TIMP: Applying External Corrosion Direct Assessment (ECDA) and Guided Wave Testing (GWT)
Presentation Overview

• Direct Assessment Overview
• Application of ECDA in Difficult to Assess Environments
  – Challenges Posed by Facilities and Casings
  – Traditional Tools
  – Area Potential – Earth Current Survey (APEC)
  – Other Technologies – Guided Wave Testing (GWT)
• Case Study and Examples
• Guided Wave Testing - Overview of Fundamentals, Technology, and Applications
Direct Assessment (DA)

- DA is one of the four methods used to verify pipeline integrity as mandated by DOT
  - Hydrostatic testing
  - In-Line Inspection (pigging)
  - Direct Assessment (DA)
  - Other Technologies (such as GWT)
    - This method requires filing a Notification with PHMSA (OTN)

- Based upon the threats of concern for a pipe segment, DA can be used to assess pipe integrity in regards to:
  - External Corrosion
  - Internal Corrosion
  - Stress Corrosion Cracking

- DA is an applied practice consisting of four well documented steps
  - Pre-Assessment
  - Indirect Inspections
  - Direct Inspections
  - Post Assessment
ECDA: Pre-Assessment

- Data Intensive Process
- Collects and Evaluates Data
  - Pipe-related
  - Construction Related
  - Soils/environmental
  - Corrosion Control
  - Operational
- Determines Feasibility
- Identify and group Regions
- Selection of Indirect Tools (minimum #, per plan)
ECDA Documentation

- Advocate rigorous documentation for the ECDA process
  - Several detailed forms as part of the detailed report
  - Per PHMSA: “If you didn’t document it, you didn’t do it…”

Data Element Form

Sufficient Data

Feasibility Analysis

Indirect Tool Selection Analysis

Region Analysis
ECDA: Indirect Inspections

- Locate Coating Faults and Areas Most Susceptible to Corrosion
- Define Severity
  - Past versus Current Activity
- Applies Indirect Inspection Tools
  - Typical Survey Tools: CIS, DCVG, ACVG
  - Survey Entire Length of Each ECDA Region
  - Aligns, Integrates and Evaluates Survey Data

Survey Procedure Review

Indication & Classification Alignment
ECDA: Direct Examinations

• Evaluate Indirect Inspection data to determine dig locations
• Collect Data (Bell Hole Inspection) to Assess Anomalies
  – Assess Coating Condition
  – Measure Pipe Surface Conditions
  – Measure Immediate Surrounding Environment Data

Direct Exam Summary Form
Direct Examination: In-Field Data Collection

Summary Details and Coating Condition

Map of Any Coating Degradation

Pipe Condition (post coating removal)

Repair Data
ECDA Post Assessment

- Remaining Life, Safety Factors, Remediation
  - Implemented during Direct Examination
- Reassessment Intervals Determined
- Program Performance and Process Effectiveness

Reprioritization of Indications

Remaining Life

Program Performance

Structural Integrity Associates, Inc.
Application of ECDA in Difficult Environments

• Challenges in facilities (terminals, compressors and generating stations)
  – Multiple pipelines varying in design, operations and corrosion susceptibility
  – Site data (drawings, design specs, sources)
  – Limitations on traditional indirect tools
  – Digging more complex

• Challenges in Casings
  – Casings can shield reads of some tools making them not feasible
    • Also an issue in non-cased pipe
  – Evaluate these issues during the pre-assessment
  – Pick tools that can provide a consistent approach to testing, analyzing and prioritizing the data
Application of ECDA in a Station or Facility

• To overcome obstacles with ECDA in facilities, it is critical to:
  – Perform a thorough collection of all available data
  – Develop a database to house available historical data
  – Implement this database to allow data integration throughout the DA process
  – Choose the appropriate indirect inspection tools for each pipe segment
  – Properly identify direct examination locations as well as difficulties that may occur during the excavation process
  – Complete a thorough lessons learned at the end of the project

