ADVANCEMENTS IN THE DETECTION AND SIZING OF "PINHOLE" METAL LOSS IN ON & OFFSHORE PIPELINES

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Outline

• Background
• MagneScan™ (MFL4) system
• Finite Element modelling
• “Pinhole” blind test program
• In-line inspection, analysis report, and dig verification
• Summary
Background ... ‘Pinhole’ corrosion

- ‘Pinhole Corrosion’ & ‘Hot Taps made by error’ significant causes of pipeline failure – EGIG report, Dec ‘11
- Result of typical corrosion mechanisms e.g. MIC or 3rd party activity e.g. illegal tapping
- ‘Pinholes’ problematic for gas & liquid operators as a primary threat for leaks
- POF definition:- Length < 1A & Width < 1A. If wall thickness \((t) < 10\text{mm}\) then \(A = 10\text{mm}\), if \(\geq 10 \text{ mm}\) then \(A = t\)
- Typically beyond the capability of MFL systems
MagneScan™ (MFL4) ... dig verification

- 1,000+ inspections ... 50,000+ km (30,000+ miles)
  - 6,8,10,12,14,16,17,18,24,26,28,30,32,34,36
- 560 km (350 miles) longest run
- 95%+ first run success in 2013-15
- 100s of digs
- 1,000s of verified features
- 90%+ in tolerance

1,000s of features categorized & verified by dimension class
... including “Pinholes”
MagneScan™ (MFL4) ... dig verification

Dig Verification ... digging down-under

45% Feature

Pinhole: 5mm x 5mm x 41% deep
(0.09mm deep in 5.16mm WT)

Photo of corrosion in field wrap zone showing target feature

GE reported 45% feature measured at 41% in ditch

Pinole 5mm x 5mm x 41% in 5.16mm wt 14” pipe from 2011
MagneScan™ (MFL4) ...attributes

• Hall Effect sensors for metal loss in 3 axes ... 216 on 6” system

• 5.4mm circumferential separation ... 2mm axial sampling

• Integrated High Resolution Caliper ... 24 sensors (1 per 20mm/0.8”circ.)

• Fiber Optic Gyroscope IMU ... 3D mapping & curvature/strain

• High field “Speed-stable” Magnetizer 0 to 5m/s (11 mph)

• ATEX Certified

Note: detail relates to 6 inch system
MagneScan™ (MFL4) ... high resolution

6” MFL3

30 tracks recorded every 3.3mm

6” MFL4
(axial only - 1 of 3 vectors)

72 tracks recorded every 2.0mm

Enhanced axial & circumferential resolution ... effectively a 3 x zoom
MagneScan™ (MFL4) ... Hall Effects in 3 axes

“Leakage” is a Vector quantity
Each MFL4 sensor track measures the 3 orthogonal components of this vector

**Axial**
- Measured down pipe
- Sensitive to “Volumetric” losses
- Measure nominal field strength

**Radial**
- Measured out/in from center
- Highest sensitivity to changes in depth
- Identifies start and end of features

**Transverse**
- Measured circumferentially around pipe
- Added sensitivity to in-plane shape & width

Enhanced detection (PoD), classification (Pol), & sizing
Finite Element Modelling ... sensor spacing & scan interval

MFL signals are affected by sensors position relative to the defect

MFL signals are affected by sensors position relative to the defect

Ideal

Real
Finite Element Modelling ... conclusions

1. Increasing # of sensors & frequency of scans does not improve detection

2. Dimensions of smallest Pinhole detectable with MFL were calculated

3. Below a minimum defect size signal amplitude falls below the noise threshold

4. MFL signal amplitude is lower for “Pinholes” leading to under-sizing
MagneScan (MFL4) ... Pinhole” specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>General Metal Loss</th>
<th>Pitting</th>
<th>Axial Grooving</th>
<th>Circumf. Grooving</th>
<th>Pinhole ***</th>
<th>Axial Slot **</th>
<th>Circumf. Slot **</th>
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<td>8%</td>
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<td>@0.5A</td>
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<td>Depth Sizing Accuracy</td>
<td>nwt (+/-)</td>
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<td>10%</td>
<td>-13%/-15%/+8%/+10%</td>
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<td>5</td>
<td>7</td>
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POD @ 90% 5mm PH > 15% in ERW

- Pinhole detection only: 4mm > 30% deep;
  3mm > 40% deep; 2mm> 90% deep

Depth Sizing @ 90% Certainty

- PH > 5mm diameter <= 50%, -15%/+10%
- PH > 5mm diameter > 50%, -20%/+10%
• World’s largest publicly traded international oil & gas co.

