Online and Real-Time Corrosion and Erosion Monitoring of Subsea Pipework and Pipelines using Permanently Installed or Retrofitted Ultrasonic Sensor Arrays

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Outline

✓ Motivations and Applications
✓ Pulse/Echo Ultrasonic Measurements
✓ UT versus ring pair probe spools
✓ Subsea configurations and communication options
✓ Executed subsea projects
✓ Future UT arrays
Online subsea corrosion monitoring - motivation and applications

Reduced capex:
- Eliminate requirements for intelligent pigging
- Select less expensive materials through increased monitoring

Reduced opex:
- Avoid or reduce cost for intelligent pig runs
- Optimise chemical injection programs

Improved Integrity Management
- Real time knowledge of exact wall thickness and wall thickness changes
Monitoring using Single Element Pulse/Echo Transducers

- Non-Intrusive
- Direct wall thickness measurement of pipe wall, weld, HAZ zone, elbow, t-piece
- Not sensitive to pipe wall thickness
- Works through solid coatings (FBE, 3LPP, PE, etc.)
- Possible to separate pipe wall front and back wall echo’s when used on coating.
- Does not discriminate between erosion and corrosion
Monitoring using Single Element Pulse/Echo Transducers

- No need for calibration:
  - speed of sound in steel is known
  - time of flight is measured using a crystal
- Works with a “stand off” between the transducer and the pipe wall - not sensitive for installation on “out of roundness” pipelines
- Fixed sensors combined with advanced signal processing detects wall loss of less than .1 mills (2.5 micrometres)
- Free forming sensor matrix to suit corrosion/erosion phenomena

\[ d = \frac{c}{2} \left( t - \frac{c}{2} \right) \]

- Pulse-echo:
  - \( c \) – speed of sound in steel
  - \( t \) – time
  - \( d \) – wall thickness
## Pulse Echo UT array versus Ring Pair Probe Spools

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UT Array</th>
<th>Ring pair probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of measurement</td>
<td>Directly measurement of the pipe wall using pulse/echo UT</td>
<td>Indirect Electrical Resistance (Same as FSM) measurement on sample rings in the ring pair probe spool</td>
</tr>
<tr>
<td>Installation on new pipelines</td>
<td>Preinstalled on standard pipe joint on top of a field weld. Truly none intrusive with no pipe wall penetration</td>
<td>Special pipe joint made sensing instrumentation inside pressure barrier with wall penetration to external electronics</td>
</tr>
<tr>
<td>Installation on existing pipework and pipelines</td>
<td>ROV or Diver deployable. Truly none intrusive with no pipe wall penetration</td>
<td>Not possible</td>
</tr>
<tr>
<td>Temperature sensitivity</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Concept for obtaining high resolution</td>
<td>High quality electronics and transducers and advanced signal processing</td>
<td>Use of thin ring-coupons (life time limits on coupons?)</td>
</tr>
<tr>
<td>Erosion versus corrosion</td>
<td>Does not discriminate between erosion and corrosion. Measures erosion on the pipeline itself</td>
<td>Measures erosion in the ring pair probe spool</td>
</tr>
<tr>
<td>Parameter</td>
<td>UT Array</td>
<td>Ring pair probes</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
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<tr>
<td>Type of measurement</td>
<td>Directly measurement of pipewall using pulse/echo UT</td>
<td>Indirect Electrical Resistance (Same as FSM) measurement on sample rings</td>
</tr>
<tr>
<td>Measurement results verifyable by reviewing of raw data</td>
<td>Yes. Well known and understood measurement concept. Result may be reproced by others</td>
<td>No. Proprietary processing, independent verification not possible</td>
</tr>
<tr>
<td>Resolution</td>
<td>&lt;0.1 mils/2.5µm measured directly on the pipe wall</td>
<td>0.005% of WT measured on ring pair probe spool</td>
</tr>
<tr>
<td>Direct measurement on weld and heated weld zone</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Detection speed (0.2 mm/year)</td>
<td>&lt;5 days</td>
<td>2 days</td>
</tr>
<tr>
<td>Measurement method</td>
<td>Direct measurements</td>
<td>Indirect estimates</td>
</tr>
<tr>
<td>Design life</td>
<td>30 years</td>
<td>25 years</td>
</tr>
<tr>
<td>Replaceable during operation</td>
<td>Yes (Retrofittable version)</td>
<td>No</td>
</tr>
</tbody>
</table>
Subsea Configurations

Retrofittable installations:
- Installed on existing subsea pipelines without production interference
- Fully ROV or diver installable, removable and movable

Fixes installations:
- Preinstalled
- 30 year life time
- Sensors installed inside insulation
- Can be installed to monitor a weld
Specifications of Permanent Installed and retrofit subsea UT Arrays:

