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PRCI Research Exchange

Tools and Methods to Assess Pipe Material Properties from Inside the Pipeline

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LEADING PIPELINE RESEARCH
Pipeline Research Council International

*Presenter

Contents

Objectives

- Objectives: Conduct a collaborative and multi-phased study - **Phase I, II, and III**
  - Phase I – A state-of-the-art review of the tools, technologies, and methods to assess pipe material properties from inside the pipe
    - Review technologies and provide performance capabilities and recommendations for future research work
  - Phase II and III would be performed after the completion of Phase I

Drivers

- Alternate Fuels – Hydrogen Transportation
- PHMSA Code of Federal Regulations (CFR): 49 CFR §192.607 guidelines

Drivers: Alternate Fuels Transportation

- **Energy industry has recognized the need to reduce carbon emissions for a more sustainable future**
  - Renewable sources
  - Increasing energy efficiency using carbon capture techniques
  - Alternative energy sources such as hydrogen
- **Movement of hydrogen can be achieved using existing pipelines at low-cost**
  - Approximately 1,600 miles of hydrogen pipelines
  - 200,000 miles of high-pressure natural gas transmission pipelines in the United States
- **Hydrogen can affect the material properties of steel pipes and pipe welds through embrittlement and other mechanisms**
- **When converting natural gas pipelines to hydrogen service, the pipe's material properties must be known**
  - Yield strength (YS), tensile strength (TS), ductility, fracture toughness, chemistry (not carbon equivalent), seam characterization, and grain structure

Drivers: PHMSA Regulations

- PHMSA Gas Transmission 49 Code of Federal Regulations (CFR) Part 192 § 192.607
- ‘Verification of Pipeline Material Properties and Attributes: Onshore steel transmission pipelines’, under the subsection ‘Documentation of material properties and attributes’, mentions that records established under this section documenting physical pipeline characteristics and attributes, including diameter, wall thickness (WT), seam type, and grade (e.g., YS, TS, etc.), must be maintained for the life of the pipeline and be traceable, verifiable, and complete (TVC).
- Under Section § 192.607 (c), it mentions that ‘If an operator does not have TVC records, the operator must develop and implement procedures for conducting non-destructive or destructive tests, examinations, and assessments to verify the material properties of above-ground line pipe and components, and of buried line pipe and components when excavations occur at the following opportunities: Anomaly direct examinations, in situ evaluations, repairs, remediations, maintenance, and excavations that are associated with replacements or relocations of pipeline segments that are removed from service.’

Approach

- Literature Review - Identify technologies that exist in the public domain.
  - ILI Service Providers, and Surface Hardness Technology Companies
- Operator/Technology Provider Meetings - Establish an understanding of the status of each technology and the potential for application into in-line tools
- Collect data. Evaluation and Analysis of Findings – Assess the status of each technology
- Follow-up discussions with technology vendors
- Final Report – Develop a comprehensive report summarizing the findings

Data Collection

- **Data Collection: Published reports, conference papers, interviews**
  - Four In-Line Inspection
    - 1 Eddy Current in MFL
    - 3 MFL
  - One Robotic Hardness tester platform

- **Material properties for this study**
  - Grade, Yield strength, Tensile Strength, and Hardness

Design: Natural Gas Pipelines

Design pressure for steel pipe for natural gas pipelines according to 49 CFR § 192.105:

P = (2S.t/D) x (F.E.T),

‘S’ is the material specified minimum YS (S or SMYS),

‘t’ is the nominal pipe WT,

‘D’ is the specified pipe outside diameter,

ILI

‘F’ is the design factor depending on the class location,

‘E’ is the joint efficiency factor, and → ≤1 depending on Seam Weld Type → **ILI MFL Technologies**

‘T’ is the temperature derating factor

- Fracture toughness is required for pipeline integrity management. However, it is not required for the design pressure calculation for a natural gas or liquid pipeline.

