Smart Pigs

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www.tdwilliamson.com
Pipeline Services
Why Pipeline Inspections?
Bellingham, WA - 1999
What Are The Threats?
Threats - Overview

- Internal corrosion: Pitting or uniform corrosion
- External corrosion: MIC, oxidation, under deposition
- Flow induced corrosion
- Cracking: Stress corrosion cracking, Embrittlement, sulfide corrosion cracking
- Hydrogen induced cracking
Corrosion
Selective Seam Corrosion
Cracking
Dent
Gouge
Hook Cracks
Wrinkle Bend Failures
What Are The Solutions?
Magnetic Flux Leakage (MFL)

Changes in permeability cause magnetic lines of flux to “leak” outside of the specimen, which can be measured by a sensor.
Low Field Magnetization

![Graph showing magnetization curves for different residual stresses.](image)
Permeability Tensor

\[
\begin{align*}
\mu_0 M (T) & \quad H (kA/m) \\
X & \quad XY & \quad XZ \\
Y & \quad YX & \quad YZ \\
Z & \quad ZX & \quad ZY & \quad ZZ
\end{align*}
\]
Wall Thickness (UT and EMAT)

**Piezo-UT**
- Crystal
- Couplant

**EMAT UT**
- Magnetic Field
- Eddy Current

**Liquids only**

**Gas and liquids**
EMAT – Magnetostrictive vs. Lorentz

**Magnetostrictive**

- Applied magnetic field is parallel to the current in the coil
- Alternating current generates a magnetic field perpendicular to the biasing field. This causes magnetostriction
- The oscillating magnetostriction generates a shear wave that propagates in the direction of the current

**Lorentz**

Uses a magnetic biasing field and pancake coil to create an acoustic wave. When a pulsed high frequency electric current is applied to the transmitting electric current is applied, a time varying magnetic field is induced into the material. This field in turn generates a pulse of elastic waves into the pipe via the magnetostrictive or Joule effect.
Guided Wave Modes

- Shear Horizontal
- Symmetric
- Anti-Symmetric
Pulse Echo Ultrasonic Inspection

- Transverse ultrasonic beams are oriented 90° to the surface of the pipe.
- They detect the reflection from the front surface and the back wall.
- This measurement is a direct measurement of wall thickness, though in welds there is a lot of scatter.
The angled beam is used to find cracks in the pipe wall that are perpendicular to the direction of the beam.

The weld reflects a portion of the sound beam dependent on fusion, porosity, slag and other heterogeneities.

Beams must be oriented in both clockwise and counter-clockwise directions in order to get full coverage.
• The maximum reflection is when a discontinuity is perpendicular to the sound beam.

• For a crack, the maximum amount of signal is reflected by its corner where it meets the surfaces.

• Because the long seam can refract the UT signal, the sensor on the crack side of the long seam has the best chance of detection.
Eddy Current Testing

a—The alternating current flowing through the coil at a chosen frequency generates a magnetic field around the coil.

b—When the coil is placed close to an electrically conductive material, eddy current is induced in the material.

c—if a flaw in the conductive material disturbs the eddy current circulation, the magnetic coupling with the probe is changed and a defect signal can be read by measuring the coil impedance variation.
Impedance Plane

Eddy Current Impedance Plane Responses

- Inductive Reactance, X
- Resistance, R

Materials:
- Steel
- Aluminum
- Air
- Magnetic
- Nonmagnetic

Factors:
- Conductivity
- Liftoff
- Permeability
- Crack
Inline Inspection Tools (Smart Pigs)
MDS and EMAT

MDS
SMFL+MFL+LFM+DEF

EMAT
Magnetostrictive with Oblique Field

Helical Magnetizer  Meander Coils  Oblique Magnetic field
How Spiral Field Works

45° to 60° - Magic Angle

Range of optimum magnetization
EMAT Sensor Function

Attenuation signal minus return

Signal return due to anomaly

Anomaly in pipe

“Transmitting pulse

Calibration receiver (measures Direct Transmission of signal into pipe)

Normal attenuation signal—no anomaly
Propagación de Ondas Horizontales de Cizalla
The traditional method of magnetization is in the axial direction as it is the easiest to design. North magnetic poles are placed at one end and South at the other.

- **Solid Body** – uses brushes to introduce flux into the pipe wall.
- **Sled** – Places magnetic bars in close proximity to the pipe.
Spiral Magnetization

- Full circumferential coverage with all sensors in the sweet spot of the magnetic field
- Magnetization at ~45° which can size axial planar, circumferential planar and pitting.
- Less dependent on tool velocity.
MFL – Anomaly Orientation

Parallel Component

Perpendicular Component

Oblique Component

Parallel Component

Radial Component

Perpendicular Component

Radial Component

Perpendicular Component

Radial Component

Perpendicular Component
Profilometry
MDS Data Results for HS - Overview
Hard Spot

High Field

Low Field

Spiral Field
Sleeved Hard Spot with Crack
Mechanical Damage
Future Work
Aligning Data Sets

Laser Profilometry

Axial High Field

Axial Low Field

Spiral Field
Strain

• Current standard sets a critical strain of 6%. This standard is an empirical standard carried over from ship manufacturing.

• Strain equations used by the industry use realistic assumptions to make the calculations solvable and repeatable.

• The greatest missing factor is the history of stress application that caused the straining process.
Toughness

- Liquid lines are failing at pressures as low as 20% specified minimum yield strength (SMYS)
- At present there are no inline solutions for measuring toughness and the nondestructive evaluation (NDE) techniques being used are still being validated.
Crack Propagation

- Crack Propagation depends strongly on material properties like toughness that are hard to measure nondestructively.
- Crack models make many assumptions and in light of recent failures many of them are under review.
- Data and algorithms for calculating failure are in most part proprietary.
- A calculation that has a safety factor of 10 can definitely use refinement.
Pipe Properties

• Because of all the mergers, acquisitions and lay-offs over the last few decades, there are many lines with missing or incomplete records.

• Operators have been operating under a grandfather clause but new regulations from PHMSA are requiring traceable, verifiable and complete documentation for every joint of pipe.

• There are solutions being proposed for NDE and ILI.
NDE Techniques

Automatic Indenter

Spectroscopy
Every data set collected by the multiple dataset tool (MDS) can be used to identify the manufacture of that joint.
Conclusion

Physics is awesome

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