Permanently Installed Monitoring System for Accurate Wall-Thickness and Corrosion-Rate Measurement

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Outline

• Motivation
• Permanently Installed Sensor System
• Power of Data through Continuous Monitoring & Trending
• Typical Applications
• Case Studies

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Corrosion Damage Accounts for the Cost of one Major Facility Annually

- Pipeline, Oil/Gas Production $8 B
- Refining & Petrochemical $1.7 B

* NACE Cost of Corrosion Study
Data Monitoring Evolution

1920s - Manual monitoring

1960s - Analog 4-20mA loop

1980s - Digital Conversion

1990s - Wireless

2010s - Age of Internet of Things (IoT)
Data-to-Desk & The Internet of Things (IoT)

- Remote sensors leverage low-cost & ubiquitous communication infrastructure
  - Modbus / RS-485
  - Cellular
  - Satellite
  - WiFi
  - Etc.
- 24 x 7 asset-health monitoring
- Data-to-desk-to-decision instantly or in minutes
- Mobile access by multiple parties

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Why Installed Sensors Today?

Costs ($) associated with manual inspections

- Pre-inspection activities:
  - T & L – windshield time
  - Excavation
  - Insulation preparation
  - Surface Preparation
  - Scaffolding
  - Rope access

- Access, permitting, approvals
- Personnel cost – technicians, equipment, training, etc.
- Cost per point is less for applications than manual data collection

Costs (intangibles)

- Safety – ropes, ladders, radiation, non-invasive, etc.
- Damages – environmental, reputation,
- Time/productivity – short- & long-term decision making & planning
- Data quality – precision & repeatability

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Data Quality Enhanced Using Installed Sensor Systems

- Operator variability
- Transducer placement variability
- Transducer coupling variability
- Acoustic velocity uniformity
- Measurement Precision
- Temperature Compensation
- Accurate Corrosion Rates
- Data Accessibility

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Measurement Precision

- Accurate and Precise UT thickness gauging requires a high precision measurement of the arrival time of the ultrasonic pulse.

- Measurement principles:
  - Depends on the precision of the TOF measurement, not the carrier frequency of the UT signal.
  - Choose high slope portion of the waveform (zero crossing) rather than a peak.
  - Waveform needs to be sampled at a sufficient speed (Nyquist +)
  - Digitizer precision needs to be enhanced: 40MSPS -> 25nS steps -> 0.003” (0.07mm)
  - Solution: 8X Upsample using low pass filter. 320MSPS -> 3nS steps -> 0.0004” (0.009mm)
  - Interpolate between points yields even greater resolution ~6.1 picosecond resolution.
Temperature change can be a significant factor in performing accurate thickness measurement.

Material velocity AND wall thickness changes, but material velocity effect >10X linear expansion effect.

Velocity in steel changes by approximately -1% per 100°F (55°F)

ASTM E790 and API 570 make recommendations for when corrections should be made and how they should be applied.

Permanently installed monitoring system requires a temperature measurement device such as a RTD or thermocouple to implement the correction.

\[ C_1 = C_0 \left(1 + k \frac{(T_1 - T_0)}{100}\right) \]

**Symbols:**
- \( d_1 \): Temperature corrected thickness
- \( C_1 \): Temperature corrected velocity
- \( C_0 \): Reference or calibration velocity
- \( \Delta t \): Measured, round-trip time of flight
- \( T_1 \): Measurement temperature
- \( T_0 \): Reference or calibration temperature
- \( k \): Correction factor in % per °F or °C
The Power of Data …

- Sufficient for **inspection** probably NOT for **monitoring**
  - 1/1/2013 inspection = 10.00mm
  - 12/30/2013 inspection = 9.79mm
- Gross corrosion rate – cannot calculate, not enough information

Wall Thickness Data (1 msmt per year)
The Power of Data (ctd) ...

- Various corrosion rates evident
- Trends evident but still large uncertainty due to measurement precision
- Summary – better!
• Various corrosion rates evident
• Regression can be used to obtain accurate corrosion rates over medium time scales.
• Various corrosion rates evident
• Regression can be used to remove measurement noise and produce very accurate corrosion rate data
• GREAT!
Corrosion Rate Measurement

- An important by-product of wall thickness measurement and monitoring is the ability to measure corrosion rates.
- Corrosion rate measurements can be used for predictive maintenance as well as for process feedback.
- CR achieved through linear regression.
- Precision is achieved that exceeds the precision of the base measurement.
- Factors:
  - Standard deviation of the measurement system
  - Measurement frequency
  - Measurement interval

\[
S_m^2 = \frac{1}{n-2} \sum_{i=1}^{n} (y_i - \bar{y}(x_i))^2 / \sum_{i=1}^{n} x_i^2 - \frac{1}{n} \left( \sum_{i=1}^{n} x_i \right)^2
\]

