Complete Pipeline and Umbilical Monitoring for Integrity Management using Fibre Optics

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Overview

- Subsea asset monitoring generalities:
  - Purposes and value of monitoring
  - What events on what system or asset
  - Measurement system objectives

- Fibre Optics background
  - Discrete measurement
  - Distributed measurement

- Application of fibre optics in pipelines and umbilicals
  - Fibre Optic integration into the subsea asset
  - Pilot projects: pipelines and umbilicals

- Conclusions
The Overall Objectives of Pipelines and Umbilicals

Power
Supply power to subsea infrastructure

Communication
Send and receive data from surface to subsea

Fluid Transport
Keeping the hydrocarbon flowing

System Integrity
Preventing or mitigating a leak
Where does Surveillance Fit?

Environmental
- Wave
- Current
- Wind

Structural Monitoring
- Tension
- Bending
- Vibration / Motion
- Fatigue – VIV, wave
- Pipe / soil interaction
- Conductor integrity
- Crack growth / existence
- Wall thickness / corrosion

Fluid Properties
- Temperature
- Pressure
- Fluid flow
- Breakage
- Blockage
- Hydrate formation
- Change

Other
- Vessel motions – GPS, 6 dof
Monitoring = Information to make decision ($value)

- Is my component fit-for-purpose?
  - Inspection

- Have I used the design life of my component yet?
  - Life Extension

- When and how can I plan this operation?
  - Operational planning and Optimisation

- Is this system performance range acceptable?
  - Operational Mediation

- Can I do thing in a better way in the future?
  - Measurable performance = Knowledge Building
Purpose of Monitoring

System
- Components
  - Failure Mechanisms
    - Asset Integrity
      - Inspection
      - Life Extension
  - Operations
    - Operational Issues
    - Operational Mediation
    - Operational Limits
    - Operational Enhancement

Everything Else is a Knowledge Building
Integrity Management

Knowledge Building

Asset Integrity
- Inspection, Maintenance and Repair
- Life Extension

Operational Enhancement
- Operational Prevention
- Operational Mediation
Controlling Hazards to Prevent Failure

An example of a hazard, event and consequence using structural integrity to prevent or mitigate a leak

Hazard | Prevention | Event | Mitigation | Consequence
--- | --- | --- | --- | ---
Loss of Wall | Design | Leak | Response | Loss of Oil
Unforeseen Interaction | Management = IMR plan | No Fluid Flow | Detect = Alarms | Environmental Disaster
Causes: Wear, Crack, Fracture, Plastic Deformation, Corrosion, Fatigue | Reduced Fluid Flow | Human Casualty
We work in the prevention and mitigation areas to
- Manage hazards
- Detect events

Corrosion | Loss of Reputation
Fatigue | Financial Loss

Schlumberger
Potential Events of Interest

- Fatigue
- Leaks
- Third party interference
- Object tracking
- Shark attack
- Marine growth
- Accidental damage
- Excessive loading
- Break or excessive strain
- VIV
- Wave loading

- Second order vessel motions
- Fluid properties
  - Fluid flow
  - Fluid temperature
  - Fluid pressure
  - Fluid content
  - Fluid slugging
  - Fluid flow restriction identification
- Pipeline walking
- Pipe/Soil interaction
- Corrosion
Qualitative Assessment of Events - Classification

- **Period** - the change caused by the effect to be observed:
  - Static Period of over 10 minutes,
  - Quasi-Static Period of between 1 minute and 10 minutes,
  - Dynamic Period of between 1 second and 1 minute,
  - Vibration Period less than 1 second.

- **Duration** - the length of time taken for the event to initiate and finish/complete, described by:
  - Quick Event completes in a matter of seconds,
  - Short Event completes in a few minutes,
  - Long Event completes in a number of hours,
  - Continuous Event always occurs.

- **Occurrence** - an indication of how often and the regularity of the event, defined by:
  - Sudden One off occurrence cannot be predicted,
  - Intermittent Repeated occurrences without regularity,
  - Regular Repeated regular occurrences,
  - Continuous Occurs all the time.
### Qualitative Assessment of Events

<table>
<thead>
<tr>
<th>Event</th>
<th>Period</th>
<th>Duration</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue</td>
<td>Dynamic, Vibration</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>VIV</td>
<td>Dynamic, Vibration</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>Excessive loading</td>
<td>Static, Quasi-Static, Dynamic</td>
<td>Short or Continuous</td>
<td>Sudden</td>
</tr>
<tr>
<td>Shock Loading</td>
<td>Vibration</td>
<td>Quick</td>
<td>Sudden</td>
</tr>
<tr>
<td>Force Monitoring</td>
<td>Static, Quasi-Static, Dynamic</td>
<td>Change, Drift</td>
<td>Continuous</td>
</tr>
<tr>
<td>Shape Monitoring</td>
<td>Static</td>
<td>Long</td>
<td>Regular</td>
</tr>
<tr>
<td>Third party interference</td>
<td>Dynamic, Vibration</td>
<td>Quick, Change</td>
<td>Sudden</td>
</tr>
<tr>
<td>Fluid Properties</td>
<td>Static, Dynamic, Vibration</td>
<td>Change</td>
<td>Sudden</td>
</tr>
<tr>
<td>Leak</td>
<td>Dynamic, Vibration</td>
<td>Change</td>
<td>Sudden</td>
</tr>
</tbody>
</table>
Measurement System Objectives

