Innovative Flexible Riser Monitoring
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OPT
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Innovative flexible riser monitoring

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Agenda – Overview

- Un-Bonded Flexible Pipe
- Goals of Flexible Integrity Management System
- Overview of Installed Base
- Flexible Riser Threats
  - Focus areas
  - Inspection
- FlexAssure: Monitoring
  - Overview
  - Development and Qualification
  - Benefits and Limitations
  - Case Study
- FlexAssure: Curvature Monitoring
  - IntegriStick
  - Remnant Life Assessment

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Un-BondedFlexible Pipe

<table>
<thead>
<tr>
<th>LAYER</th>
<th>MATERIAL</th>
<th>FUNCTION</th>
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</thead>
<tbody>
<tr>
<td>EXTERNAL SHEATH</td>
<td>POLYMER</td>
<td>EXTERNAL FLUID BARRIER</td>
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<tr>
<td>TENSILE ARMOUR</td>
<td>CARBON STEEL</td>
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<td>PRESSURE ARMOUR</td>
<td>CARBON STEEL</td>
<td>HOOP STRENGTH</td>
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<td>POLYMER</td>
<td>INTERNAL FLUID BARRIER</td>
</tr>
<tr>
<td>CARCASS</td>
<td>STAINLESS STEEL</td>
<td>COLLAPSE RESISTANCE</td>
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</tbody>
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Annulus – Space between the two extruded polymer fluid barriers
Protects the Carbon Steel Wires which are not Corrosion Resistant

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Goals of Flexible Riser Integrity Management System

- To improve integrity and reliability of flexible risers
- Prevent failure of flexible risers through early detection
- Enable safety assessment monitoring and plan predictive maintenance
- To accurately assess remaining service life
Flexible Pipe: Overview of Installed Base

- ~ 17,600 flexible pipes in service
- > 189,552 flexible pipe operational years
- 93% of all flexible pipe have design pressure ≤ 413 bar
- 93% of all flexible pipe is ≤10-inch (ID)
- 70% pipes are used for design temperature less than 80° C
- 74% of all flexible risers in water depths ≤ 1,000 m WD

Source: Oil and Gas UK
Flexible Riser Threats

Unbonded Flexible Risers
DAMAGE & FAILURE CASES, GROUPED BY PIPE LAYER / COMPONENT
SureFlex JIP 2017

Source: Oil and Gas UK
Flexible Riser Threats: Outer Sheath

- External – Environmental Barrier
- Robust - Polymer Extruded Layer ~8-14mm
- Breach = Flooded Annulus ~ Reduced Life
- Breach = Carbon Steel Layers in Seawater
- Multiple Outer Sheaths
Flexible Riser Threats: Tensile Armours

- Provide Tensile Capacity
- Two/Four Helically Crosswound Layers
- Carbon Steel Wires
- Material Selected H$_2$S or CO$_2$ Content
- Corrosion - Fatigue

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Flexible Riser Threats: Tensile Armours – Inspection

- Direct Inspection Not Possible
- Non Destructive
- Ultrasonic – Proven with Extensive Track Record
- Couplant – Confirms Flooding
- Wire Thickness Measurements
- Wideband (ART) No Couplant Required

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Flexible Riser Threats: Monitoring

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FlexAssure: Monitoring – Motion and Acoustic

Wire break causes unique structural vibration and acoustic emission

Five sensors (basic configuration):
- Acceleration X/Y/Z
- Gyroscope (axial rotation)
- Microphone

Data Analysis Methodology
- Threshold level defined per sensor
- If four/five sensors above threshold:
  • Potential break and alarm raised
  • Confirmation by human evaluation

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FlexAssure: Development & Qualification

Operator promoted development of multiple technologies:
- Inspection and monitoring
- Built-in and retrofit

Pulse Qualification Tests:
- Lab Tension-Tension Test
- Lab Dynamic Fatigue Test
- Offshore Background Noise Test

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FlexAssure: Development Tension–Tension Static Test

- Only Tension Loading
  - No Pressure
  - No Bending
- Range of sensors were used in the test to capture as many parameters of riser failure as possible.
- Sensors not marinised (prototype).
- Cables and connectors designed for laboratory tests.
- Sensors logged directly to computer.
FlexAssure: Development Tension-Tension Static Test Arrangement

CONNECTOR A
SIMPLY SUPPORTED

CONNECTOR B
FULLY FIXED

Coating removed

Outer Armour Wire Layer
Inner Armour Wire Layer

40 - 80Te

1.0m

4.3m

1.2m

6inch

FLEXIBLE RISER

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FlexAssure: Development Tension–Tension Static Test Methodology

- Improved understanding
- Different technologies trialled
- Cuts induced controlled break

Armor Wires Break

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FlexAssure: Development Tension–Tension Static Test Results

Note: Failure threshold defined based on offshore background noise recorded at a later test stage.