• Keys to success:
  – GIS
  – Traditional inspection tools versus other inspection methodologies
  – Maintaining and updating data
3-D Modeling and Geographical Information Systems

- Digitization of available data and drawings allows for the integration of 3-D models of the site in a database format
  - Pre-assessment data easier to analyze
  - Selection of indirect inspection tools more efficient
  - Dig site selection readily available in a visual format
  - Post Assessment contains an auditable set of records in a database and visual format
3-D Geographical Information Systems

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<th>Diameter</th>
<th>Wall Thickness</th>
<th>Material</th>
<th>Grade</th>
<th>Install Date</th>
<th>Description</th>
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<td>0.516</td>
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</table>
Difficult-to-Assess Piping

- Difficult-to-Assess Piping consists of locations where traditional indirect inspection tools such as CIS, DCVG and ACCA are limited in their ability to differentiate locations where corrosion control systems are functioning or inadequate:
  - Plants or stations that are tied to the common grounding system
  - Locations of congested piping
  - Multiple pipeline corridors
  - Casings....
  - Any location where electrical continuity adversely affects indirect inspection results
Half Cell Measurements and Mixed Potentials

• A half cell measurement is actually an area measurement of mixed potentials consisting of the soil and all subsurface structures that are exposed to the environment
  – For example, the steel piping below may have a native potential of around -400mV, but the copper may be closer to -200mV
  – The resulting area potential will most likely be closer to -300mV
  – Analysis of this location by potentials alone could lead to erroneous conclusions regarding active corrosion cells
Limitations of Traditional Techniques

**CIS**
- Additional structures drastically influence the potential measurements of the structure intended for assessment.
- Low potential indications may be a factor of adjacent structures, not a lack coating or cathodic protection.

**DCVG**
- Voltage gradient indications may be masked by adjacent coating holidays or structures.
- Locating coating holidays and remote earth measurements may be infeasible.
APEC Overview

• Uses industry standard equipment
• Employs principles of both Close Interval Survey - CIS (used to gauge CP system effectiveness in controlling pipe corrosion) and Voltage Gradient Surveys - (used to identify coating degradation)
• The novelty is that we are using three half-cells simultaneously during the cell-to-cell survey. This permits the observation of corrosion currents within a highly congested area – which is an indication of the relative corrosion activity.

Further detail on the APEC approach can be found in the NACE Corrosion 2011 publication: “Methodology for Surveying Buried Plant Piping for Coating Condition and CP Effectiveness”, NACE Paper 11181
Voltage Gradients and Earth Current Vectors

- By collecting three half cell readings simultaneously in a grid pattern, voltage gradients can be measured between the half cell.
- These voltage gradients can then be converted into earth current vectors in a polar coordinate system, allowing for easier data interpretation in a real world environment.
- In the example on the right, the area potentials measured result in 100 mV gradients in the x and y coordinate directions, resulting in a 45 degree earth current gradient.
Direct Examinations

- In difficult-to-assess areas such as terminals, compressors, fabricated gates and generating stations, excavations can be complicated by unusual depths and multiple pipelines in the dig region
  - In these areas, the use of GWT can provide screening of difficult to access sections

- The 3-D GIS database can also be used to identify and more precisely define dig locations
Case Study

- ECDA was chosen to assess the integrity of buried piping in a crude oil storage and delivery facility. The objectives of the assessment were:
  - Evaluate the existing level of cathodic protection
  - Identify locations of coating anomalies
  - Determine the extent of low potential areas
  - Identify critical areas for excavation and direct examination
  - Perform direct examination supplemented by Guided Wave at identified locations
  - Determine the effectiveness and feasibility for applying ECDA to terminal station piping
Case Study – Pre-Assessment

- Pre-Assessment concluded that ECDA was feasible
- Regions were defined as:
  - Region 1 – Non-Cased buried piping for the seven buried piping segments west of the manifold and pump units
  - Region 2 – Above grade piping and soil to air interfaces
  - Region 4 – Buried piping from the manifold to the pump units
- Indirect Inspection Tools were selected:
  - Close Interval Pipe-to-Soil Potential Survey (CIS) and Direct Current Voltage Gradient Survey (DCVG) for Region 1
  - B-Scan and Guided Wave Ultrasonic Testing (GWT) for Region 2
  - Area Potential Earth Current Gradient (APEC) for Region 4
Case Study – Indirect Inspections

