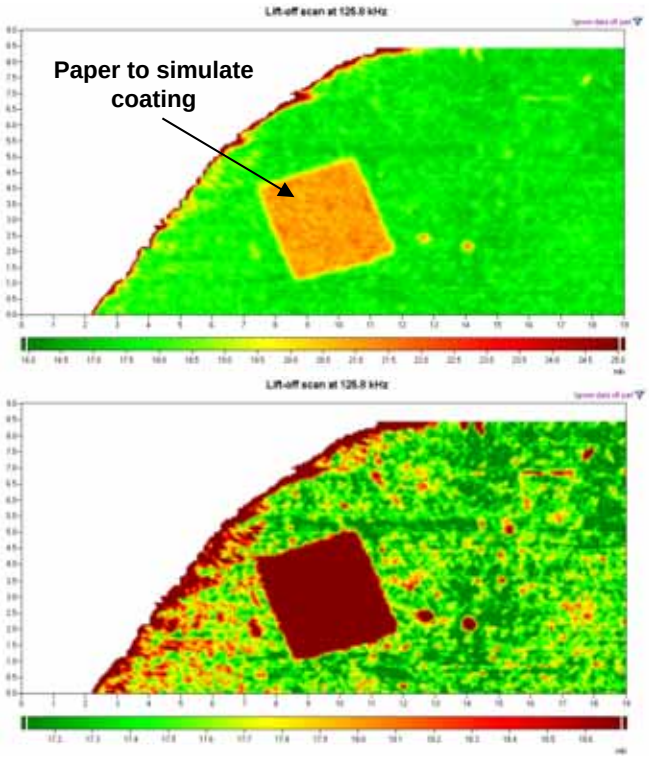
Pipeline Sample Provided by Applus/RTD



Conductivity Images

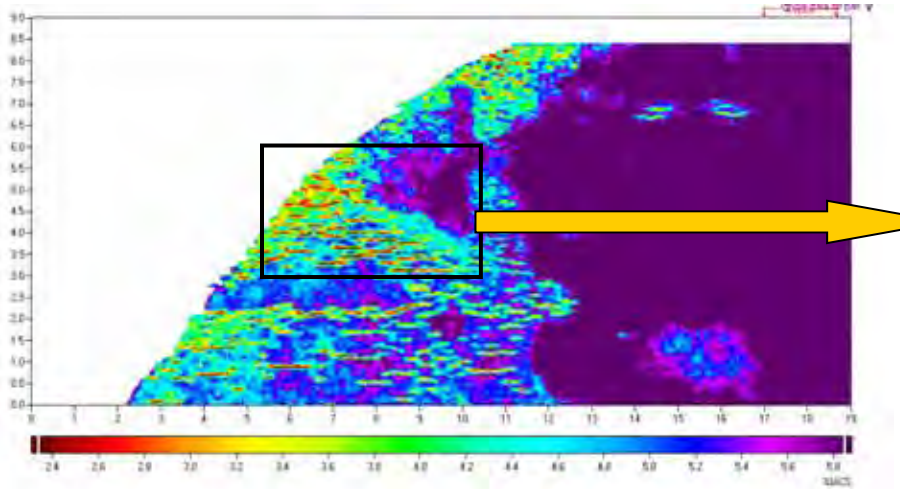


Lift-Off Images

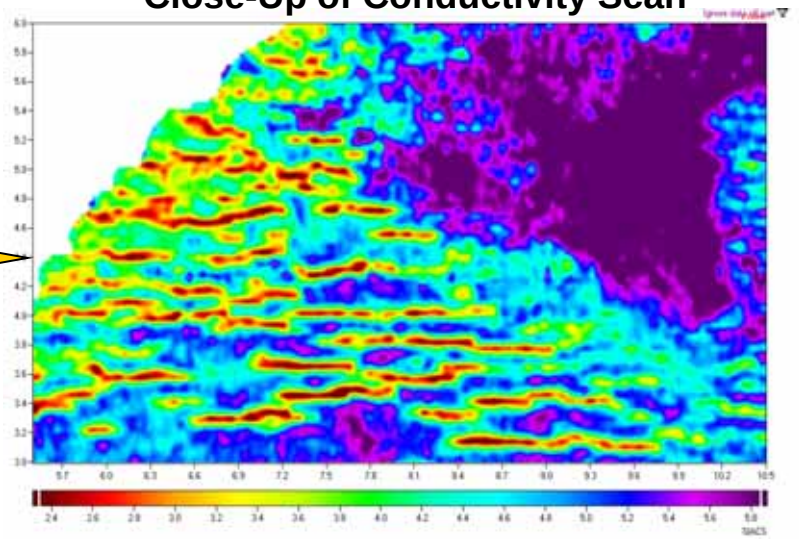


FA28 Imaging of Stress Corrosion Cracking

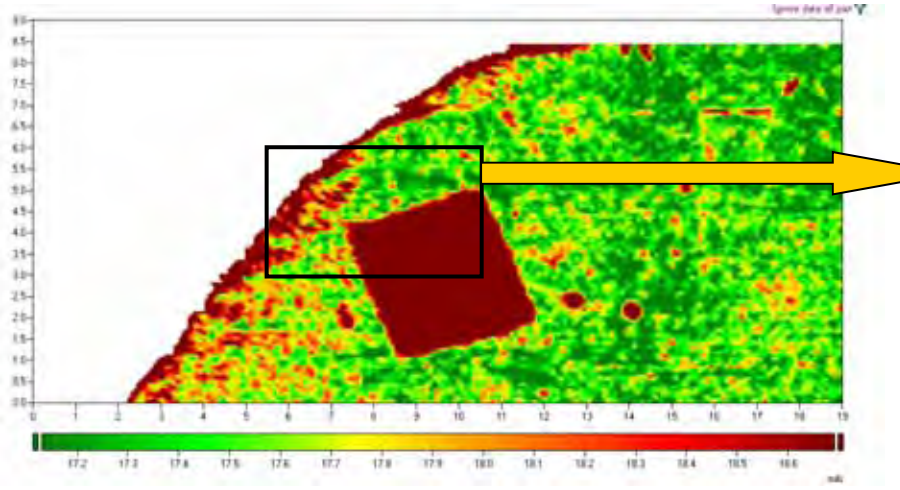
Conductivity Scan



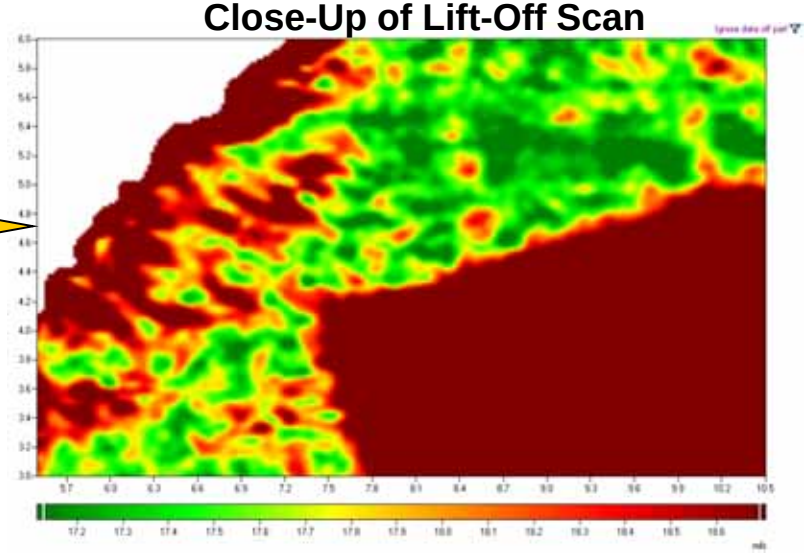
Close-Up of Conductivity Scan



Lift-Off Scan - Through Coating

