Managing The Integrity Threat Of Subsea Pipework Fatigue Failure

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## Contents

- Vibration-induced fatigue as an integrity issue subsea
- Fatigue assessment of subsea equipment – the challenges
- Vibration of subsea systems - improving understanding
- A combined monitoring and predictive methodology for subsea equipment qualification
- Energy Institute subsea JIP
Vibration-induced fatigue as an integrity issue subsea
Topsides experience

UK Offshore industry - causes of pipework failure (topsides)

Source: UK Health & Safety Executive

- Degradation of material properties: 29%
- Incorrect installation: 21%
- Fatigue/Vibration: 21%
- Operator error: 4%
- Erosion: 9%
- Corrosion: 4%
- Inadequate isolation: 2%
- Inadequate procedures: 4%
Assessment of subsea systems to vibration-induced fatigue has been largely limited to vortex-induced vibration (VIV) of riser systems and unsupported pipeline spans (i.e. environmental loading).

Until recently, operational experience has indicated that vibration caused by internal flow (i.e. process excitation) has not been a significant issue subsea.

However, piping vibration due to process excitation has started to become an issue on manifolds and jumpers, in part associated with increasing flow rates.

Additional problems have been experienced with valves and instrumentation.
Internal flow induced excitation mechanisms

- Flow induced turbulence
- Pulsation: flow induced excitation (deadleg)
- Pulsation: flow induced excitation (rough bore risers/jumpers)
- High frequency acoustic excitation (acoustic fatigue)
- Surge/momentum changes due to valve operation
- Cavitation and flashing
- Vortex induced vibration
Flow induced turbulence

- Broad band, low frequency, excitation generated by turbulent flow through valves, expansions and bends
- Excitation of the low frequency modes of the piping system by energy transfer from fluid momentum to pipe wall
- Frequency range: typically up to 50Hz

Flow velocity vectors

Turbulent kinetic energy
Pressure pulsation

> Discrete frequency excitation generated by flow instability / vortex shedding
> Generally confined to ‘dry’ gas systems
> Frequency range: typically up to 300 Hz but can be as high as 1000 Hz

‘Dead leg’ side branch
Generation of vortices in the mouth of the branch which can ‘lock on’ to system acoustic resonances

Flexible riser / jumper
Discrete frequency excitation caused by ‘dry’ gas flow over the internal corrugations
Fatigue assessment of subsea equipment – the challenges
Challenges

‘Hidden’ threat

> No obvious sign that vibration is occurring (possible exception is flow induced pulsation from a riser, which may be heard topsides)

Difficulties in obtaining subsea measurements on existing equipment

> The ideal would be to measure dynamic strain at the fatigue sensitive locations
> In practice, on existing equipment, we can only measure vibration accelerations at ‘remote’ locations
> In-situ monitoring is expensive
> Limited ‘real-time’ capability

Uncertainties in simulation/prediction

> Level of excitation
> Coupling of excitation to piping system
> Mass loading/damping
Vibration of subsea systems - improving understanding
‘Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework’ were first published in late 1999.

Public domain methodology to assess the risk of a piping vibration issue.

In 2004, copyright of the guidelines was transferred to The Energy Institute (EI) and in 2005, a new JIP was initiated to update and improve the original MTD Guidelines document.

The second edition was published in January 2008. They are now known as the EI Guidelines (2nd edition).

Sponsors: BG, BHP Billiton, BP, ChevronTexaco, ConocoPhillips, LR, Nexen, Petrofac, Shell, Total, Health & Safety Executive
Flexible risers JIP (FLIP)

- Extensive small scale and full scale tests of corrugated carcasses
- Determination of influence of riser / jumper carcass geometry on:
  - Frequency content (Strouhal Number)
  - Pulsation amplitude
  - Onset velocity
- Identification of liquid content threshold above which flow induced pulsation does not occur
- Sponsors: BP, ExxonMobil, Shell, Statoil, Health & Safety Executive, Bureau Veritas
Project experience

> A number of projects have now been completed or are currently underway
> Simulation: prediction of excitation levels for each type of excitation mechanism and associated structural response (vibration acceleration/velocity and dynamic strain/stress)
> Measurement: practical experience gained of deploying suitable measurement systems
> Validation
  
  *Comparison of measurement and simulation
  *Improvement in understanding of key assumptions*
A combined monitoring and predictive methodology for subsea equipment qualification
Proposed approach
> EI Guidelines supplemented with flexible risers JIP methodology
> Information required: 
  > P&IDs 
  > PFDs 
  > Initial pipe support layout
> Provides a Likelihood of Failure (LOF) score for each excitation mechanism
> Actions determined based on LOF score
> Sensitivity to changes in process conditions and/or gross structural parameters (pipe diameter, wall thickness, degree of support) can be assessed
Simulation

> Detailed simulation requires knowledge of piping system layout, piping support and process conditions
> First step is the prediction of excitation levels for process condition(s) of concern
> Second step is the calculation of piping structural response (vibration accelerations/dynamic stresses) using finite element methods with the predicted excitation levels as input
> Key assumptions relate to:
  - Structural boundary conditions
  - Level of excitation
  - Coupling of the excitation to the piping
  - Structural damping
> Use of results to identify ideal measurement locations
Monitoring system specification

> Two principal types of monitoring system:
  Vibration acceleration
  Dynamic strain

> Key considerations:
  Bandwidth
  Dynamic range
  Anti-aliasing
  Phase relationship between sensor pods
  Transducer placement and installation / mounting
  Data recovery
Verification & validation

> Visual inspection of as-built piping system and verification against design, particularly piping supports
> Conducted in the construction yard once piping systems complete
> Modal testing of piping systems and support structure
  Non-intrusive technique
  Validation of boundary conditions used in simulation
  Identification of in-air structural natural frequencies, mode shapes and damping
  Determination of relationship between vibration velocity and dynamic strain at critical locations can also be obtained using temporarily installed strain gauges
Monitoring & assessment

> Monitoring results correlated with process data
> Results fed back into simulation to update model and determine global dynamic stresses and fatigue damage
> Use of simulation to predict response levels at future conditions
Energy Institute subsea JIP
Energy Institute JIP

- EI Subsea JIP for avoidance of vibration induced fatigue failure in process piping
- Funding in place via EI Scientific and Technical Committee (STAC)
- First meeting held 2nd June 2011
- Steering committee includes BP, Chevron, Nexen, Shell, Total, HSE, LR
- Objective: produce engineering guidelines for use at the design stage or when changes to existing systems are being contemplated
- Next meeting 10th January 2012
- Timeframe: draft for review Q1 2012
Independent, integrated thinking