- Similarly, design pressure calculation does not require chemistry, hardness, and microstructure.
  - No ILI tool can determine the fracture toughness, chemistry, and microstructure

Design: Hydrogen Pipelines

- Alternate fuels like Hydrogen can cause hydrogen embrittlement in certain materials, making material selection critical
  - Pipelines, both body material and seam weld, should be constructed from materials resistant to hydrogen-induced cracking
- Compatibility: Grade (YS, TS), chemistry, ductility, hardness, fracture toughness, and microstructure
- ASME B31.12 explicitly allows the use of grades up to X80 for hydrogen service, with restrictions on allowable stresses and operating pressures
- Non-mandatory appendix A of ASME B31.12 states expressly that only grades up to X52 are proven in hydrogen gas transportation and references AIGA/EIGA guidelines for material selection

- Hardness Requirements:
  - ASME B31.12:2019 [3], for carbon steels, has a maximum permitted hardness of 235 HV10

Populations

- Separate populations of similar pipe segments for each combination of the following material properties and attributes must be defined by the operator:
  - Diameter,
  - Nominal wall thicknesses,
  - Grade,
  - Manufacturing process,
  - Pipe manufacturing dates, and
  - Construction dates

- An operator may use a sampling program, including the use of ILI, to verify material properties and attributes for a population of multiple comparable segments of pipe without TVC records

Material Property Determination using Tools from the Inside of the Pipe

- ILI tools can inspect the entire pipeline, require limited excavations, and have sufficient accuracy, making it an attractive approach for measuring a pipe's material properties.
  - ILI tool requires a launcher and receiver for inspection
- Predominant principle of these technologies
  - Eddy current and/or
  - MFL-based
    - Identify patterns correlated to pipe material properties
- Robotic Tool: A robotic ID tool measures hardness in-line through a pipeline.
  - Provides hardness data, which is useful in estimating YS using CRTD Vol 57 and TS using ASTM A370
  - Robotic tool can be launched into and retrieved from a pipeline via a **hot tap fitting**

ILI Technologies

- Electromagnetic principles are leveraged to develop technologies for material property identification
  - Material properties and their relation to microstructure, heat treatment, and chemistry can be correlated to the magnetic properties of the materials
  - Property detection, mainly grade, YS, and TS.
- No ILI technologies exist that determine the fracture toughness and microstructure from inside the pipe.
- Two primary technologies combined with other supplemental technologies can determine/discriminate grade, seam weld type, OD, WT
  - Magnetic Flux Leakage and
  - Eddy Current in MFL

Magnetic Flux Technology

- **Inspecting corrosion and mechanical defects damage evaluation by several technology providers**
  - When the MFL tool detects corrosion, high magnetization levels are applied to minimize the effects of the variation in the steel's magnetic properties, thus producing signals from the metal loss areas only

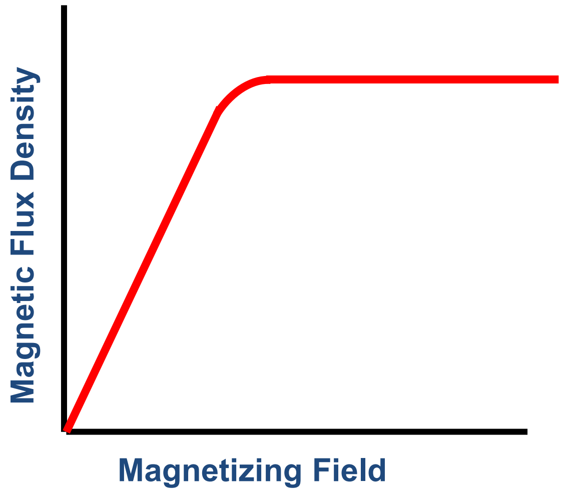
- **Recently, low-field and high-field MFL tools have been used for pipe property discrimination**
  - Magnetic properties of the pipe undergoing different manufacturing processes and having different grades are also different
  - Characterization does not measure or estimate the grade, YS, or other physical properties of the pipe material; however, signatures/patterns can be used to discriminate the grades of different pipes.
    - Grade can be determined using the validated in-ditch material properties