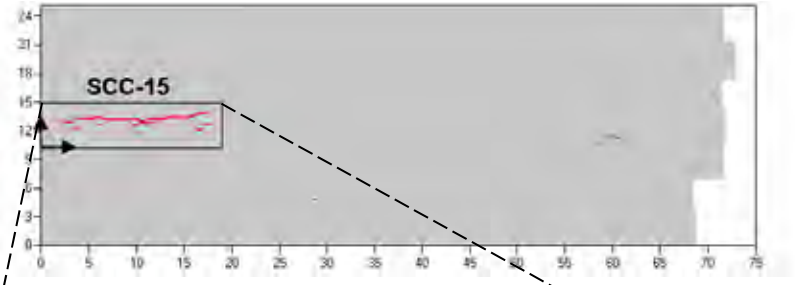


Close-Up of Lift-Off Scan

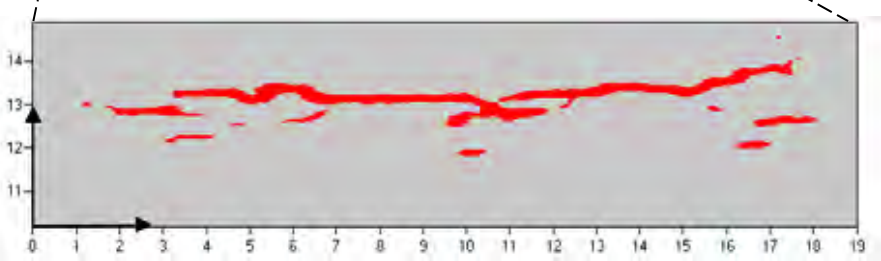


FA28 Imaging of SCC in Pipeline Sample

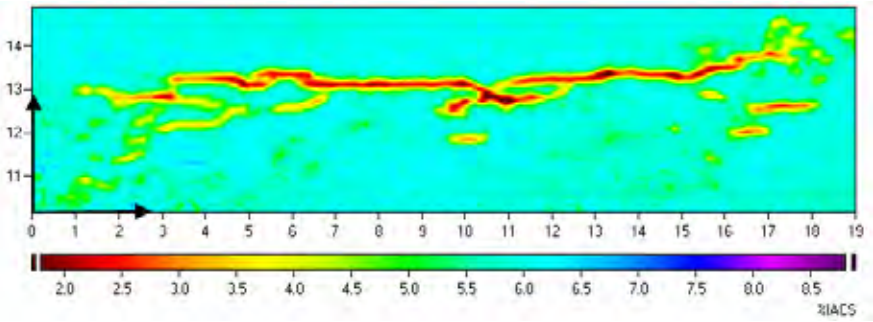
Scans of Pipe Section with Identified SCC



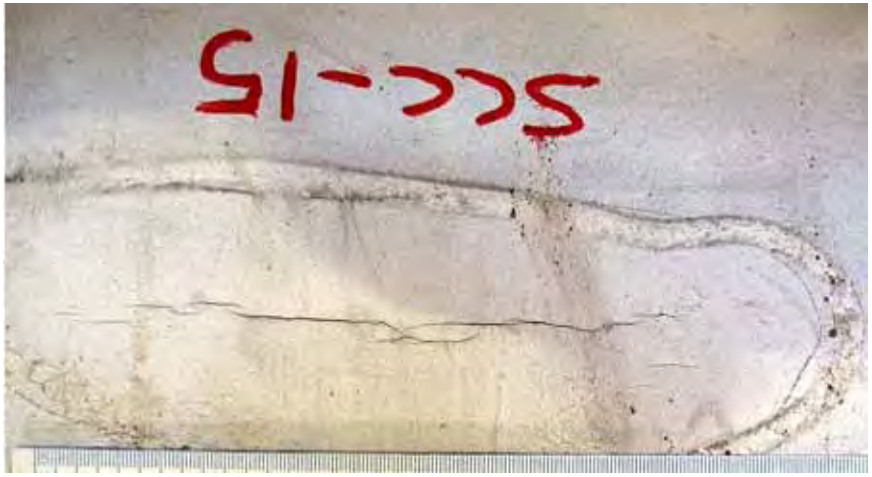
MWM-Array Threshold Image



MWM-Array Spectrum Color Image

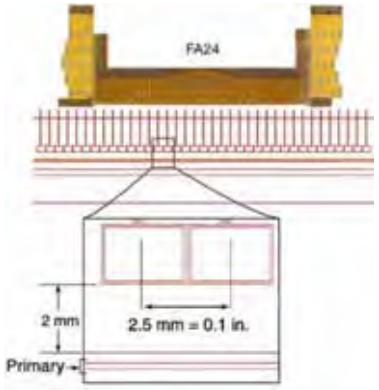


(RTD p/n NPS34 #1)