95% C.I. \(\approx m \pm 2s_m \ (n - 2 \geq 6)\)
Data-to-Desk & The Internet of Things (IoT)

- Data available across the organization – remote viewing for critical decision making
- Archiving & record retention simplicity
- Alarms & Warnings
- Saving raw data: RF Signal
- Google Maps & GPS

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Typical Applications

- Replacement of ER probes/ Corrosion Coupons
- Baseline of new infrastructure
- Crude Unit Overhead w/ chemical Injection and/or Water Washes
- Injection/Mix-point Corrosion
- High temperature (900F) real-time monitoring
- Gas Spheres / containers
- Sand erosion/corrosion in offshore production
- Buried Pipelines
- General Inspection
# UT Sensor Case Studies – Oil & Gas

<table>
<thead>
<tr>
<th>Process Control</th>
<th>Inspection</th>
<th>Re-Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Corrosion RATE monitoring</td>
<td>• Localized corrosion monitoring</td>
<td>• TML reduction programs</td>
</tr>
<tr>
<td>• Chemical inhibitor injection mgmt.</td>
<td>• Gas spheres</td>
<td>• Cellular UT sensors in lieu of manual inspection (<em>2 readings per month</em>)</td>
</tr>
<tr>
<td>• Different crude TAN rates require more/less chemical to reduce exposure to wall loss</td>
<td>• “underbelly” pitting/corrosion</td>
<td>• &lt;1 mil/yr. for +5 yrs.</td>
</tr>
<tr>
<td>• <strong>Temporary UT wireless sensors</strong> placed in misc. areas (<em>1 reading per hour for 3 months</em>)</td>
<td>• Inspection crews sent bi-weekly to inspect known areas on 4 spheres</td>
<td>• 27,000+ TML locations, <em>cost &gt;$3M to inspect 1/3 per year</em></td>
</tr>
<tr>
<td>• Reduction in chemical inhibitor spend varying based on crude slate (in this instance is estimated to be ~$20K/wk.)</td>
<td>• Cost $25K each time</td>
<td>• Were able to reduce from 27,000 TML points to 13,000 TMLs</td>
</tr>
<tr>
<td>• Manual UT gauges marked “low” spots, <strong>tethered UT sensors</strong> placed (<em>3 readings per wk. using tablet</em>)</td>
<td>• Manual UT gauges marked “low” spots, tethered UT sensors placed (<em>3 readings per wk. using tablet</em>)</td>
<td>• <strong>Saving ~$1.7M/yr</strong> in manual inspection cost</td>
</tr>
<tr>
<td>• Saved &gt;$150K in first 3 months of program</td>
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UT Sensor Case Studies – Power Gen.

<table>
<thead>
<tr>
<th>Transmission</th>
<th>Storage</th>
<th>Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Regulation driven</td>
<td>• Buried high pressure storage lines</td>
<td>• Ongoing projects &amp; evaluation ...</td>
</tr>
<tr>
<td>• Buried river &amp; road crossings</td>
<td>• Installed tethered/manual UT sensors on <strong>new (replaced) segments of pipe</strong> where corrosion had previously been found (<strong>2-3 readings per yr.</strong> or as necessary via tablet)</td>
<td>• FAC programs</td>
</tr>
<tr>
<td>• UT sensors placed on defined areas - tethered/manual collection</td>
<td>• Savings from <strong>avoiding unplanned outages</strong></td>
<td>• Corrosion rate R&amp;D</td>
</tr>
<tr>
<td>• Junction boxes placed 100’ from road tethered UT sensors installed (<strong>1 reading per qtr.</strong>)</td>
<td></td>
<td>• MIC programs</td>
</tr>
<tr>
<td>• Savings in <strong>government fines</strong></td>
<td></td>
<td>• Installed sensors in lieu of manual inspections for known pitting between outages</td>
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<tr>
<td></td>
<td></td>
<td>• High-point vent</td>
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<td></td>
<td></td>
<td>• Installed sensors in lieu of manual inspection to <strong>detect gas voids</strong></td>
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<td>• EHS – avoid radiation areas where possible</td>
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Summary & Q/A

The world is changing ... use technology to your advantage

Installed sensors can be used to optimize safety & asset integrity for inspection as well as monitoring for corrosion/erosion & cracking

The power of data ... predictive uptime, real-time asset health monitoring, reduce unplanned outages

Applications for installed sensors exist everywhere, know your short- and long-term goals for any project/program
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