High Field MFL

- High-field MFL detects volumetric metal loss, mill anomalies, and extra metal
- **High-field MFL is less sensitive to local pipe material differences than Low-field, which can be distinguished based on magnetic fingerprints**
- Axial MFL - Most common MFL tool for corrosion detection and characterization
- Circumferential MFL - Pipe seam weld and seam weld defect characterization, identification of axial flaws
- Helical/Spiral MFL
  - Allows the detection of longitudinal aspects of material changes and long seam characteristics
  - Inspection of longitudinal pipe axis, including weld seams, and
  - Detection of other longitudinally oriented anomalies, whether in the seam or pipe body (axially extended metal loss, gouging, hook cracks, lack of fusion, and selective seam weld corrosion)
- Ultra-High Resolution MFL
  - Contains a denser sensor array with higher data sampling to deliver higher spatial resolution of the MFL signal

Low-Field MFL

- Subtle permeability variations within the material are not captured in traditional MFL technologies
  - Variations are not apparent at magnetic saturation
- High field levels
  - Flux density is primarily a function of the H field,
  - Effects from subtle variations in the material are lost
- Magnetic field levels < Saturation level for the pipe material
  - Flux density is a function of both the H (magnetizing force) field and the material's permeability
- Decoupling
  - To distinguish the flux leakage because of permeability changes from the flux leakage due to volumetric metal loss
  - Removing the geometric portion of the signal remaining are the effects of permeability variation



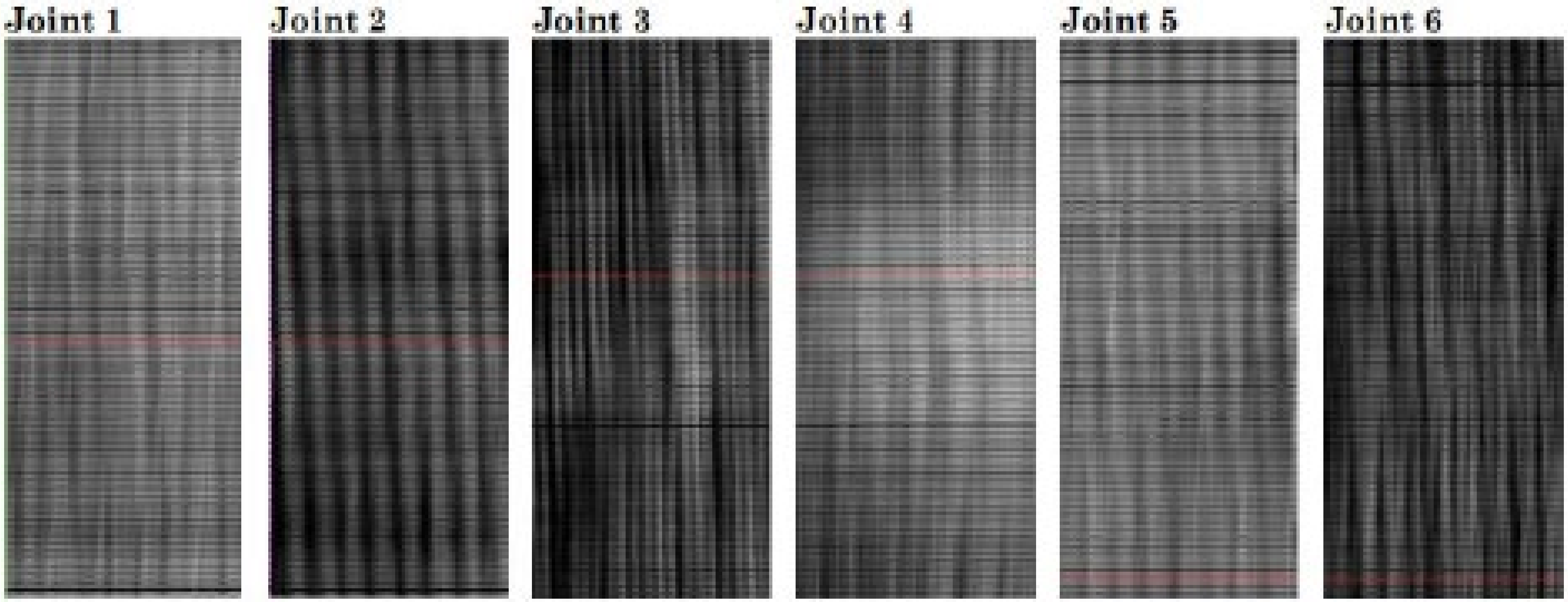
Low-Field MFL

- Low-field MFL data is used to create a pipe signature and magnetic fingerprint for individual pipe joints, facilitating a discrepancy analysis of pipeline component records

- Low-field MFL offers an effective dataset for identifying unique metallurgical anomalies that indicate the history of a single segment of pipe.