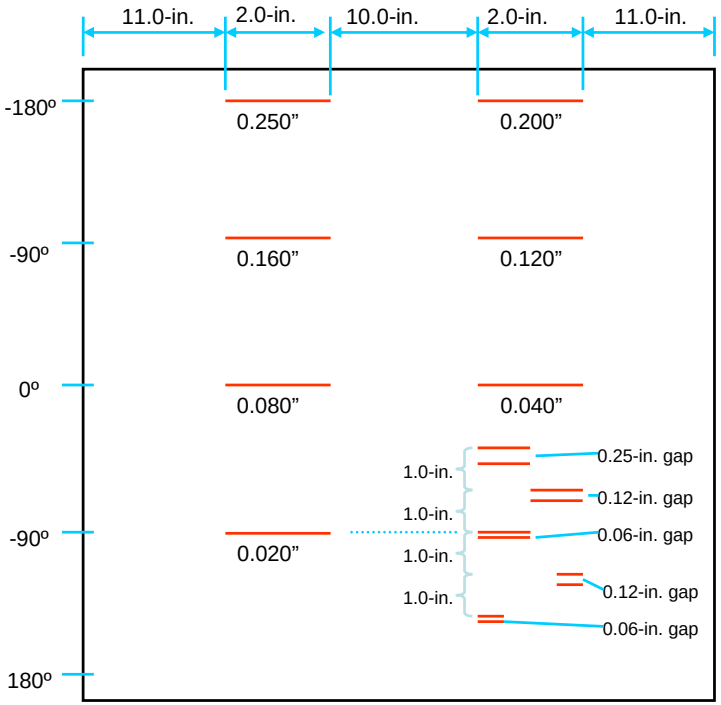


EDM Notch Pipe Samples

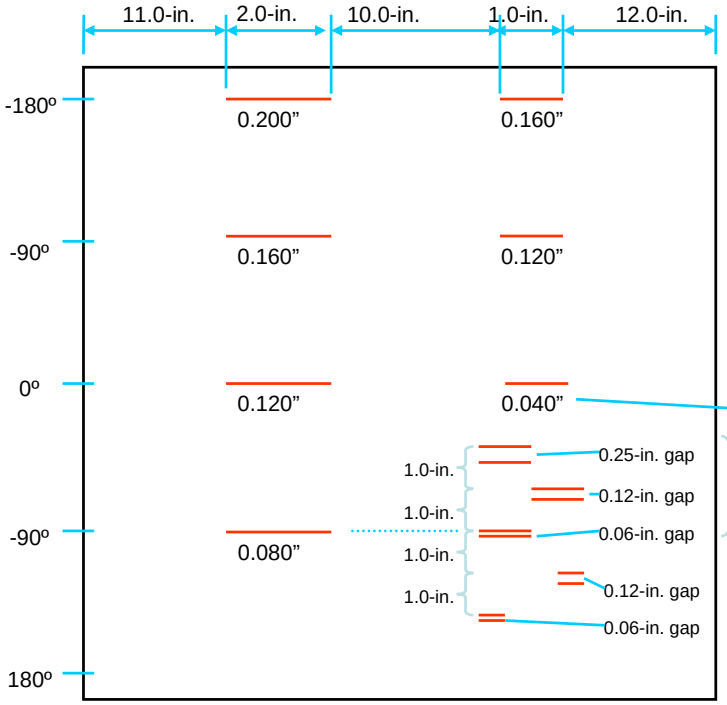
- **36-in. long, 8-in. diameter pipes**
- **Axial EDM notches located at various positions around each pipe**
- **Scanned with FA24 (medium size) MWM-Array**
  - Wider array and sense elements compared to FA26