• Design temperature: -20 to 150°C
• Design pressure exposed electronics: 300 bar (10000 feet)
• Design pressure canister datalogger: 300 bar (10000 feet)
• Design life permanent installations: 30 years
• Design life retrofit installations: 15 years
• Transducer density >30%
• Resolution: <2.5 µm
• Wall thickness: <200 mm
Permanently Installed Subsea UT Sensor Array
Layout of permanent UT Array

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transducer cassettes</td>
</tr>
<tr>
<td>2</td>
<td>Mounting plates</td>
</tr>
<tr>
<td>3</td>
<td>Transducer (T) Housing</td>
</tr>
</tbody>
</table>
Transducer configuration
Wall thickness plot from one sensor

Probe 3

a = -0.00 mm/year

Rms = 0.0013 mm
Pressure compensator

ROV grab bar

ROV power and communication interface

Retrievable datalogger
Network interface - Display Data

Subsea Signal Processing

Main control system

Ethernet
Modbus TCP/IP
Modbus RTU
Canbus

Transfer of display data
~20 per unit, 1-6 times per day

Pipe Cross Section
12 o'clock position
Corrosion rate: 0.2 mm/yr
Temp.: 50°C

3 o'clock position
Corrosion rate: 1.8 mm/yr
Temp.: 50°C
Amount of disply/engineering data for communication

• 6 readings per day on a tool with 500 sensors
• Local Data logger processess raw data and converts to wall thickness and communicates results, inclusive one temperature reading per cassette and housekeeping data; ~ 24 kB per day, og 4 kB every 4 hours.

• Power consumption
  ✓ active < 10 W
  ✓ idle/sleep: <0.001w
Network Interface
- RAW Data

UltraMonit console

Main control system

Subsea Control System

Ethernet
Modbus TCP/IP
Modbus RTU
Canbus

Transparent link or allocated register in Modus/Canbus register

Subsea Signal Processing
Amount of data communicated collecting raw data

- Raw data for 52 weekly readings for one cassette having 17 sensors equals about 3500 kB of data.
- Raw data is relevant for
  - commissioning
  - post processing for detailed corrosion analysis
Permanent UT Array deployed on BP Shah Deniz 2

• 16 inch flow lines (10) feeds condensate from 30 deep water wells
• One fixed UT array installed on top of the weld on the first pipe joint after the FTA (Flowline Termination Assembly)
• Online and real-time feedback on corrosion inhibitor effectiveness
BP Shah Deniz In-Situ:

- Transducer array with 144 sensors covers straight pipe, field weld and HAZ zone.
- Real-time feedback on corrosion inhibitors effectiveness gives reduced opex cost.
- The ability to rapidly detect corrosion rate changes enables the operator to plan and execute necessary actions to ensure that the corrosion rate does not exceed the maximum allowed rate (30 year design life time).
Retrofittable Subsea UT Array

- Non-intrusive ROV or Diver installation
- Works through solid coatings
- Autonomous operation with battery life time up to 10 years
- Wireless acoustic communication options
Data storage and collection – Battery Operation

- Local data processing and storage
- Wall thickness data transfer via acoustic link
- 10 year battery life (@ 4 measurements per day and 100 transducers)
- Consumption active: <10w, idle/sleep: <0.001w
Data storage and collection using hard wire

✓ Local data processing and storage
✓ Consumption active: <10w, idle/sleep: <0.001w
✓ Communication interfaces: Ethernet, Modbus TCP/IP and RTU, Canbus (SIIS level 3 and SIIS level 2)
✓ Power: 24V DC
Retrofittable UT Array deployed on a 34 inch subsea crude oil pipeline

- Pigging showed local corrosion areas
- A 34” UltraMonit® subsea tool was installed to verify the chemical inhibition program
- Real time communication to the platform via radio link
- Data buoy with solar panels, batteries, data logger and radio link
- Anchor structure with subsea backup Data Logger
- Data showed little or no corrosion – inhibition successful
Retrofittable UT Array on a 34 inch subsea crude oil pipeline

- 746 Transducers
- Installed by divers
- Maintained by ROV
- 18 months of monitoring enabled adjustment and verification of chemical inhibition program
ROV Deployable UT Sensor Arrays for Inspection
UT Arrays for Subsea Pipeline Inspection

✓ ROV deployable inspection tool providing autonomous scanning using an array of pulse/echo transducers operated by a battery driven data logger
ROV flies in and mount an anchor frame. The anchor frame may be left in position to enable re-inspection of the same spot.

ROV flies in the inspection unit. A green light will indicate completed inspection cycle.
Any Questions, please?
Thank You!

Trondheim by night
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