- Indirect inspections were completed
  - 8 digs sites were selected from the surveys

- Results included:
  - Region 1 – CIS & DCVG for 7 line segments
    - 4,700 feet (1,432.56 m) of piping
    - 4 Scheduled ECDA Categories
    - 11 Monitored ECDA Categories
  - Region 2 – GWT and B-Scan for over 400 feet (121.92 m) of piping
    - B-Scan testing identified two significant indications of corrosion on piping at the gated, southwest section of the facility
    - Internal wall loss was detected near the 6 o’clock position representing approximately 40-45% wall loss
  - Region 4 – APEC inspection completed for 138 grids in the manifold
    - Inspected surface area of 13,800 ft² (1,282.06 m²)
    - 8 Scheduled ECDA Categories
    - 25 Monitored ECDA Categories
    - 44 grids displayed atypical current responses associated with possible coating damage
Case Study – Direct Examinations

• Results included:
  – Region 1 (CIS & DCVG) – 5 sites
    • 3 excavations per the operator’s ECDA Plan
    • 2 additional discretionary direct examinations
    • Mechanical damage due to trenched telephone cable was found at one excavation
    • No remediation beyond buffing the small gouges to surface level and recoat was required at this site
    • No other sites required remediation beyond recoat
  – Region 4 (APEC) – 3 sites on 4 lines in the manifold area
    • 4 direct examinations
    • Mechanical damage due to trenched conduit was found at one excavation
    • Type B Sleeve was installed
    • No other sites required remediation beyond recoat
APEC Excavation with Mechanical Damage
After Coating Removal
APEC Excavation with Sleeve Installed
Case Study – Post Assessment

• Post Assessment was completed in accordance with the operator’s ECDA plan
• Direct Examination results were used to calculate the remaining life and re-inspection intervals
• Process was deemed effective and provided useful data
• All final data from the project integrated into a GIS database for future use
• Application of appropriate indirect inspection tools was essential
Case Study Conclusions

- ECDA worked for Facility Piping!
- GIS and database was essential to organize inspections
  - GWT
  - UT
  - CIS
  - DCVG
  - APEC
  - Direct Examinations

- Indirect inspections and direct examinations utilized both traditional and other inspections methodologies
  - Optimized the results of the process
GUIDED WAVE TESTING (GWT)
OVERVIEW & FUNDAMENTALS
Definition

**Guided Wave** - a wave (acoustic, mechanical, or electromagnetic) whose propagation characteristics are dictated by the properties AND boundaries of the medium in which they travel.
Natural Waveguide Examples

- Plates (aircraft skin)
- Rods (cylindrical, square, rail, etc.)
- Hollow cylinder (pipes, tubing)
- Multi-layer structures
- Curved or flat surfaces on a half-space
Principle Uses of GWT

• Used to detect internal or external wall loss
  – Volumetric: Change In Cross Sectional Area

• Difficult to assess areas, such as casings, CUI, station piping, ICDA

• Where large lengths and difficult to access piping need to be assessed

• Based on acoustic waves in the pipeline walls
GWT Piping Assessment

- Inspection over long distances from a single probe position.
- Scans the entire volume of pipe
- Qualitative to Semi-quantitative
- Excellent as a screening tool (similar to indirect inspection)
- Ability to inspect inaccessible structures
- More difficult, pattern recognition
Guided Wave Concept

Propagation along, not through, a structure

The pipe walls form a guide for ultrasonic waves, which directs them down the length of the pipe.
Standard UT versus Guided Waves

**Conventional UT**
- high frequency
- short wavelength
- sensitive to wall thickness
- point measurement

**GWT**
- low frequency
- long wavelength
- sensitive to cross sectional area and symmetry
- rapid screening
Wave modes in pipes

