Combined State of the Art Inspection and Analysis of Flexible Risers

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Subsea Inspection, Monitoring and Life Extension

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Flexible Riser Inspection and Assessment

Flexible Riser Inspection Operation

Defect Detection
(cracks, pitting, wire misalignment)

Data Reporting

Risk / Life Time Assessment by FEM Analysis (FLEXAS™)
Inspection of Flexible Pipe

- Outer Sheath
- Fabric Tape
- Tensile Armour 1
- Anti-Wear Tape
- Pressure Armour
- Pressure Sheath
- Tensile Armour 2
- Anti-Wear Tape
- Inner Carcass
## Flexible Riser - Inspection Techniques

Overview of existing external deployed NDT techniques for Flexible Riser Inspection

<table>
<thead>
<tr>
<th>Principle</th>
<th>DETECTION</th>
<th>DEPLOYMENT</th>
<th>Digital Radiography (DRT)</th>
<th>MEC-FIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic</td>
<td>Pulsed Echo Ultrasound</td>
<td>Thickness of outer tensile armour wire</td>
<td>(Electro-) Magnetic Field Stress</td>
<td>(Electro-) Magnetic &amp; Eddy Current Field Induction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fully Severed Wires in the Outer Wire Layer when scanning</td>
<td>External Radiography</td>
<td>• Corrosion (pitting)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mainly used for topsides to date, but can detect:</td>
<td>• Thickness Loss</td>
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<tr>
<td></td>
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<td></td>
<td>• Cracks</td>
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<td></td>
<td>• Corrosion</td>
<td>• Wire Misalignment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Loss of interlock</td>
<td>• Detection in 1st, 2nd and partly 3rd layer</td>
</tr>
<tr>
<td></td>
<td>ROV deployed</td>
<td>Annulus flooding required</td>
<td>ROV Deployed</td>
<td>ROV Deployed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No flooding required</td>
<td>Fast Scanning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No flooding required</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Requires calibration</td>
</tr>
</tbody>
</table>

**Overview of existing external deployed NDT techniques for Flexible Riser Inspection:**

- **Ultrasonic:** Pulsed Echo Ultrasound
  - Principle: Thickness of outer tensile armour wire
  - Deployment: ROV deployed
  - Detection: Fully Severed Wires in the Outer Wire Layer when scanning
  - Ultrasonic: Thickness of outer tensile armour wire
  - Deployment: ROV deployed
  - ROV Deployed
  - No flooding required
  - External Radiography

- **MAPS-FR:**
  - Principle: (Electro-) Magnetic Field Stress
  - Deployment: ROV deployed
  - ROV Deployed
  - No flooding required
  - External Radiography
  - Mainly used for topsides to date, but can detect:
    - Cracks
    - Corrosion
    - Loss of interlock

- **Digital Radiography (DRT):**
  - Principle: Ultrasonic
  - Deployment: ROV deployed
  - ROV Deployed
  - No flooding required
  - External Radiography
  - Mainly used for topsides to date, but can detect:
    - Cracks
    - Corrosion
    - Loss of interlock

- **MEC-FIT:**
  - Principle: (Electro-) Magnetic & Eddy Current Field Induction
  - Deployment: ROV deployed
  - ROV Deployed
  - Fast Scanning
  - No flooding required
  - Requires calibration

- **Corrosion (pitting)**
- **Thickness Loss**
- **Cracks**
- **Wire Misalignment**
- **Detection in 1st, 2nd and partly 3rd layer**
MEC-FIT™
Magnetic Eddy Current Flexible Riser Inspection Tool

• External scan, detection in 2 (up to 3) layers:
  o corrosion pitting
  o corrosion thickness loss
  o cracking
  o wire misalignment / gaps

• Fast external scanning

• No flooding required
MEC (Magnetic Eddy Current)
Magnetic Field controlled High Frequency Eddy Current

Detection of Far Side Defects

Signal Response

Detection of Near Side Defects

Signal Response
MEC - A Comparative Method

Calibration defects

Far side defect signal phase

Near side defect signal phase
MEC-FIT Development

Wire Gap and Defect Indications

Increased Wire Gap

Crack Simulation (machined)

Localised Pitting (machined)

Signal Phase Signatures
MEC-FIT Development
Defect Signature Database

**Tests / Signal analysis**

- Localised Wall Loss
- Wire thinning
- Wire crack
- Defects Drilled from Inside out