- **Event detection**
  - Along length of pipeline and umbilical detect events that occur,
  - Track and report changes in system
  - Identify what the event is, such as a leak,

- **Fatigue tracking**
  - Monitor strains at critical locations, such as:
    - Bend stiffener, Lazy wave, Touch down point, etc
  - Track fatigue damage to determine the usable life left within structure

- **Knowledge development**
  - All measurements provide the ability to improve and develop knowledge of the measurand
Why Fibre Optics?

- A single optical fibre provides over long distance the following:
  - Sensing element, and,
  - Power supply (light) transfer mean
  - Communications highway all in one

- High and flexible spatial resolution measurement
  - Discrete measurements with many Bragg gratings (strain sensors)
  - Distributed measurements with backscattering light interpretation
  - Easy integration/interface with subsea structural assets

- Compliant with subsea asset and associated environment
  - Generally subsea electric power is not required
  - Measurement not subject to electromagnetic interference
  - Not sensitive to humid environment

- Robust measurement
Discrete Strain Sensing Technology

- FBG “written” in to fibre core

FBG wavelength increases linearly with applied strain

Direct Strain Measurement
No Calibration Required
Discrete Strain Sensing Technology

Emitte light from light source

Reflected light received at different timeslots

Processor

Reflected light from FBGs

Sensor array

Light Source

Discrete Strain Sensing Technology
Fibre Optics for Point Measurements
DTS Measurement Principle

- Incident Laser Light
- Backscattered Light
- Laser Source
- Receiver
- Directional Coupler
- Fiber Optics Cable
- DTS System
- Brillouin Lines
- Strain
- Temperature sensitive
- Not Temperature sensitive
- Vibration
- Stokes Raman Band
- Rayleigh Band
- DTS Measurement Principle

ΔT

- Not Temperature sensitive
- Temperature sensitive
- Strain
- Vibration
- DTS System
- Laser Source
- Anti-Stokes Raman Band
- Directional Coupler
- Receiver
- Fiber Optics Cable

- Incident Laser Light
- Backscattered Light
- Brillouin Lines
- Strain
- Temperature sensitive
- Not Temperature sensitive
- Vibration
- DTS System
- Laser Source
- Anti-Stokes Raman Band
- Directional Coupler
- Receiver
- Fiber Optics Cable
Potential Distributed Measurements

<table>
<thead>
<tr>
<th>Scattering Effect</th>
<th>Attenuation</th>
<th>Temperature</th>
<th>Strain</th>
<th>Vibration</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rayleigh</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Raman</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brillouin</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Event</td>
<td>Bragg Grating</td>
<td>DSTS</td>
<td>hDSTS</td>
<td>DTS</td>
<td>DVS</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>---------------</td>
<td>------</td>
<td>-------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Local</td>
<td>NA</td>
<td>Global</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>VIV</td>
<td>Local</td>
<td>NA</td>
<td>Global</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Excessive loading</td>
<td>Local</td>
<td>NA</td>
<td>Global</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Shock Loading</td>
<td>Local</td>
<td>NA</td>
<td>Global</td>
<td>NA</td>
<td>Global</td>
</tr>
<tr>
<td>Force Monitoring</td>
<td>Local</td>
<td>Global</td>
<td>Global</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Shape Monitoring</td>
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<td>Global</td>
<td>Global</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Third party interference</td>
<td>Local</td>
<td>NA</td>
<td>Global</td>
<td>NA</td>
<td>Global</td>
</tr>
<tr>
<td>Fluid Properties</td>
<td>Local</td>
<td>Global</td>
<td>Global</td>
<td>Global</td>
<td>NA</td>
</tr>
<tr>
<td>Leak</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Global</td>
<td>Global</td>
</tr>
</tbody>
</table>
Event Detection

- Events along umbilical detected using
  - DSTS distributed strain and temperature sensing
  - DTS distributed temperature sensing
  - DVS distributed vibration sensing

- Top side equipment and software to learn how the umbilical performs and identify significant events

- From events identify leaks and report to operator

- Technology status
  - Distributed measurements exist and can detect changes
  - Working to improve the understanding of how operating environment will effect measurements
  - Taking measurements from laboratory to field
Illustration of Signals Strength from a Leak

- Signal Strength
- Temperature
- Vibration
- Noticeable Pressure Drop

Pin Hole | Small | Large | Pipe Diameter | Hole Diameter
Fatigue Tracking with Bragg Grating

- Using point strain measurements track strains at
  - approximately 8 Hz sample rate
  - at up to 50 locations per fibre optic strand

- Convert into orthogonal bending strains and determine fatigue damage along measured umbilical lengths