Low-Field MFL

- Wave shapes and frequency result from the milling pattern, which is presumed consistent for pipes of the same type from the same producer



MFL – Vintage and Modern Pipe Discrimination

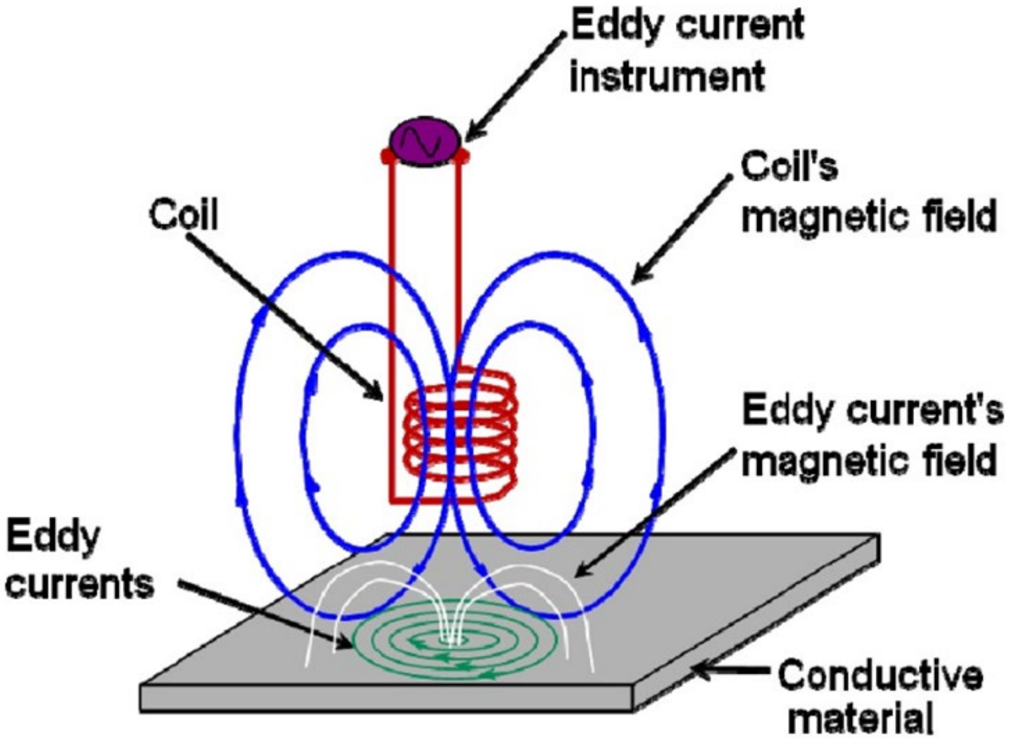
- Vintage pipe - metallurgy and manufacturing processes - manifest in the magnetic response in both low-field and high-field MFL signals
- Not possible to define the pipe manufacturing year precisely by MFL signal characterization
- A combination of datasets – MFL, construction history, pipe lengths, wall thickness variation, and others - may classify these pipes as vintage or modern

Library of signatures

- Technology provider is developing a library of signatures for various pipe types and pipe features correlated with the true data by field verification
  - Verified signatures will maximize the value of the data indications

Eddy Current Based Technology

- Eddy currents are induced electrical currents that flow in a circular path on the surface of a conductive material