Schedule 80 Sample



Schedule 40 Sample

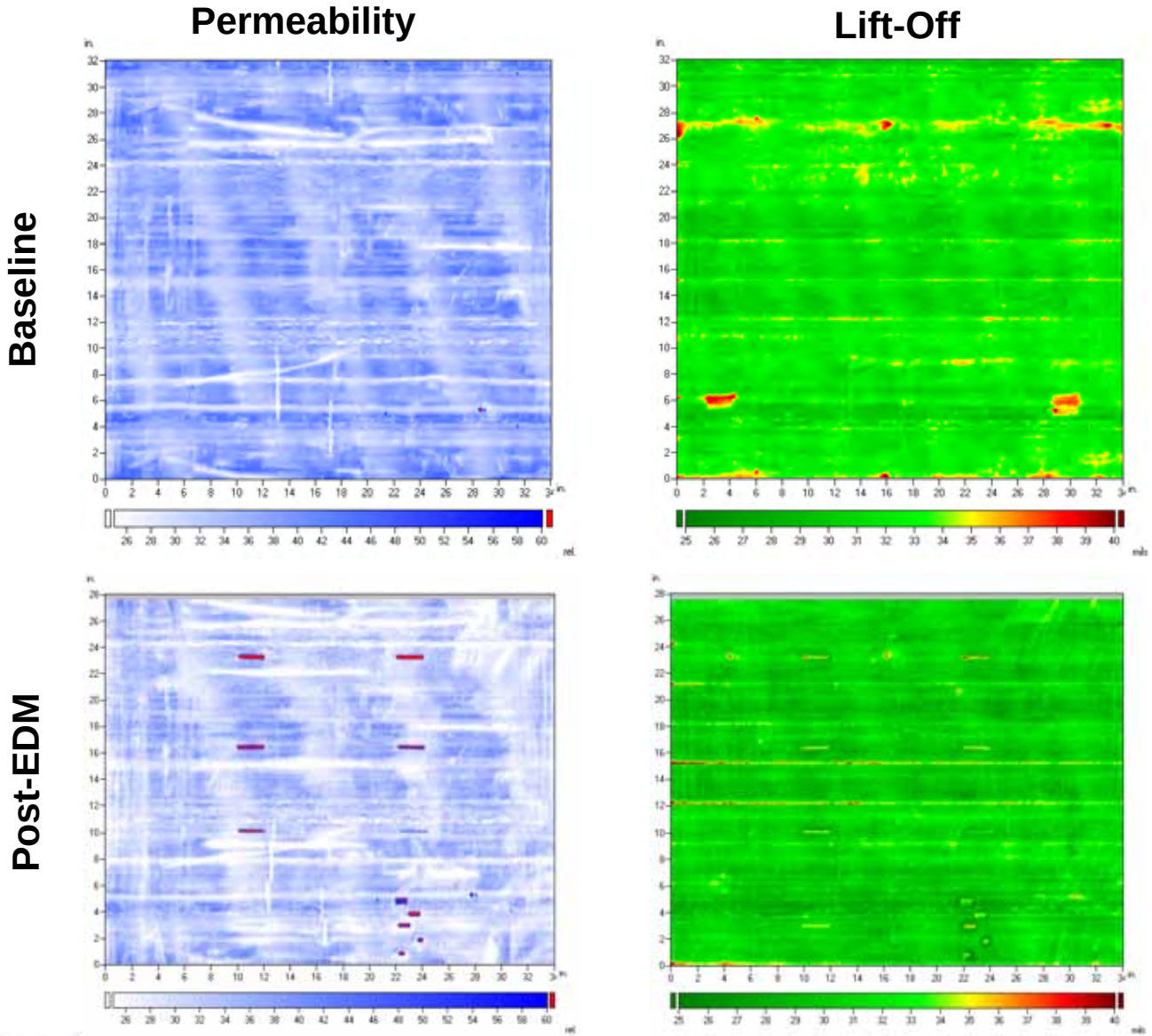


Depth of notch is indicated

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.

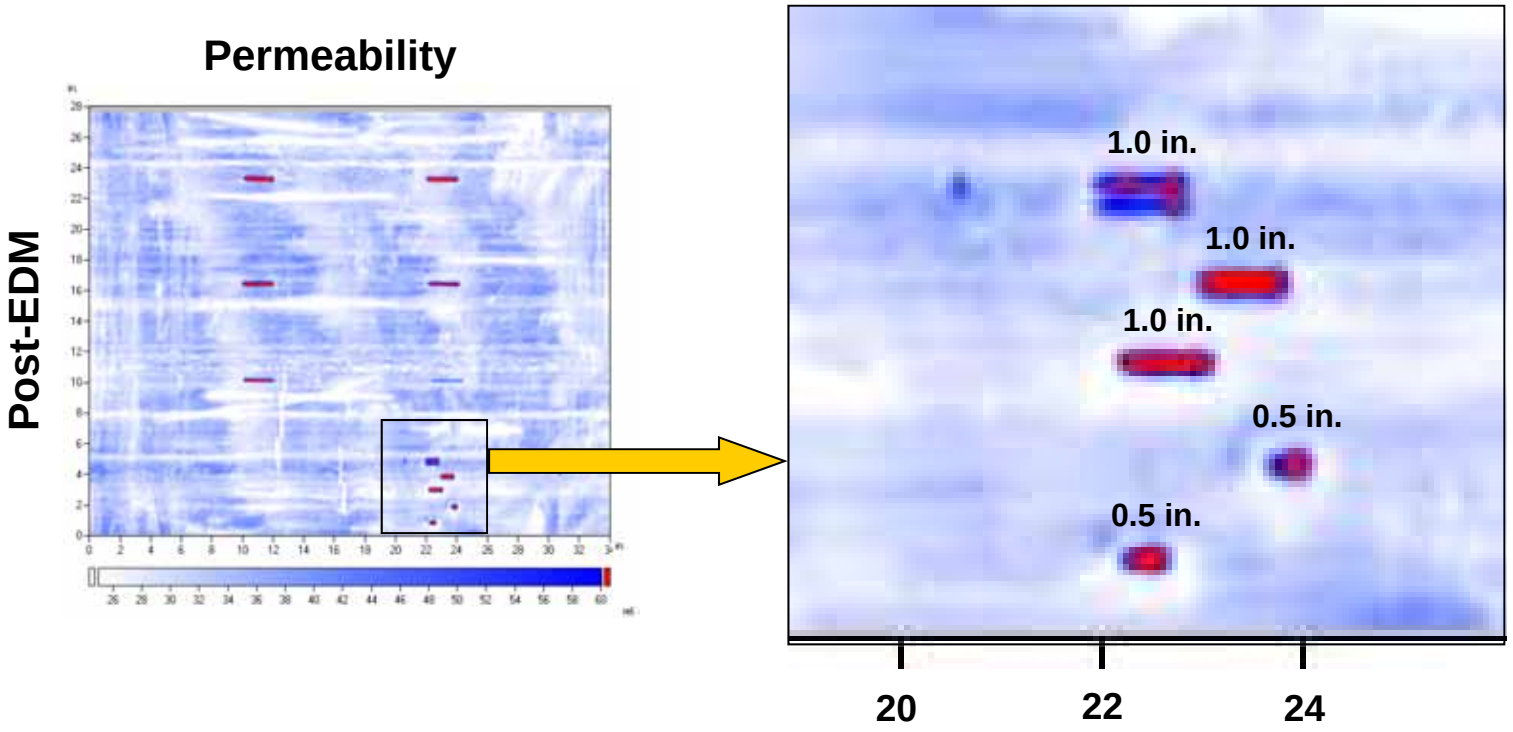
FA24 MWM-Array Scan of EDM Notch Pipe Sample