• Industry leading inventory of global oil & gas resources

• World’s largest refiner of & marketer of petroleum products

• Applying science & innovation to find better, safer, & cleaner ways to deliver the energy the world needs

AVONMOUTH PIPELINE

• Fawley Refinery to Avonmouth Terminal

• 6” x 133km refined product

• Previously inspected with MFL 22/03/05; 21/02/98; 23/08/93

• Concerns over ‘Pinholes’ & ‘illegal tapping’
**ExxonMobil test program ... set-up**

- 12 pulls with 06” MFL4
  - pulls from 0.5 to 4.5 m/s
  - included one conditioning run
- 77 features in 5.6mm wt test spool
  - 57 external & 20 internal
  - 41 drill hole & 36 conical
  - 64 covered by detection specification, 13 below
  - 44 covered by sizing specification, 33 below

- Note: assumed diameter of conical features = average of top & bottom e.g. 5/3 = 4mm
ExxonMobil test program ... detection

Note: Exxon defects boxed & referenced

- POD @ 90% 5mm PH > 20% NWT in SLS
  Pinhole Detection only: 4mm > 30% deep; 3mm > 40% deep; 2mm > 90% deep
ExxonMobil test program ... detection

- 100% detection of 64 in-spec features across all runs
- 94% detection of all 77 features across all runs

POD @ 90% 5mm PH > 20% NWT in SLS
Pinhole Detection only: 4mm > 30% deep; 3mm > 40% deep; 2mm > 90% deep
ExxonMobil test program ... depth sizing

### In-Spec Features

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<th>Depth</th>
<th>In</th>
<th>Out</th>
<th>In%</th>
<th>Min%</th>
<th>Max%</th>
<th>Rge%</th>
<th>- %</th>
<th>+ %</th>
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<td>49</td>
<td>6</td>
<td>89%</td>
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- Sizing performed with optimized pinhole algorithms
- 44 in-spec features (>=5mm) sized within specification
- Defect under metal casing was undersized as expected
- 43 non-spec features (<5mm) undersized as predicted by FEA

89% of in-spec features within depth sizing tolerance
ExxonMobil … inspection & report

- Completed full survey of Fawley Refinery to Avonmouth Terminal pipeline on 9th/10th July 2013
- Inspection confirmed 133.141km length & predominance of seam-less pipe of 5.6mm wall thickness
- “Pinhole” listing included 49 entries (25 categorized as pinholes, and 5 features in 9.27mm wt pipe)
- 15 inspection/dig sheets provided based on Feature Selection Rules including 2 for Pinhole features
ExxonMobil ... dig verification

- **General area of corrosion:** Overall length reported slightly shorter due to low level corrosion around the periphery
- **Pin Hole:** Two reported and found. Deepest actual below PII’s published specification
- Capability to detect & size pinholes validated on multiple features from 7+ dig sites

<table>
<thead>
<tr>
<th></th>
<th>PII Inspection Report</th>
<th>In-Field Measurement</th>
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<tbody>
<tr>
<td></td>
<td>Depth</td>
<td>Length</td>
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<tr>
<td>Overall Area - (Cluster)</td>
<td>54%</td>
<td>162mm</td>
</tr>
<tr>
<td>Deepest individual Pin-Hole</td>
<td>50%</td>
<td>3mm</td>
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</table>
ExxonMobil ... dig verification

- 11 of 13 features found were detected
- 2 pinhole features not detected were below the detection threshold.

All features detected were sized within depth sizing tolerances, including 3 features in 9.27mm wall thickness pipe.
Off-shore example ... North Sea

- Metal loss feature reported in 2008 as 29% x 10mm x 14mm (Pinhole)
- Same feature reported in 2014 as 74% x 6mm x 9mm (Pinhole)
- Improved axial & circumf. resolution better captures signal profile
- Higher resolution triax array & new algorithms for more accurate sizing
- Repeatability of MFL enables assessment of corrosion growth rate

More accurate sizing of “Pinhole” feature ... Signal to signal repeatability for Corrosion Growth Assessment
Summary

• capability of MagneScan (MFL4) to detect & size “Pinhole” features validated on-shore & off-shore

• enhanced performance through latest generation hardware, software, algorithms, & analysis processes

• modelling & testing suggests hardware configuration is optimal for this application

• further work required on discrimination of “Pinholes” in heavily patterned seamless pipe

• success through Pipeline Owner(s)/Operator(s) & ILI Vendor working together

• significant recent activity in detection & prevention of pilferage/illegal tapping of on-shore liquid lines
Q&A
ADVANCEMENTS IN THE DETECTION AND SIZING OF "PINHOLE" METAL LOSS IN ON & OFFSHORE PIPELINES

In the last 4 years more than 800 inspections have been completed on & off-shore with the latest generation MFL ILI technology, capturing information on tens of thousands of kilometres of pipe, and generating a significant volume of dig verification data.

In collaboration with Oil & Gas pipeline operators around the world this growing dig verification database has been utilized to improve software models, algorithms, & analysis processes to validate and further enhance system detection, sizing, & reporting capabilities.

This paper focuses on the recent collaboration between ExxonMobil and PII, to investigate system capabilities with respect to "Pinholes", to address a known threat to a specific pipeline in the United Kingdom.

This paper will describe the:
• Evolution of the “Pinhole” specification that captured the interest of ExxonMobil.
• Use of Finite Element models to predict entitlement for characterization of “Pinhole” type defects
• Detail of and results from the ExxonMobil sponsored test program that was conducted in early 2013
• The in-line inspection, analysis report, and dig verification that followed for the pipeline in question.

This joint paper prepared by PII in collaboration with ExxonMobil will reflect the perspective and synergy of ILI vendor & and Pipeline Owner/Operator
At PII, we are dedicated to predicting our customers’ potential problems, before they become real problems. Our heritage of providing reliable and accurate data sets us apart from our competitors, and helps promote environmental and public safety. Together with our customers, our goal is zero pipeline failures.