- Technological status
  - Fibre optics Bragg gratings used many times in the field for bending
  - Drift effects can be removed
  - Comprehensive coverage using multiple fibre optic strands and interrogators
Strain to Fatigue Damage

- Processed in real time using 20 minute samples
- Which results are required?
  - Cumulative fatigue damage
  - Fatigue damage rate
  - Stress histogram
  - Stress spectra
  - Stress timetraces
Schlumberger Private Fibre Optics Embedded into Composite Material
Flexible pipe annulus

- **Annulus**
  - Outer sheath: Damage → water ingress
  - Armours (carbon steel): Corrosion and fatigue → rupture
  - Pressure vault: Diffusion of water → ageing → rupture

- **Carcass**
  - Ageing → rupture
Schlumberger Flat Pack Cable

Single optical fibre containing multiple Bragg gratings in fibre optical bundle. Other optical fibres in bundle allow distributed measurements or are spare.

Extruded Plastic Coating

Distributed fibre optics in steel tubes
### Schlumberger Flat Pack Cables

<table>
<thead>
<tr>
<th>Braff Grating</th>
<th>Single Mode Cable</th>
<th>Multi Mode Cable</th>
<th>Point Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>Temperature (10 m res)</td>
<td>Strain, Vibration, Temperature (1 m res)</td>
<td>Distributed Measurement</td>
</tr>
<tr>
<td>Strain (10 m res)</td>
<td>–</td>
<td>Strain (10 m res)</td>
<td>Distributed Measurement</td>
</tr>
<tr>
<td>–</td>
<td>Vibration (10 m res)</td>
<td>–</td>
<td>Distributed Measurement</td>
</tr>
</tbody>
</table>

- **Fibre Optic Cable**
- **Steel Tube**
- **Extruded Plastic Casing**

**Distributed Temperature Sensing for DSTS**

**Strain Sensing**

**Distributed Vibration Sensing**
Strain Measurements in Pipelines and Umbilicals

- Strains measured on steel tube at four locations around circumference
- Four locations allows determination of bi-axial bending and tension

Schlumberger cables incorporated into the structure to enable strain, temperature and vibration measurements

Schlumberger design cables to enable fibre optic measurements of subsea structures
Example of Pipeline Incorporating Schlumberger Flat Pack Cable
## Generic Monitoring System for Cylindrical Structures

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Length</th>
<th>Spatial Resolution</th>
<th>Measurement Resolution</th>
<th>Accuracy, Precision</th>
<th>Sample Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>15 km</td>
<td>1 m</td>
<td>0.3 °C</td>
<td>±1 °C ±4 °C</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Vibration</td>
<td>100 km</td>
<td>10 m</td>
<td>-</td>
<td>-</td>
<td>5 seconds</td>
</tr>
<tr>
<td>Strain</td>
<td>50 km</td>
<td>10 m</td>
<td>&lt;40 με, 2 °C</td>
<td>&lt;150 με, 2 °C, 40 με, ±2 °C</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Point Strain</td>
<td>3 km</td>
<td>0.01 m (50 points)</td>
<td>0.8 με</td>
<td>&lt;50 με, 3 με RMS</td>
<td>8 Hz</td>
</tr>
</tbody>
</table>

Contains:
- 2 x strain free fibre optics
- 3 x fibre optic Bragg grating arrays
- 5 x strained fibre optics
Monitoring System Architecture

- Simplified diagram
  - Schlumberger flat pack cable
  - Fibre optic interrogators
  - Data logging and storage
  - Interpretation
  - Display
  - Remote storage
  - Off site access to data
Top Side System

- Flat pack cables connect to fibre optic interrogators
- Two hardware systems
  - Event detection
  - Fatigue tracking
- One display system
- One historian
Top Side Wiring

Control Room
- 12 fibre optic Bragg grating arrays to fatigue tracking
- 20 single mode and 8 multi-mode fibre optic cables to Event detection

Fatigue Tracking

Event Detection

Control Room Junction Box
- Transports 40 fibre optic cables from umbilical to control room
- Distributes fibre optics to control room

Cabling

Junction Box
- Terminates flat pack cables and connects to top side cables

Junction Box

Flat Pack Cable Tails
- Four flat pack cables run from umbilical to junction box.

Pipeline or Umbilical

Four flat pack cables run from umbilical to junction box.
Complete Pipeline Monitoring

- Schlumberger has been working with clients to realise complete pipeline and umbilical monitoring capability
- Providing real time
  - Event detection and identification,
  - Fatigue tracking
- Measurements a laboratory and field proven,
- The application is in development
- Field trials planned for 2014
Accuracy, Precision and Resolution

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>is the degree of exactness which the final product corresponds to the measurement standard.</td>
</tr>
<tr>
<td>Precision</td>
<td>refers to the ability of a measurement to be consistently reproduced. May also be termed noise</td>
</tr>
<tr>
<td>Repeatability</td>
<td>refers to the consistency of accurate results over consecutive measurements over time.</td>
</tr>
<tr>
<td>Resolution</td>
<td>the smallest increment that is digitally measured</td>
</tr>
</tbody>
</table>