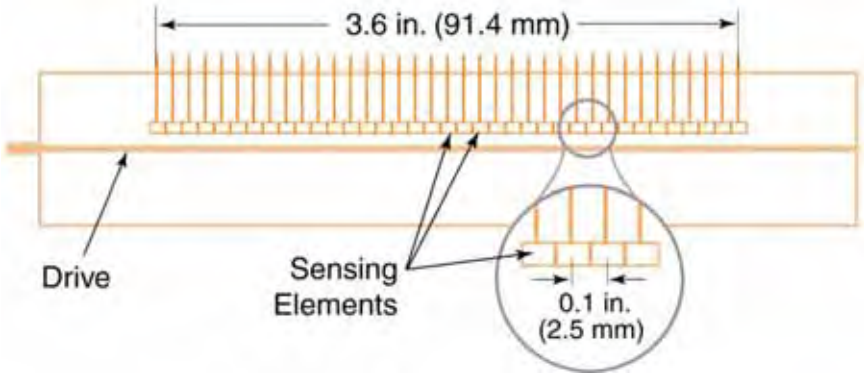
Baseline & Post-EDM Fabrication Data on Schedule 80 Sample



FA24 MWM-Array Scan of EDM Notch Pipe Sample

Baseline & Post-EDM Fabrication Data on Schedule 80 Sample

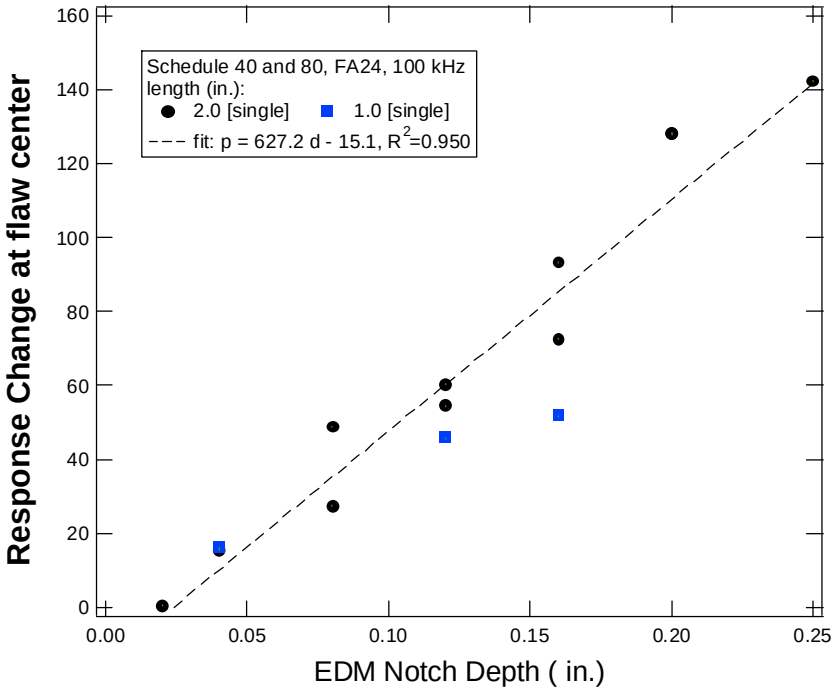




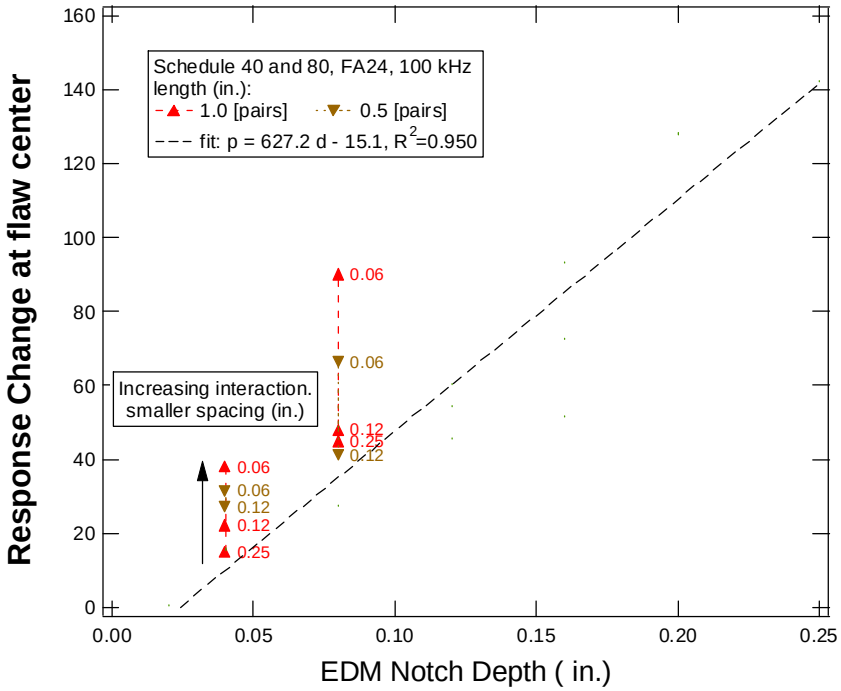
Response Variations with Notch Depth

- FA24 (medium size) MWM-Array scan results
- Sensitive to notch depth over this range
- Nearby notches can lead to interacting responses