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FlexAssure: Development Dynamic Fatigue Test

Description

- Flexible Riser Qualification for Operator (part of full process)
  - Fatigue: damage ≤0.1
  - Strength: sustain severe environments and operational loading
- Validate Vendor methodology to estimate damage 1.0
- Improve understanding of wire break phenomena

- Test per Standards
  - N-2409 (Operator)
  - API-17B
- Loading combination blocks
  - Pressure
  - Tension
  - Bending
- 6in Production Riser

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FlexAssure: Development Dynamic Fatigue Test
Arrangement

- Same sensors with removal of extra arm extension
- Introduction of similar marinised version
- Introduction of reference sensor

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FlexAssure: Development Dynamic Fatigue Test
Arrangement

- 1.5 years of testing
- Weekly reports of events
- Gamma ray inspection
  - At damage 0.3 > no breaks
  - At damage 0.8 > no breaks

Pipe Region
FlexAssure: Development Dynamic Fatigue Test Results

Note: Utilisation refers to number of time above threshold

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FlexAssure: Development Dynamic Fatigue Test
Results and Conclusions

- **Blind Test**
  - Number of breaks identified during dissection was only informed after disclosure of detected breaks

- **All breaks detected**
  - 45 breaks
    - ~4 in the inner armour layer
  - Lab estimate based on acoustic measurement was 10-20
FlexAssure: Benefits & Limitations

**Key Benefits**
- Early detection of progressive armour wire failure prior to catastrophic failure
- Retrofit-able
- Marinised
- Intrinsically Safe (Exd rated)

**Associated benefits**
- Motion and acoustic record can be used for further operational response evaluation
- May be integrated with complimentary monitoring

**Limitations and Challenges**
- Only detects a failure as it occurs, cannot retrospectively identify a failure.
  - Magnetic inspection tool typically recommend to set base line and validate eventual breaks identified (e.g. MAPS).
- Max detection range/distance is unknown.
  - Failures expected near Bend Stiffener
- Background noise/acceleration may lead to “detection failure” or “false alarms”.
  - Multi sensor and human evaluation to address that.

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FlexAssure: Case Study

- External Turret FPSO
- Water Depth 970m
- Hang-Off Above Water
- System retrofitted to installed risers
- 5 risers being monitored

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FlexAssure: Case Study

- Data screening and validation
  - Threshold definition per sensor (and riser)
    - 5 standard-deviation used as starting point
- Events generally filtered as
  - **green** events:
    - 1 sensor above thresholds.
  - **red** events:
    - 4 of 5 sensors above thresholds – alarm.
- Log Rate 2000/s;
- Statistics and record 1/s (std-dev, min, mean, max);
- Reference Sensor
  - Located on turret outer radius. Relative acceleration between risers hang-off and reference sensor during FPSO pitch and roll will be different.

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FlexAssure: Curvature Monitoring Remnant Life Assessment

- INTEGRIStick – Dynamic Curvature Sensors
- Attached to outside of riser
- Measures change in riser curvature in two planes
- Results used to calibrate global/local models
FlexAssure: Curvature Monitoring
Remnant Life Assessment

- Measured curvature and angles – identify trends
- Combined with measured environmental data
- Additional input for remnant life assessment
- Reduction of conservatisms

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Summary

- Flexible risers have complex failure modes
- Tensile armour wires are key structural component
- FlexAssure provides innovative monitoring solution
- Provides early detection of failure
- Avoids catastrophic failure
- Combination of acoustic and motion sensors
- IntegriStick monitors curvature
- Data can be used for further operational evaluation
- System can be retrofitted on existing riser system

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Questions

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