- **Longitudinal**
- **Torsional**
- **Flexural**
Reflection of a Guided Wave from a Feature

- Guided waves are reflected from a change in cross sectional area
- The change can be either an increase or decrease in area
- If the cross sectional change is symmetric then the reflected wave is primarily symmetric (torsional or longitudinal depending on excitation)
- If the cross sectional change is not symmetric then the reflected wave will have higher a higher flexural component
- Reflections cause less energy to propagate down the pipe incrementally reducing the sensitivity
GWT EQUIPMENT
GWT Inspection Equipment Manufacturers

FBS

GUL: G3 Wavemaker

Southwest Research

Plant Integrity:

Structural Integrity Associates, Inc.
GWT Components

- Electronic Control Unit for system
- Laptop PC
- Transducer Collar
GWT ANALYSIS
Corrosion is typically indicated by large red component.
• Dead Zone
  – Collar cannot transmit and receive at the same time
  – This leads to dead zone shown in green on the data trace
  – Typically ~ 1 ft. in length.
• Near Field
  – Region where the guided waves are forming
  – Length typically ~2-5 ft. depending on collar type
  – Features still detectable but sizing accuracy reduced
- Example data trace
  - 12” diameter
  - Dead Zone 1’4”
  - Near Zone 5’3”
Shot looks like this when data comes in:

X axis: distance from collar  Black signal: symmetric
Y axis: signal amplitude     Red signal: asymmetric
Amplitude decays over distance

- The reflected amplitude from distant features will be smaller than for close features
- The range is limited
- Two things that cause signal decay
  - Reflection from features
  - Attenuation from coating, soil, generalized corrosion, etc
Decay of the amplitude is caused by:

- Welds
- Fittings
- Branch connections
- Corrosion damage
- Supports
- External coatings
- Internal coatings
- Soil
- Material itself

Coatings generally have the greatest attenuating affect
Corrosion can also attenuate the sound significantly

- Incoming wave (100% of energy)

  
  Reflected wave (100% of energy)

  Transmitted wave (0% of energy)

- Incoming wave (100% of energy)

  Reflected wave (20% of energy)

  Transmitted wave (80% of energy)

- Incoming wave (100% of energy)

  Reflected wave

  20%  80%

  16%  64%

  13%  51%
Four Distance Amplitude Curves (DACs)

DAC levels can be changed for different applications.

Flange DAC: 100% ECL
Weld DAC: ~23% ECL
Call DAC: 5% ECL (detectability threshold/sensitivity level)
Noise DAC: 2.5% ECL (Set to 1/2 detectable threshold)
What is sensitivity?

- It is the percent cross sectional area that can be detected at a given signal to noise ratio (SNR)
- It is expressed as % ECL or CSC (change in cross-sectional area)
Things to Consider about Sensitivity

- **DAC:** Distance amplitude curve is expressed as percentage of cross sectional area. Weld DACs are usually 23% ECL.
- **S/N Over Background:** To have better confidence level a S/N ratio of 2:1 is needed. Noise DAC = \( \frac{1}{2} \) Call DAC
- **Inspection Range:** Is a function of required Sensitivity.

**PHMSA (18 points require)** 5% sensitivity or value corresponding to a defect that would fail a Hydrotest, whichever is less.
GWT Example Result

Defect 1 - 0°
~3”x3” Blend Out
50% Max Wall Loss

Defect 2 - 270°
~4”x4” Blend Out
50% Max Wall Loss

Defect 3 - 315°
Three Flat Bottom Holes
1” Diameter, Depth=60%
Spacing between holes = 1 ft.
GWT Example Result

A-Scan

“C-Scan”
GWT on Buried FBE Coated Pipe (Sample)

- Piping was accessed from excavations; the excavation locations were selected by based on other above ground indirect assessment data.
- The objective was to use GWT to assess the condition of the piping outside of the excavations.
- The piping configurations here are ideal for good GWT penetration power as the exterior coating present on the piping is FBE (~0.030” thick)
As shown, good penetration was achieved (136 ft. of pipe assessed from one location) with a high signal to noise ratio allowing for easy analysis and prioritization of indications for follow-up.
Photographs of Severe Corroded Areas Identified with GWT and Subsequently Excavated for Prove-Up
GWT TECHNOLOGY ADVANCEMENTS
GWT Focusing

• GWT Focusing is a new development that has the potential to increase sensitivity, confidence, and provide approximate defect sizing information.