Eddy Current Based Technology

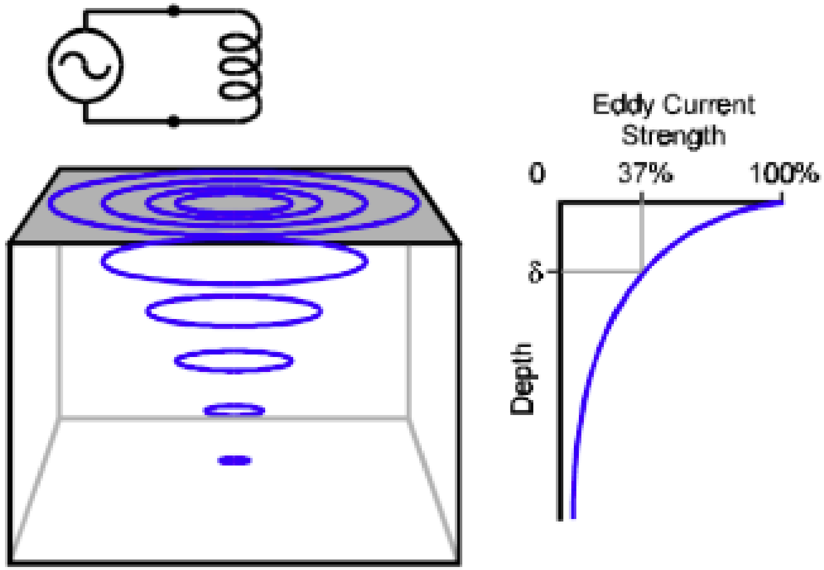
Eddy current with pre-magnetization of the pipe steel can be utilized to determine the steel grade

Standard depth of penetration δ is given by the formula: $\delta = 1/\sqrt{(\pi . f . \sigma . \mu)}$

δ is the penetration depth,

f is the applied excitation frequency, and

σ and μ are the electromagnetic properties of conducting material



Other Supplemental (Non-Primary) Technologies

Assist in Population Creation

- Caliper:
  - Seam weld can be defined by the signature they create in the caliper data
  - Using caliper data, the 1970s Flash Welded can be distinguished from the more modern seam welding technique, Double Submerged Arc Weld pipe
- High-Resolution Deformation
  - Measures changes in the inner pipeline bore
  - Detect standard pipeline features – such as valves, tees, bends, dents, ovalities, expansions, and weld misalignments
- Internal/External (IDOD)
  - Sensitive to ID surface permeability changes in the radial direction
  - Designed to detect metal loss on the ID
- Mapping (GPS): Provides high-resolution mapping that provides pipeline routing and enhances dig programs when tied to above-ground coordinates.