Single Crack

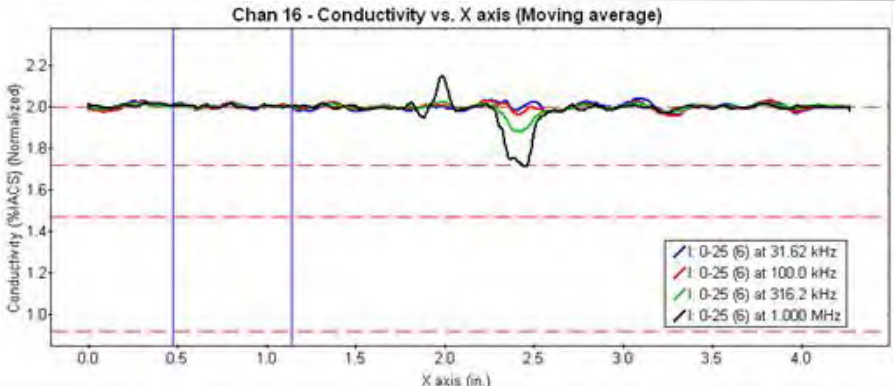


Crack Clusters



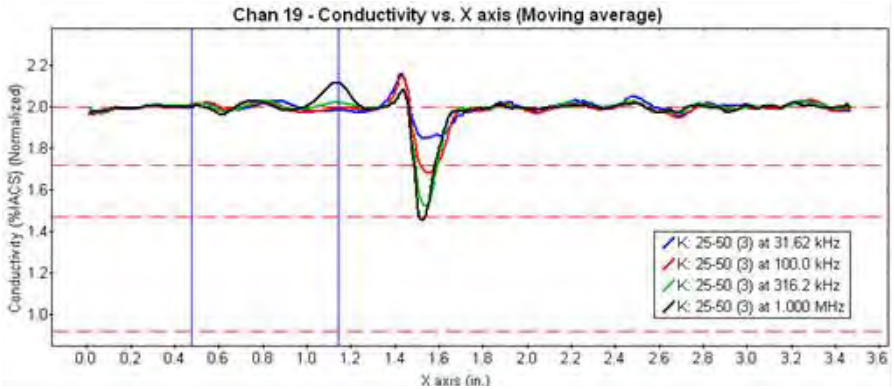
Imaging and Characterization of Pitting

FA24 Imaging of Stainless Steel Tubes



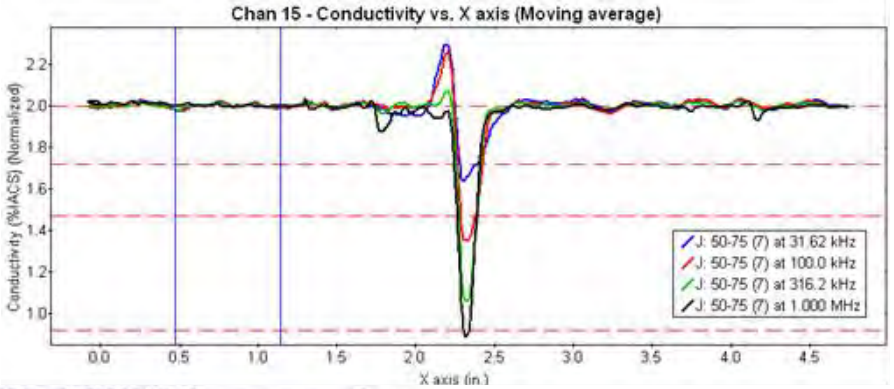
Pit I

0% - 25%



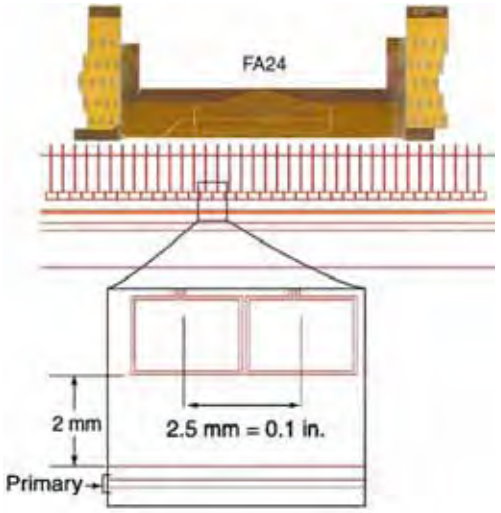
Pit K

25% - 50%



Pit J

50% - 75%



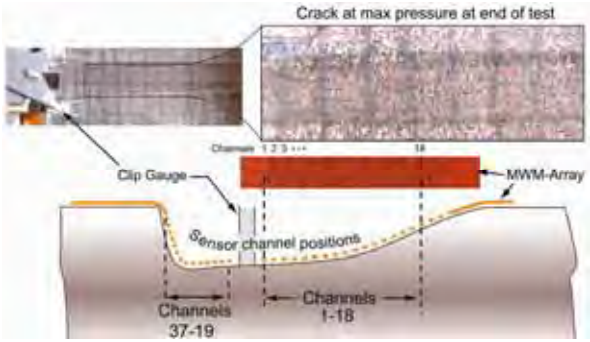
- **High frequency imaging of surface breaking pits in stainless steel tubing**
- **Development of a pit depth algorithm is ongoing**
- **Actual depth of representative defects are needed**

DOT/PRCI Test by JENTEK

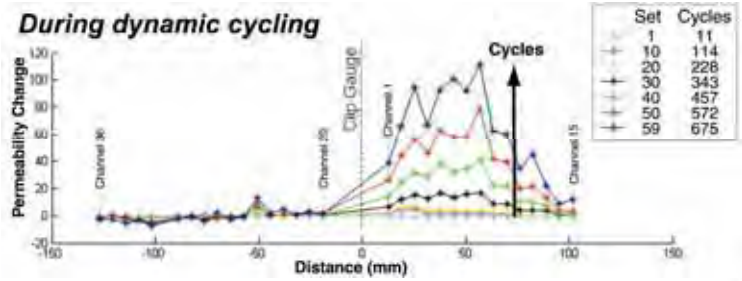
at GDF Suez Research & Innovation Division (CRIGEN) in St. Denis, France

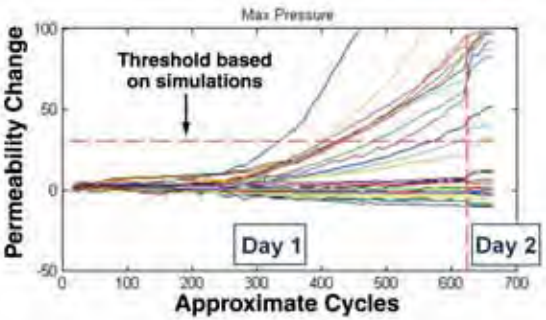
Previous success under DOT and PRCI funding with GDF Suez