**Signal Signature Catalogue**

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>Loop Magnet off</th>
<th>Loop Magnet Intermediate</th>
<th>Loop Magnet On</th>
<th>Phase</th>
<th>Change Mag-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gap upper level</td>
<td></td>
<td></td>
<td></td>
<td>310°</td>
<td></td>
</tr>
<tr>
<td>2 Cut wire Lower layer</td>
<td>x</td>
<td></td>
<td></td>
<td>310°</td>
<td></td>
</tr>
<tr>
<td>3 Grinding on upper wire</td>
<td></td>
<td></td>
<td></td>
<td>310°</td>
<td></td>
</tr>
<tr>
<td>4 Cut wire Surface (crack like)</td>
<td></td>
<td></td>
<td></td>
<td>310°</td>
<td></td>
</tr>
<tr>
<td>5 Mat. in-homogeneity</td>
<td>x</td>
<td></td>
<td></td>
<td>310°</td>
<td></td>
</tr>
<tr>
<td>6 Far side ml in solid Pipe</td>
<td>x</td>
<td></td>
<td></td>
<td>310° (90° for SLOFEC)</td>
<td></td>
</tr>
<tr>
<td>7 Near side ml in solid pipe</td>
<td></td>
<td></td>
<td>310° (90° for SLOFEC)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Flexible Riser Inspection with MEC-FIT™
MK1 – ROV deployed to MK 3 top side deployed
What to do with Inspection Results?
Global Analysis with MEC-FIT™ Damage Data integrated in a FLEXAS™ Model
Modelling of Defects

How do you incorporate local defects into a global model?

- A detailed FEM model is required over the whole length of the riser to capture the complex geometry and nonlinear kinematics.

- In order to extract accurate flexible riser fatigue life predictions it is necessary to compute accurate tensile armour wire stress time-histories from each wire.

- However, computing with these FEMs in commercial FE solvers is major hurdle:
  - ExxonMobil/Seaflex (2007): “direct use of local analysis tools* [based on the finite element method] for long time-domain simulations is very computationally intensive and impractical.”
  - Technip/IFP (2012): Abaqus nonlinear quasi-static analysis of a 7 meter flexible for one bending cycle 48 hours on 36 CPUs in parallel

* includes special purpose flexible’s FE analysis software, which utilize very much simplified models.
Non-linear Dynamic Substructuring (NDS)

- NDS is an extension of the framework of Dynamic Substructuring* capturing its computational efficiencies while operating in fully nonlinear mode

- NDS makes feasible time-domain nonlinear dynamic simulations of complex systems represented by detailed 3D FEMs in system configurations and under full set of dynamic load time-histories

- These systems are otherwise not feasible to compute

* First developed in 1965 by W. C. Hurty, UCLA
  - Core analysis method in aerospace, aeronautics, defense, and automotive industries for complex system analyses
  - 1000s of peer reviewed publications
NDS solver: Computational Advantages

- Enables orders of magnitude reduction in the size of the nonlinear dynamic simulations
- Enables solver algorithms to operate efficiently by updating only the nonlinear substructures undergoing a "state" change
- Enables a fully IMPLICIT solution even for global system configurations
FLEXAS™ – an NDS Solver

- FLEXAS™ is INTECSEA's multibody NDS solver

- Provides computationally efficient time-domain nonlinear dynamic simulations of systems comprised of finite element models (FEMs)

- Input FEMs can be as detailed as required to accurately capture non-linear kinematics and produce realistic stress time-histories over the whole length of a flexible.

- FLEXAS™ is qualified by major operators for highly complex system simulations not feasible in FE solvers:
  - BP
  - ExxonMobil
  - DeepStar
DeepStar and ExxonMobil validation through FLEXAS™ local benchmarking

- Experimental benchmarking\(^1\):
  - 8 pitch lengths, cyclic loading
  - 238 computed armour strains were compared against strain gauge measurements for axial tension and bending cases resulting in very good agreement

\(^1\)Experimental work published by De Sousa Et al, OMAE2013-11384, OMAE2015-41436

The FLEXAS solver is capturing the complex kinematics of the flexible’s helically wound layers resulting in excellent numerical and very good experimental comparisons
Integrated Local and Global Modelling

20 pitch (12m) riser simulation with 80 million DoF using FLEXAS™

34 wire stress time-histories

Total computation time for this nonlinear dynamics simulation (FLEXAS™): 300 secs
Integrated global analysis, NO separate local analysis required

Entire riser made of detailed FEMs (NDS)

Wire Stress Timehistory - Fatigue Spectra
Fatigue Analysis

1. Execute global fatigue analyses on a flexible in lazy wave configuration
   - 24 irregular wave cases (1hr each)
   - 26 regular wave cases

2. Extract tension and curvature for simulations of local hang-off model
   - Irregular wave cases:
     1 hr long tension/curvature
   - Regular wave cases:
     max tension/curvature

Irregular Wave Load Case 07

32 wire corner stress locations
Fatigue Analysis

S-N Fatigue Spectra - Regular vs Irregular

Higher Resolution for Irregular in Low-Cycle Regime

Sharp drop-off for Irregular Approach in High-Cycle Regime
Benefits of this New Approach

- MEC-FIT provides accurate defect measurements.

- Non-Linear Dynamic Sub-structuring software (FLEXAS) allows efficient analysis, which permits the inclusion of:
  - As-built data
  - Measured defects
  - Fatigue Analysis based upon Irregular Wave Analysis

- Unlock fatigue life by replacing simplifications, conservatisms and assumptions with actual data.

- Extend the life of flexible pipe.
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