Riserless Coiled Tubing Subsea Pumping Well Interventions

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Offshore Well Intervention
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Riser & Conductor Engineering

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Riserless Coiled Tubing Subsea Pumping Well Interventions - Best Practices and Limitations

Offshore Well Intervention Conference
22nd October 2015

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Agenda

- Introduction
- Configuration Description
- Operation and Design Issues
- Critical Sheave Locations
- Failure Mechanisms
- Strength Design Criteria
- Fatigue Design Criteria
- Fatigue Management Strategies
- Technology Gaps
- Conclusion

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Introduction

- Subsea acid pumping used to stimulation well production.
- Riserless subsea pumping well intervention is a lower cost alternative to traditional methods.
- Coiled Tubing over-boarded and suspended using a sheave or an injector head. This presentation is specific to sheave deployed.
- As with all emerging technology, there are new challenges that must be solved.
- Goal of presentation is to bring awareness to “blind spots” when performing coiled tubing subsea pumping.

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Traditional Well Intervention Comparison

Traditional Intervention Stackup vs. Riserless Intervention Stackup

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A vessel of opportunity is often selected rather than a traditional intervention vessel.

Reeled coiled tubing is deployed over a sheave through the vessel’s moonpool or over the vessel’s side.

Coiled tubing extends from the vessel to an elevation of approximately 25-75 ft above the mud line.

Sheave geometry controls the displacement controlled strain/loading condition.

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Seafloor Configuration Description

- A clump weight near the bottom of the coiled tubing limits the system’s dynamic response during installation and operations.

- Clump weight is required to straighten the coiled tubing as it passes over the sheave.

- Connected to the bottom of the coiled tubing is a flexible flying lead which connects to a subsea equipment package that provides access to the wellbore.

- The flexible flying lead is allowed to lie on the seabed between the coiled tubing and the subsea equipment package. Decouples the coiled tubing from the subsea assembly. 

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Operations and Design Issues

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The geometry of the sheave dictates the strength and fatigue response of the system.

A smaller sheave radius will induce the following:
- Increased low cycle fatigue damage induced during reeling;
- Increased residual stresses in the suspended region of the coiled tubing;
- Increased strains in “on sheave” sections of the coiled tubing induced by vessel motion.

Sheave diameter should be at least 48 times larger than the OD of coiled tubing [NORSOK D-002]

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Critical Sheave Locations

- A fatigue hotspot exists just below **Point B**.
- **Cannot** assume coiled tubing is tangent to the top and side of the sheave at Point A and Point B.
- If true, these points would instantly transition from finite to infinite curvature.
- Stiffness of the coiled tubing causes a “peel off” region.
- “Peel off” region shifts with vessel motions resulting in an area of low fatigue life.

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Wall Thinning and Material Flow

- Putting coiled tubing through plastic strains during reeling causes wall thinning.
- Why is it an issue?
- Reduces the tensile capacity of the coiled tubing string and lead to failure
- Typically fibers in compression experience more wall thinning

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Location of Fatigue Failures

- ~40% of fatigue induced cracks initiate along the fibers at the fatigue hotspot in tension. — Based on Study by Dr. Steve Tipton

- ~60% of fatigue induced cracks initiate along the fibers at the fatigue hotspot in compression.

- Majority of the fatigue induced cracking initiates on the inner surface. Failure sometimes referred to as pinholes.

- This means that visual inspections will typically not catch a fatigue induced crack until a rupture occurs. This behavior makes pre-operation analysis of coiled tubing extremely important.
Strength Criteria
Coiled Tubing Strength Criteria

- API-RP-5C7 (Coiled Tubulars) Section 5.2.6 is not valid because it does not consider the load history of the coiled tubing.

- Several strength checks that consider residual stress and displacement controlled loading conditions are presented.

- The industry consensus on the applicability of these methods is still ongoing under API-RP-17G2.

- Use and applicability of given strength criteria are project specific.

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Compression Check

- The low ratio of flexural rigidity (EI) to length makes coiled tubing susceptible to Eulerian buckling.
- As such, the system must remain in tension for its entire length.
- The compression check, per API 17G, must consider dynamic effects in the system.

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Strength Checks

- Current recommendation is to perform all 4.
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Method 1 – Displacement Controlled Loading Criterion

- API-STD-2RD Method 4 displacement controlled loading condition criteria.
- Assumes that the coiled tubing will never fail due to bending.
- Entire strength response governed by the local pressure gradient and the local effective tension.

\[ F_D \geq \sqrt{\left(\frac{P_i - P_e}{P_b}\right)^2 + \left(\frac{T}{T_y}\right)^2} \]

Where,
1. \( p_i \) is the internal pressure;
2. \( p_e \) is the external pressure;
3. \( p_b \) is the allowable burst plastic pressure;
4. \( T_y \) is the allowable axial plastic capacity;
5. \( T \) is the maximum tension in coiled tubing;
6. \( F_D \) is 0.90 for service limit state.

