Measuring Circumferential Metal Loss Rates in Subsea Pipelines

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Introduction to Corrosion Monitoring
Integrity Management

Integrity Monitoring forms an essential part of any Integrity Management Strategy
Introduction to Corrosion Monitoring

Corrosion Modelling

\[ i = \pm f_0 \cdot 10^{ \frac{E_{\text{corr}} - E}{b}} \cdot \prod_{i=1}^{n_i} (1 - \theta_i) \]

\[ R_{\text{FeCO}_3} = \frac{A}{V} \cdot f(T) \cdot K_{ip} \cdot f(S) \]

\[ \frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial x} \left( \varepsilon^{1.5} D_j^{\text{eff}} \frac{\partial \varepsilon_j}{\partial x} \right) + \frac{\varepsilon R_j}{1 + K_{al/d} C_{H_2S}} \]

\[ 1 - \theta_{H_2S} = \frac{1}{1 + K_{al/d} C_{H_2S}} \]

\[ \frac{d_{\text{crit}}}{D} = \text{Min} \left\{ \left( \frac{d_{e_0}}{D} \right), \left( \frac{d_{e_0}}{D} \right) \right\} \]

\[ - A_G \left( \frac{dP}{dx} \right) - \tau_{\text{WG}} S_G - \tau_i S_i - \rho_G A_G g \sin \theta = 0 \]

\[ - A_L \left( \frac{dP}{dx} \right) - \tau_{\text{WL}} S_L + \tau_i S_i - \rho_L A_L g \sin \theta = 0 \]

\[ \left( \frac{d_{\text{max}}}{D} \right)_{\text{dense}} = 2.22 C_{\text{H}}^{0.6} \left( \frac{\rho_G U^2 D}{\sigma} \right)^{-0.6} \left( \frac{\varepsilon_w}{1 - \varepsilon_w} \right)^{0.6} \left( \frac{\rho_m}{\rho_G (1 - \varepsilon_w)} \right) \]

\[ \left( \frac{d_{\text{max}}}{D} \right)_{\text{dilute}} = 1.88 \left( \frac{\rho_e (1 - \varepsilon_w)}{\rho_m} \right)^{-0.4} \left( \frac{1}{\rho_e} \right)^{0.6} \left( \frac{1}{\rho_m} \right)^{0.8} \]
Cumulative Corrosion \((x_0 - x) = f(V_S / V_R)\)
Corrosion rate = \(-dx / dt\)
Basic implementation of high resolution ER measurement.
RPCM™ Technology Overview

Key Attributes

- Full circumference corrosion and temperature measurement (8 sectors)
- CEION® technology sub-micron measurement
- Welded or flanged into pipe
- Designed for life of field (>25 years)
- No diameter transition / ‘piggable’
- Typical applications: flowline spools, export pipelines, onshore
- ‘Online’ device (Modbus, Canbus)
- 18-30VDC continuous, <10W
- Qualified for subsea HTHP applications
  - 15kpsi, 350F, 3000m water depth
RPCM™ Technology Overview

Components

- Recoverable Electronics
- Drop Protection Frame
- PUP Piece
  - Customer supplied Material
- HPHT
  - (High pressure High Temperature)
- PUP Piece
  - Customer supplied Material
- Inner spool
- Forged Reducers

Components:

- Inner spool
- Forged Reducers
- PUP Piece
  - Customer supplied Material
- HPHT
  - (High pressure High Temperature)
• Ceramic coated rings machined from free-issue pipe (usually carbon steel) are retained between 2 CRA flanges.
• Sample rings inner surfaces are left uncoated.
• Ceramic provides isolation and corrosion resistance.
• Wires attached on outside of sensor rings are fed out to a non-retrievable pod via primary and secondary HTHP penetrators.
RPCM™ Technology Overview
Measurement Operation

- Sample and Reference Rings are in series with one another and a controlled current source.
- Each Ring Pair operates independently from other Ring Pairs (allows redundancy).
- For each measurement cycle, current is injected in Mode 0 (4sec), then switched to Mode 1 (4 sec).
- Total measurement cycle is approximately 10 seconds.
- Real time calculation of Metal Loss per sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Metal Loss (nm)</th>
<th>Ref Temp (degC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
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<td>4</td>
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<td>5</td>
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<td>6</td>
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<tr>
<td>7</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### RPCM™ Technology Overview

#### Ring Pair Configurations

<table>
<thead>
<tr>
<th>Ring Pair Type</th>
<th>Corrosion Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>“Uniform”, TOL, Mesa, Pitting</td>
</tr>
<tr>
<td>Welded</td>
<td>Preferential Weld</td>
</tr>
<tr>
<td>CRA (e.g. Duplex)</td>
<td>Pitting</td>
</tr>
<tr>
<td>Pre-Pitted</td>
<td>Pitting / Crevice</td>
</tr>
<tr>
<td>High Sensitivity</td>
<td>All</td>
</tr>
<tr>
<td>Redundant</td>
<td>All</td>
</tr>
</tbody>
</table>

- Corrosion mechanisms measured by changing geometry and ring material
- 2-4 RPs is the ‘standard’ configuration but more possible.
- Typical Config: 4 RPs, 2 General, 2 Welded
Measurement Performance
The Importance of Resolution

<table>
<thead>
<tr>
<th>Corrosion Rate</th>
<th>Time to Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 micron resolution</td>
<td>100 microns resolution</td>
</tr>
<tr>
<td>0.1 mm / yr</td>
<td>&lt;4 days</td>
</tr>
<tr>
<td>0.5 mm / yr</td>
<td>&lt;18 hours</td>
</tr>
<tr>
<td>1.0 mm / yr</td>
<td>&lt;9 hours</td>
</tr>
</tbody>
</table>

- Resolution is defined as the smallest change that can be detected.
- High resolution enables changes in corrosion rate to be identified quickly.
- An amount of metal equivalent to the resolution is lost before the operator has a chance to respond.
Measurement Performance
The Importance of Resolution

- Low pass 1st order filter with TC ~ 3 hours
- Resolution determined by magnitude of resistance
- Relatively insensitive for large pipe diameters
Measurement Performance
Top-of-Line Corrosion Case Study

- Stratified flow / high temp
- Dissolved CO2 / H2S
- Cold spots are vulnerable
- Organic acids (acetic, HCl)
- BOL protected by inhibitor

Figure 3: Liquid condensation inside the pipe
Case Study
CoP Judy Jade North Sea 2001

2 x 16” Spool flanged into SSV
Case Study
CoP Judy Jade North Sea 2001

Performance of subsea spool after 5 years continuous operation
Conclusions

- RPCMs have extensive field history
- Widely accepted technology for subsea pipeline corrosion monitoring
- Full circumferential view
- Versatile configuration – allows monitoring of: PWC, other alloys, pitting etc
- Flexible platform for other measurements
  - PT
  - Conductivity (EIS)
  - Single Phase Flow
- Resolution circa 1 micron (near real-time)
Thank you for your attention!