FA178 MWM-Arrays



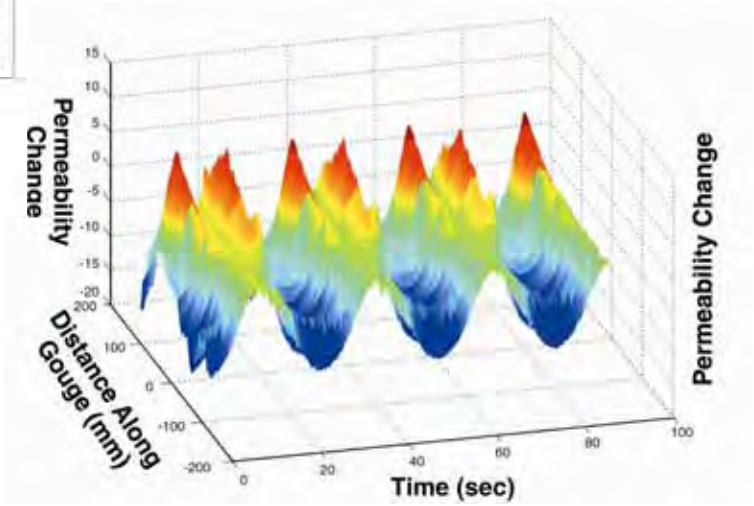
Damage Monitoring



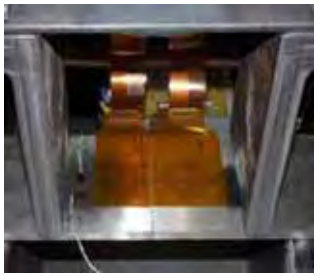


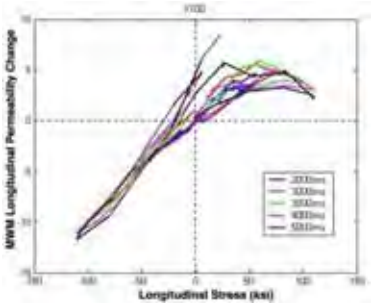
Stress Monitoring

Dynamic pipeline pressure testing



4-pt static load testing of coupon





JENTEK ILI Development

Generation 1 - 2010

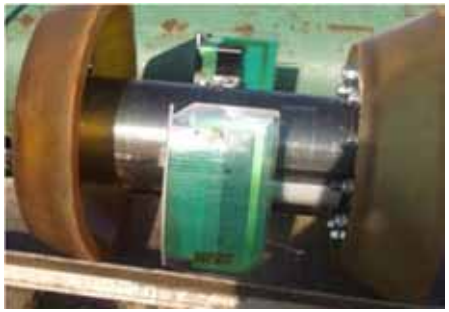
Preliminary capability demonstration in December 2010

- 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

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)



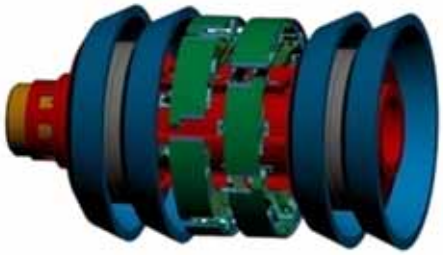
Generation 3 – 2012/2013

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 and reduce power consumption for battery operation of instrumentation

Improved durability and hardening of the instrument, including isolation from the environment.



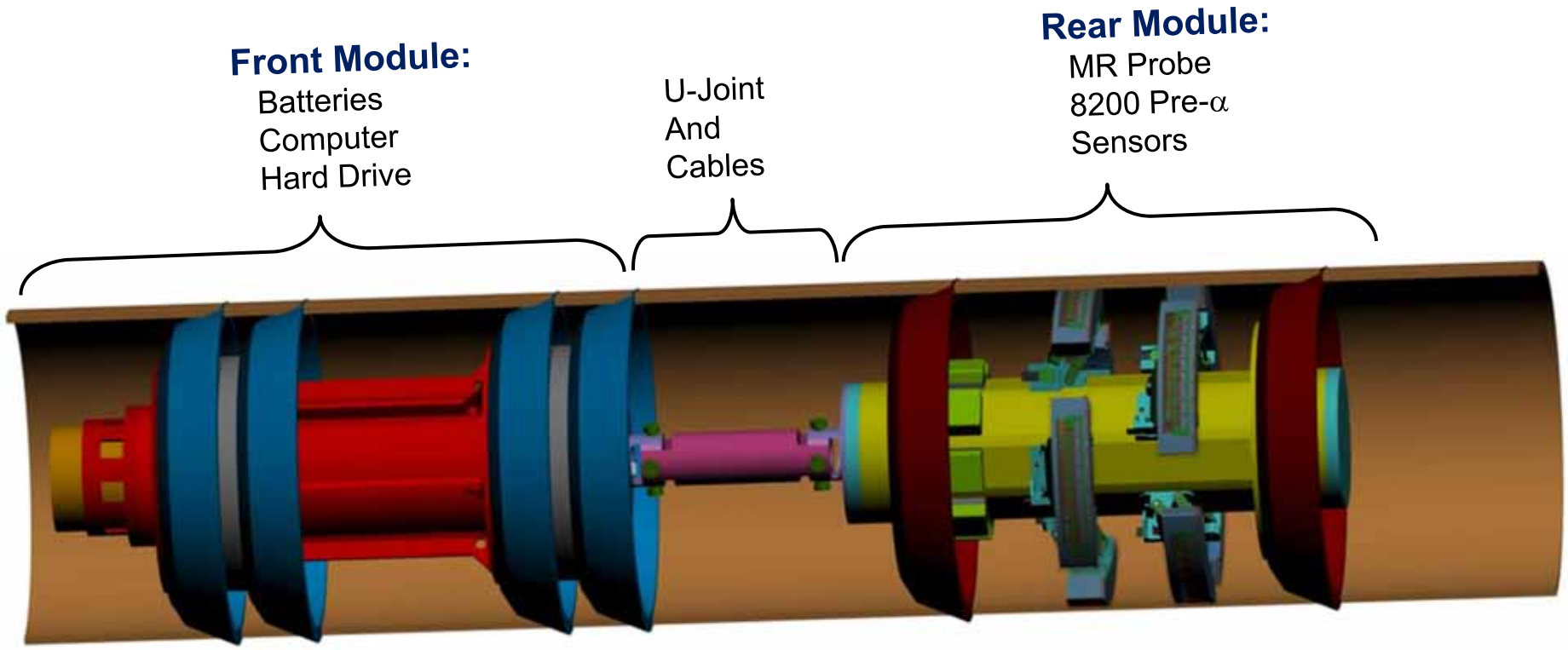
Generation 4 – 2013/2014

Integrate low frequency measurement technology for pipeline wall thickness measurements for detection of external corrosion and mechanical damage