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Method 2 – DNV OS F101 Strain Criterion

- Strain limits provided by DNV as installation criteria
- Static and dynamic loading conditions

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<td>0.26%</td>
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Method 3 – Pressure and Tension Limits

- “Coiled-Tubing Pressure and Tension Limits,” written by K.R. Newman and D. Schlumberger
- Plot the pressure differential against axial tension
- All pressure differential and axial tension combinations within the working limit curve are deemed fit-for-purpose.

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Method 4 – Alternative Acceptance Criteria

- End user can prove the coil is fit for-purpose by providing:
  - Material and operational testing for the given system
  - An operational field history for similar interventions

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Fatigue Criteria

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Fatigue Damage Acceptance Design Criteria

- Coiled tubing undergoes low cycle and high cycle fatigue during its service life.
  - Low Cycle: Reeling Damage (<1000 cycles to failure)
  - High Cycle: Operational Damage (>1000 cycles to failure)

- **Problem:** Low and high cycle fatigue damage do not sum linearly.

- **Three Analysis Options:**
  - Linear Damage Rule
  - Non-Linear Damage Rules
  - Periodic Overload Curve
Miner’s Rule (Linear)

- Used to sum fatigue damage from same damage classification
  - High cycle + high cycle OR low cycle + low cycle

- \( D_T = \sum \frac{n_i}{N_i} \)
  - \( D_T \) is the total damage
  - \( n_i \) is number of cycles in a certain stress / strain histogram,
  - \( N_i \) is number of cycles to fail for that particular stress / strain amplitude in the stress / strain histogram.

- Miner’s rule is generally considered to be under conservative when assessing low and high cycle fatigue together

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Non-Linear Damage Summation

- **Converts** fatigue damage calculation of a given classification to an equivalent fatigue damage of the other classification.
- Fit curve; material testing encouraged.
- Loading sequence is important with the power rule.
- Power rule can be used without the above information by assuming conservative p-value and conservative loading sequence.

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Effective Strain-Life Curve with Linear Damage Rule (LDR)

- Used to create a composite fatigue curve that accounts for the effect of reeling cycles (overload cycles) on operational cycles.
- Typically used in the Automotive Industry.
- Developed by applying periodic overloads (reeling cycles) at certain maximum intervals so that all the applied high-cycle, low-strain (operational cycles) ranges are fully effective.
- When the specimen fails, an equivalent fatigue life for the low-strain cycles can then be obtained using LDR.

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Constructing the Effective Strain-Life Curve with LDR

Period overload curve de-rates the fatigue performance.

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Weld Type Fatigue Interpretation

Seam welds
- Critical to the manufacturing of the coiled tubing.
- Typically modeled as B2 in air S-N curve. Additional qualification recommended.

Bias welds
- Result of splicing sheets of steel during the manufacturing process.
- Helical in shape.
- Recommendation that an additional safety factor of three (3) is used.

Butt welds
- Circular welds
- Result of segments of the coiled tubing with defects being removed.
- Extremely fatigue critical.
- Not recommended.

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Case Study

- Predicted fatigue life can be less than a month at hotspot.
Fatigue Management Strategies

- Strategies given in this section can help operators and service providers:
  1. Ensure the safety of personnel, environment and assets;
  2. Accurately track fatigue damage;
  3. Possibly extend the service life of the coiled tubing string;
  4. Eliminate accidental discharges;
  5. And, ultimately reduce costs.

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FEA Based Fatigue Management

- FEA fatigue analysis performed for a range of expected environmental conditions.

- Results of the fatigue analysis used to generate expected fatigue damage rates for the range of environmental conditions.

- The theoretical fatigue damage rates generated from the FEA analysis can be in conjunction with seastate monitoring to determine a conservative accumulated fatigue damage value incurred in the coiled tubing in real time over the course of a campaign.

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Over-Reeling

- Coiled tubing is deployed to a deeper than prescribed depth and is reeled in a specified length at specific time intervals.
- This serves to alleviate fatigue damage accumulation at a specific location that is within the “hot-spot” region and shifts that point down the length of the coiled tubing.
- It is critically important to permanently mark the fatigue “hot-spot” locations on the coiled tubing in order to prevent or limit reuse of that segment of tubing within the fatigue “hot-spot” in the future.
- The coiled tubing should not be marked in any way that could damage the pipe and form a stress concentration. This would greatly reduce the fatigue life of the coiled tubing at that location.

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Technology Gaps

- Strength Criteria
- Fatigue Curve Refinement
  - High Cycle Fatigue Test Data
  - Industry Material Periodic Overload Curve
  - Sour Service Fatigue Data
- Post Service Testing

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Conclusion

- The analysis methodologies and operational guidance proposed are merely a step in the right direction.

- However, there is still much that remains unknown.

- Expanded material testing is recommended to truly understand the behavior of the coiled tubing as it relates to this application.

- It is the goal of the presentation to promote awareness of the technology gaps with the hope that their value to the industry, as a whole, is realized.

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