Inspection of Refinery Piping and Vessels from the Outside for External and Internal Corrosion

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Primary Session: Downstream
NDT & SHM Applications for MWM-Arrays, a flexible eddy current sensor technology

NDT
Nondestructive Testing

Deepwater Pipelines (CUI)
Deepwater Risers (CUI)
In-Ditch Pipeline (Mechanical Damage)

Refinery Piping (CUI)

Land-Based Turbine Blades (Cracks)

In-Ditch Pipeline (SCC)

“Common Box”

“Common Electronics”

SHM
Structural Health Monitoring

Full-Scale Test Stress & Damage Monitoring
Buried Pipe Stress & Damage Monitoring
“Smart” Washers for Cracks
Aero Turbine Blade (Cracks)
Pipeline ILI (Corrosion, Cracks, & 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

**VWA001 MWM-Array**

*Note: Other MWM winding designs provide better performance*

\[ \text{Skin depth: } \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \]

\[ \text{Depth of Penetration} = \frac{1}{\text{Re}(\Gamma_n)} \]

**Low Frequency Limit**

\[ \Gamma_n = \sqrt{\left(\frac{2\pi n}{\lambda}\right)^2 + \frac{j^2}{\delta^2}} \]

1 inch = 25.4 mm
HyperLattices & Multivariate Inverse Method (MIM)

Hyperlattices are Precomputed Sensor Response Databases

**MIM**

- Rapid means for converting multiple frequency MR-MWM-Array data into material and geometric properties
- Grids (two-unknown databases), Lattices (3-unknowns), Hyperlattices (4+ unknowns) are generated and stored in advance
- Rapid search through database for solution

![Diagram of wall thickness and coating/insulation with MIM example graphs]
Corrosion Under Insulation (CUI) Inspection
MWM-Array Inspection for CUI

Problem Definition

Wall loss imaging for internal and external corrosion through insulation and weather jacket
MWM-Array Inspection for CUI

Problem Definition

Pre-Alpha System Performance (Wall Thickness Image)

Improved Resolution with Alpha System (Wall Thickness Image)

\[ \Delta_p = \text{Remaining pipe wall thickness} \]
\[ h = \text{Lift-off} \]
\[ \mu_p = \text{Pipe wall magnetic permeability} \]
\[ \Delta_{\text{ext}} = \text{External wall loss} \]
\[ \Delta_{\text{int}} = \text{Internal wall loss} \]
\[ \Delta_n = \text{Nominal pipe wall thickness} \]
\[ \mu_c = \text{Permeability of internal corrosion product layer} \]
\[ \Delta_c = \text{Thickness of internal corrosion product layer} \]
\[ \Delta_I = \text{Coating/insulation thickness} \]
Oil & Gas Application Examples

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

**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

**MD**
- Mechanical Damage
  - Magnetic profilometry
  - Crack Detection in Dents
  - Developing residual stress mapping
Previous MWM-Array Results

Using VWA001 MWM-Array

Distance Measured From Weld at Flange Neck

Ground Supports – Limited Access

Riser section of interest

0.5 in. coating

1.0 in. coating

Defect
In-Line Inspection (ILI) Tools
JENTEK ILI Development and Demonstrations

Generation 1 – 2010 (Completed)

Preliminary capability demonstration, 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 (Completed)

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 (Ongoing PRCI Program)

Increase channel count and data rate – Q3 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
- Improved durability and hardening of the instrument, including isolation from the environment.

Generation 4 – 2013/2014 Options

Integrated Capability Development and Demonstration
- Improved durability and hardening of the instrument, including sealing for environmental protection in oil and gas environments and shock protection
- Reduce power consumption for battery operation of instrumentation
- Reduce the size of the electronics to consolidate the tool into one module
- Team with an ILI tool vendor to support testing in a flow line
- Perform first flow line test
Generation 2 Technology: Pull Test Results

MWM-Array 2
Pull Speed ~0.36 mph
Cracks

NDT

SHM
Crack Imaging & Depth Measurement Capability

- Crack Detection
- Multiple-Channel MWM-Array Crack Depth Measurement
- C-Scan Imaging on Flat and Curved Surfaces, using Conformable MWM-Arrays and MR-MWM-Arrays

Representative data on flat plate specimen with EDM notches
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

- 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.

Schedule 40 Sample
FA24 MWM-Array Scan of EDM Notch Pipe Sample
Baseline & Post-EDM Fabrication Data on Schedule 80 Sample
Crack Imaging & Depth Measurement Capability

- Representative FA24 data at 100 kHz
- 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
- Pairs of notches show increased response as notches are closer together
- Sensitive to notch depth over this range
FA28 MWM-Array Imaging of SCC

Pipeline Sample Provided by Applus/RTD

Conductivity Images

Lift-Off Images

Paper to simulate coating
FA28 Imaging of Stress Corrosion Cracking
MWM-Array Imaging of SCC in Pipeline Sample

Scans of Pipe Section with Identified SCC (FA28 sensor)
Full-Scale Fatigue Test at Mechanical Damage Site

under DOT and PRCI funding with GDF Suez

**Damage Monitoring**

*During dynamic cycling*

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**Stress Monitoring**

Dynamic pipeline pressure testing

4-pt static load testing of coupon
Weld Imaging
MWM-Array Residual Stress Imaging

For Post-weld heat treatment (PWHT)

Effect of Thermal Stress Relief on Weld in Witness Coupon, Pressure Vessel Steel

Permeability/stress scanning across the weld

Large dent on coupon