ILI Technology

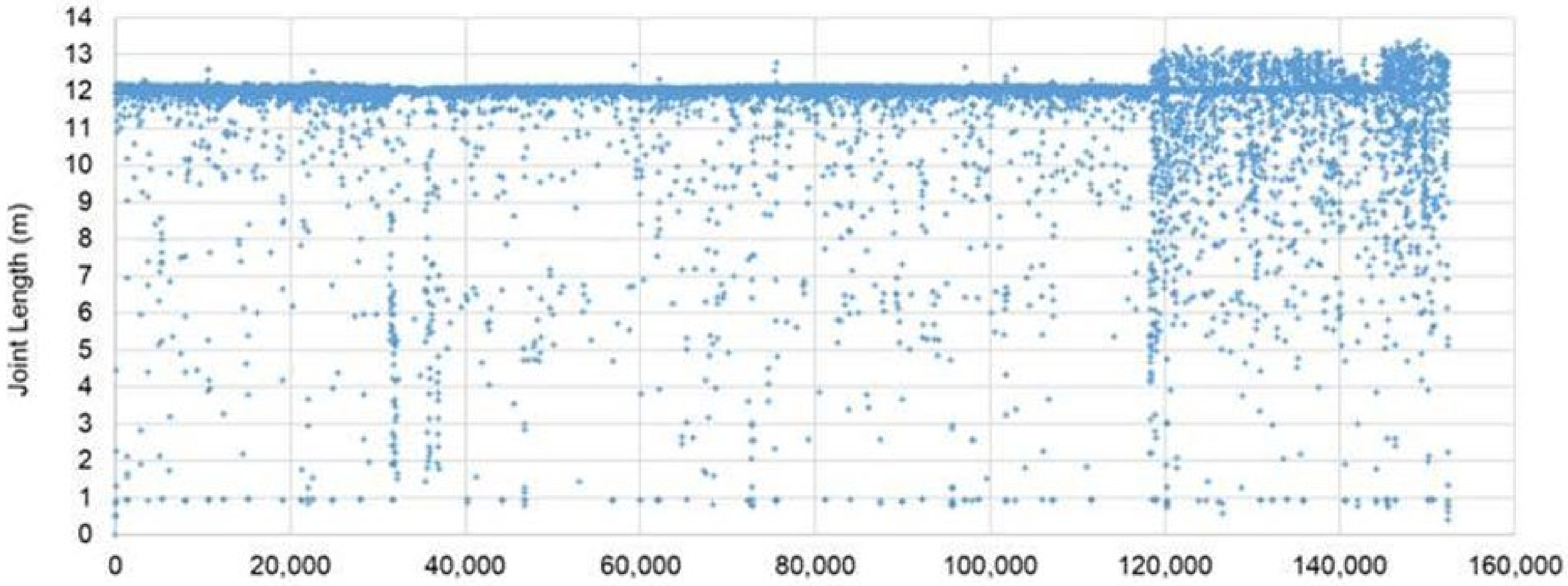
Primary Technology	Primary Technology	Other Technologies used	Properties	Welded vs. Seamless pipe discrimination	Discriminate different seam weld types	Discriminate vintage and modern pipes?	Commercially available technology?
ILI Eddy Current*	Eddy Current in MFL	MFL, Caliper	Can **determine** Grade, YS, TS	Yes	In R&D stage[b]	Yes[c]	Yes for Grade Determination
ILI – MFL	Low-Field MFL	High-Field MFL, Spiral MFL, Deformation Tool	Can distinguish (Grade, YS, TS)[a]	Yes	Possibly	Yes[c]	Yes for Grade Discrimination
	Ultra High Resolution MFL Tool	Circumferential MFL, IDOD	Can distinguish (Grade, YS, TS)[a]	Yes	Possibly	Yes[c]	
	Axial MFL, Circumferential MFL	IDOD, Caliper	Can distinguish (Grade, YS, TS)[a]	Yes	Possibly	Yes[c]	

[a]Primary MFL technologies can distinguish between pipes of different grade. The actual grade, YS and TS can be determined after in-ditch validation
[b]Weld types discrimination is in the R&D stage. However, approach is able to discriminate some weld types using information from ILI and industry knowledge
[c]Combination of datasets – MFL, construction history, pipe lengths, wall thickness variation, and others - may be utilized to classify the pipes as vintage and modern pipes

*Performance specification of YS and TS determination is ±8 ksi at 80% confidence level. The service can be applied to carbon steel pipeline materials from Grade A to X70.