• There are different types of GWT focusing
  1. Frequency tuning
  2. Passive focusing / Synthetic focusing
  3. Active focusing / Phased array focusing

• The term focusing in this context is referring to methods that improve the signal to noise at a location through manipulation of sending and/or receiving the guided wave signal.
Frequency Tuning

- Most equipment providers can provide frequency tuning
- GUL equipment has the frequency slider bar which makes it easier for interpretation
- The Teletest equipment has selected frequencies that can be toggled between. A bit more difficult with interpretation.
- PowerFocus (PF) has a mapping feature to identify optimal features / signal response at different frequencies
- Frequency tuning/focusing is the first type of focusing that is almost always used and required in the 18 Points.
Channel Segments

- GWT transducer collars are divided in either four to eight segments around the pipe.
- Loading or receiving from a given segment can provide location data and improve signal to noise ratios of a reflection.
Passive/Synthetic Focusing

- Some manufacturers use segment focusing / synthetic focusing to develop an unrolled pipe display.
- The segment focusing is just on receiving the signal, not transmission.
- This focusing can provide information on the circumferential extent of a reflector.
Axisymmetric Scan

Synthetic Focus Scan

Weld
Defect
Key Advancements

- Breadth in technical capabilities offered by operating multiple platforms

- **Focusing**
  - **Passive Focusing** – Unrolled Pipe Display
  - Through FBS – new *active focusing* can improve sensitivity
  - Three Ring torsional/longitudinal versus two Ring configurations

- Crews trained on the fundamental operating concepts of the methodology in addition to operation of a particular platform.
EMERGING GWT ASSESSMENT TECHNOLOGIES
Guided Wave Monitoring (GWM)

**PowerFocus MagnetoElastic Focusing (MEF) Collar**

- Developed by FBS, Inc.
- Utilizes magnetostrictive effect to maximize loading area and transduction efficiency while minimizing the size of the near field.
- Swept-frequency excitation using torsional guided waves.
- Capable of active (during excitation) wave focusing and passive (via post processing) wave focusing.
- Has a low profile, can be permanently installed, will be more cost-effective than the competing technologies, and will be unique to SI.
PowerFocus© MagnetoElastic Focusing Collar for SHM (Developed with FBS)

- Potential for improved penetration power and sensitivity.
- Small Near Field (<2ft)
- Low Profile (2” axially, <1” circumferentially)
- Only requires installation of a single low-cost sensor strip (see picture below)
- Potential for monitoring for corrosion under supports, repairs, and penetration areas.
- Can be used for buried pipe monitoring (dig once inspect often).
Guided Wave Monitoring (GWM)

- A guided wave sensor is permanently mounted to the structure.
- A reference (baseline) data set is collected at the time of installation.
- Future data sets are compared to the baseline data set to monitor for changes in the component.
- Can be installed in excavations, high-rad areas, difficult-to-access locations, or on critical components.
- Facilitates “removal” of coherent noise for improved sensitivity and data trending.
- Facilitates inspection of more complex piping geometries.
Comparison of Results with MEF Sensor

• From a GWT perspective, typical inspection distances achieved in buried piping are ~25ft, often at ~10% sensitivity.

• With new MEF technology, ~5% sensitivity has been demonstrated for a similar configuration.