Improved durability and hardening of the instrument, including sealing for environmental protection in oil and gas environments and shock protection

Generation 3 Technology

Preliminary Design



- **72 channels**
- **>5000 measurements/sec./channel**
- **Full circumferential coverage**
- **Internal corrosion and internal profilometry**

Generation 2 Technology

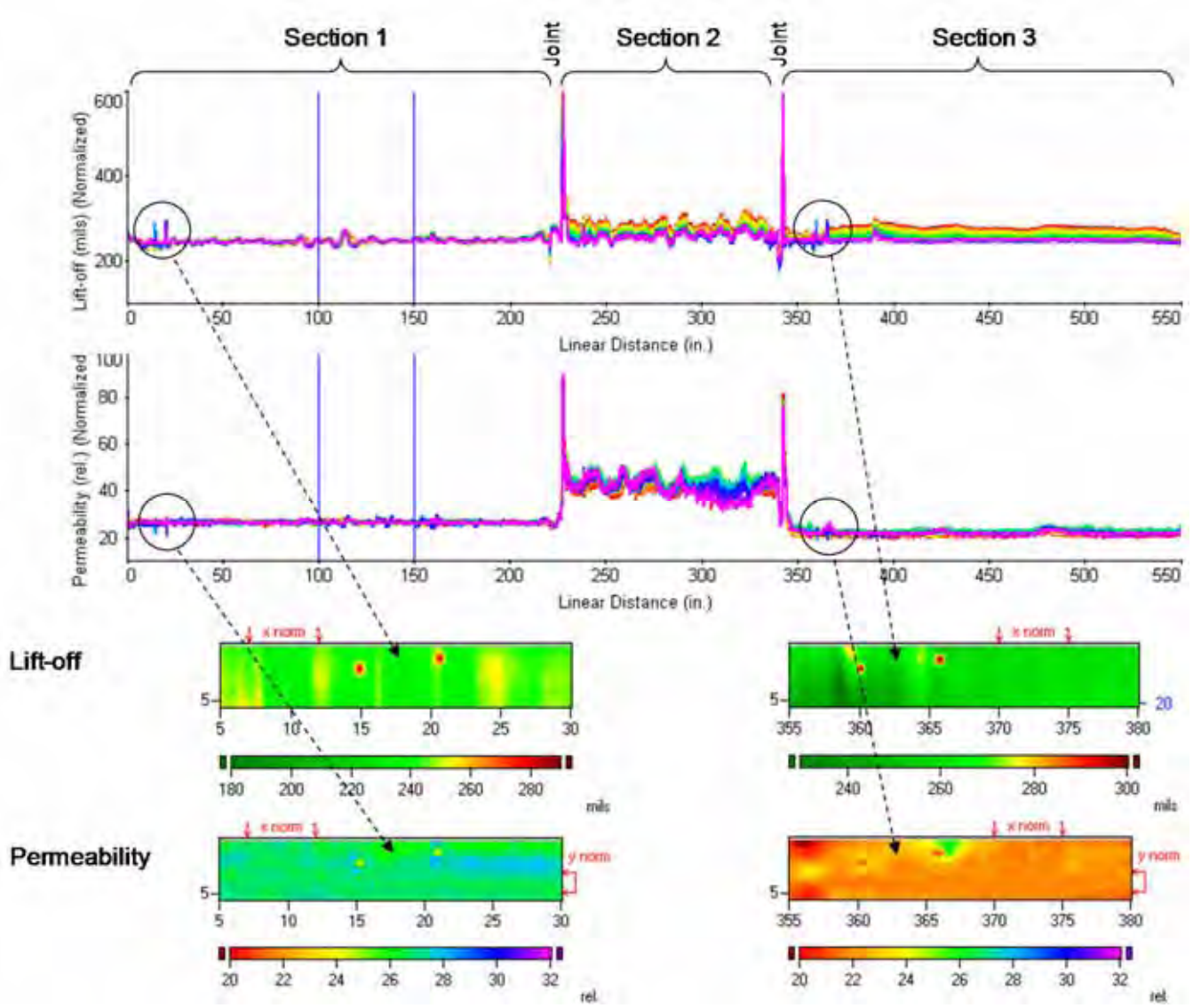
Enhanced capability demonstration in September 2011

- Two medium MWM-Arrays (VWA005) mounted on a 2nd generation tool for straight sections
- Larger MWM-Arrays to accommodate larger lift-offs (e.g., 0.25-in.)
- Integrated electronics with only power supply tether
- Similar flaw images as pull Test 1, but both sides imaged at same time
- Generally see local change in effective lift-off and permeability for flaws

Generation 2 Technology

Pull Test Results

MWM-Array 2
Pull Speed:
~0.36 mph



Summary

- MWM-Array technology provides a flexible model-based eddy-current array for imaging of pipeline material condition
- Demonstrated capabilities for numerous applications
  - Pipe wall thickness measurement through coatings/insulation
  - Underwater inspections (shallow water and deepsea) for pipe wall thickness measurement
  - SCC mapping and crack depth estimation
  - Characterization of pitting in stainless steel tubing
  - Permanently mounted sensors for continuous monitoring
  - In-line inspection (ILI)

Questions?

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