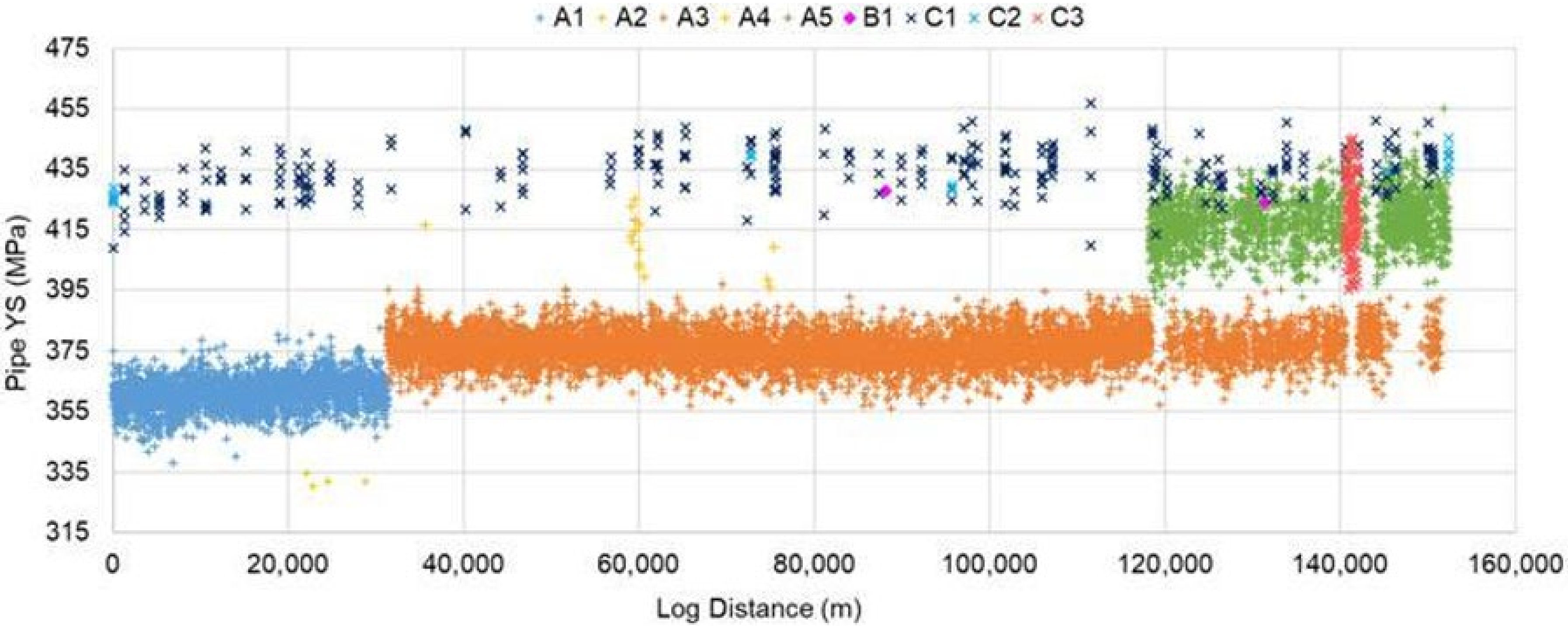
Populations: Eddy current in MFL based technologies

- Grade, YS, and TS can be determined based on the signal from the eddy current tool
- Data Integration with other data sets - Allocate pipes and bends into ‘populations’
  - WT, OD, joint length seam type, signal pattern, and geographical data from an IMU
- Each population consists of pipes with a shared combination of characteristics and properties.
- By analyzing the multiple data sets in detail, the distinct populations can be delineated



Populations: Eddy Current in MFL Based Technologies

- Color-coded populations identified by using multiple datasets, including differences in yield strength
- Letters indicate a different wall thickness.
- Populations A1 – A5 are all 0.25” WT, but they are distinctly different populations with the same wall thickness but different strengths, nominal joint length, and signal pattern.



Population Classification using MFL Technologies

- Review Historical Records: pipeline material, prior inspection data, to understand information gaps
  - May help decide which ILI sensor to select
- Pipe Grade Reference Signal Analysis
  - Establishes median reference signal per pipe joint
  - Vendor's reference library, variation in pipe reference levels - newer pipe - tighter tolerances
- Outer Diameter: mechanical caliper data
- Wall Thickness
  - Derived from the overall magnetization level obtained in the axial MFL data combined with the geometry tool.
  - Ultrasonic compression wave
- Joint length
  - Odometer wheels measure and record the distance along the ILI run
  - MFL sensors record each girth weld
- Long-Seam Type
  - Long-seam type is assigned by visual pattern recognition via data analysis
  - Combination of MFL signal appearance, signals from other supplemental ILI tools like IDOD and Caliper, differences in joint length, knowledge of welding characteristics for the various seam types, and construction history data (i.e., manufacturer and year)
    - Double submerged arc welded, flash welded, single submerged arc welded, and lap welded can also be distinguished. Rare cases: HF-ERW and LF-ERW

Population Classification using MFL Technologies

- Welded vs. seamless pipe
- Attribute variance
  - Newer pipes have shown trends in having less variation in WT
- Pipe components:
  - Flange, pipe, tap, tee, valve, and casings are estimated by Circumferential MFL/Ultrasonic Compression Wave
  - Appurtenances – forged fittings or hot taps/stopples may have short joint lengths that may be identified since they interrupt the linear response of the pipe grade reference signal in the high-field MFL
- Corrosion Patterns
  - Old vs. New Pipes