• From a GWM perspective, much smaller sensitivities (or larger diagnostic lengths) may be achieved due to monitoring capabilities.
PAUT Roller Probe

- Light-weight, rugged, portable
- Adaptable to different pipe sizes
- Encoded data capable of capturing of 90,000+ points over a 1 sq. ft. area
- Quick – Scanning speed of up to 4 in./s

Encoded Phased Array UT

**The Sonatest Array Wheel Probe**

- Designed for efficient hand scanning of large flat or slightly curved surfaces using phased array ultrasound.
- Compatible with the Olympus Omniscan and other portable phased-array systems.
- Acquires thickness data over a 2-inch wide path as the probe is rolled along the surface.

Sample result from a scanned area of corroded piping showing accurate representation of defect shape and depth.
GWT AND CASINGS (SPECIAL APPLICATION)
The Million Dollar Question and major challenge to cased segments:
What will be the Shot Distance?

- Estimates can be provided based on piping and coating characteristics, but you don’t really know until you shoot the pipeline.
- Distance should be referenced with regards to sensitivity:
  - Correlates to what size defect will be detected.
  - Industry practice (and defined in 18 points) to have a 2:1 SNR.
Review of the 18 Points

18 Points were defined to help standardize on some industry best practices to eliminate missed / false calls

- Generation of Equipment & Software
- **Inspection Range (5% CSA, 2:1 SNR)**
- **Complete Inspection (2:1 SNR, 5% Overlap)**
- Sensitivity *(5% at max. range and minimum sensitivity achieved must be able to identify the smallest defects that will fail by rupturing in a hydrostatic test.)*
- Frequency (at least 3 frequencies analyzed)
- Signal or Wave Type (at least torsional)
- DAC required for inspection
- Dead Zone (adjacent area to collar must be inspected and/or multiple shots)
- Near Field Effects (not extend into casing)
- **Coating Type (impact on range must meet inspection requirements)**
- End Seal (dampening effect on range, remove and evaluate to validate)
- Weld Calibration (welds are used to set DAC curve)
- Validation of Operator Training
- Traceable Equipment (vendor to contractor)
- On-site Calibration
- Use on shorted casings (cleared if interferes, must be addressed by operating procedure)
- Direct Examination of all indications above testing threshold (5% CSA) be assessed
- Direct Examination Schedule / Timeline

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### Required Pipeline Response

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<th>GWUT Criterion</th>
<th>Less than 50% SMYS</th>
<th>Over 50% SMYS</th>
<th>Over 50% SMYS</th>
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<td>Interval &lt; 12 month</td>
<td>Interval &lt; 6 months</td>
<td>Interval &lt; 6 month</td>
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<tr>
<td>Leak survey once /month</td>
<td>Direct Examination +</td>
<td>Direct Examination +</td>
<td>Direct Examination +</td>
</tr>
<tr>
<td>Direct Examination</td>
<td>MOP @ discovery</td>
<td>MOP @ discovery</td>
<td>Reduce to 80% MOP @ Discovery</td>
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<tr>
<td>Leak survey once /month</td>
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ANALYSIS AND REPORTING
Core Components of a GWT Report

- Basic information: Pipeline name, inspected sections, location, date of inspection, date of report and description of scope
- Overall assessment and conclusions on piping inspected.
- A summary / table summarizing GWT results identifying indications representing wall loss
- Schematic drawings and/or GIS Location Maps/Files
- Reviewed GWT data results / shot record
- Photographs collected
- Technician certifications
- Equipment calibration certificate
- Specialized Forms similar to ECDA
Analysis Tools: 3-D Modeling and GIS

- Geodatabase systems, digitizing pipeline information and modeling / analyzing data can be very useful in analysis.
- Recent integration of assessment data into 3-D models, key benefits:
  - Assessment data easier to view and analyze
  - Selection of indirect inspection tools more efficient
  - Dig site selection readily available in a visual format
  - Post Assessment contains an auditable set of records in a database and visual format
Data Management via GIS (web based)

• Industry trend migrating inspection results to a Geodatabase with GIS
  – Overlay of results on facility map

• Layers and/or Grouping application specific
  – Examples:
    • Inspection Date, Risk Level
  – Fully customizable

• Centralized location for data
  – Design, Inspection, etc…
Thank You

Questions?

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