Robotic Technology for Hardness Determination

- Live, in-line, non-destructive quantification of material property - hardness for piggable and unpiggable natural gas pipelines.
- Hardness tester has been integrated on the 20/26 robotic platform for the 20 in.- 26 in. OD pipelines
- Robotic platform commercialized in 2013
  - Not currently provided as a service.
  - Tool remains available
- Robotic platform can carry sensors to detect pipeline corrosion defects, cracks, dents, and ovality. Design scalable to other pipe sizes
- Technology demonstrated to inspect pipe segments with unpiggable features, such as plug valves and 90-deg mitered bends, underflow, or no-flow conditions
- No need to shut down or reduce gas flow in the pipeline during the inspection
- Robot is launched into and retrieved from a pipeline via a hot tap fitting
  - No pre-built infrastructure required

Robotic Technology for Hardness Determination

- Robot tool provides live video images of the pipeline and integrity data
- Video imagery and integrity data acquired by the robots are analyzed by a technology provider team of analysts using proprietary software
- Hardness tester module will be able to
  - Prepare pipe surface,
  - Perform the measurement, and
  - Log the data for later analysis
- Measurement can be made on pipe between 20 and 26 in. OD, within the pressure of 0-750 psi, and the entry type is a full-size hot tap
  - Minimum WT for direct Rockwell is 0.250 in
- Sample readings do not match those taken inside the test loop and fell outside the target specifications.
  - Likely reason: Sample not from the same type of pipe as the tested sites

Conclusions

- Three technology approaches, two for the ILI and one for the robotic hardness testing, were mainly reviewed to understand the capabilities for material property determination.
- ILI primarily uses MFL and/or eddy current in MFL technology
- Robotic platform uses a hardness tester
- Eddy current in MFL as primary technology
  - Specifications for YS and TS determination (±8 ksi at 80% confidence)
  - Discriminate between pipe grades and determine the YS and TS
- MFL technology
  - Discriminate between different grades
  - Performance specifications of the MFL-based primary technologies for grade discrimination are not published
  - Grade, YS, and TS can be determined by in-ditch validation

Conclusions

- Grade determination is vital for natural gas or liquid pipelines requiring conversion to hydrogen pipelines, which can be determined using the ILI technologies
- Hardness, which can be converted to grade, can also be determined using the robotic hardness tester
- Fracture toughness and ductility measurement and microstructure determination using direct measurement from the ILI tool do NOT exist

- Recommendation
  - **Phase II**: Perform a pull test for these ILI technologies to validate their capabilities further
  - Robotic technology-tested hardness requires further validation to understand the performance specifications for hardness measurements

Value to Members

- Summarize ILI technologies that can identify the installed pipe **grade, WT, OD, and seam type**
- Characterization of pipe properties would help **assess suitability** to operate with **alternative fluids/fuels** that can cause accelerated cracking
- Material characterization of strength and other properties would help operators ensure that the company records are **TVC** and accurately reflect the pipeline's physical and operational characteristics

Closing remarks

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Disclaimer

- The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied

World lost a great man

Ming Gao, PhD

Brilliant Scientist and respected academician

Significant contributions to

- Fracture Mechanics
- Metallurgy
- Crack Integrity Management
  - SCC-3-7 “Evaluation of EMAT Tool Performance and Reliability by Monitoring Industry Experience”
  - SCC-6-3 “Methodology for Assessing Seam Weld Anomalies Using In-Line Inspection Data”
  - SCC-2-10 “Improved Site Selection Model Based on Correlating ILI Results with Operational and Geotechnical Characteristics”
- Dent Integrity Management
  - MD-1-4 “Performance Evaluation of Current ILI Technologies for Detection and Discrimination of Mechanical Damage using Improved In-Ditch Tools”
  - MD-1-13 “Qualification of Pull-Through ILI Runs made at PRCI’s TDC on 24-inch diameter Mechanical Damage Features”
  - MD-1-N, MD 1-Q

- More than 200 publications

thank you

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