Mechanically Connected High Thermal Efficiency Pipelines

Reducing SURF Costs by 30%

How to rethink the installation of pipe-in-pipe
no more offshore welding with mechanical connectors
1. Introduction
2. Description of mechanical connectors
3. History and background
4. Qualifications
5. Flow-line specific challenges for connectors: mech. loadings, size & chemistry
6. Offshore assembly
7. Challenges with PiP
8. ITP PiP description
9. Onshore Construction process
10. Offshore timings
11. Conclusion
Mechanically Connected Pipe – History

  - Pipeline Connection Method and Effects on Deepwater Construction Operations – 1988
  - Mechanical Connections for J-Lay - 1993

- The first connected flowline (24in, 2km) was installed by BP in the Harding field using a Hunting Merlin© axial make-up connector.

  - Low cost pipeline connections systems
  - Connection testing specification joint industry project


- Deepstar, VIII CTR#8301 – “Mechanically Coupled Risers and Flowlines” in 2006.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Start of SCR connector joint development program with SBM offshore</td>
</tr>
<tr>
<td>2009</td>
<td>ISO 21329 full scale test program conducted in Houston</td>
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<tr>
<td>2010</td>
<td>ISO 21329 qualification witnessed and certified by DNV</td>
</tr>
<tr>
<td>2011</td>
<td>ICP development program for connected Risers initiated</td>
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<tr>
<td>2011</td>
<td>Award of first connected riser project for subsea mining application</td>
</tr>
<tr>
<td>2013</td>
<td>Award of Moho-Nord TLP tendon connector project</td>
</tr>
<tr>
<td>2013</td>
<td>API STD 2RD:2013 references ISO 21329 standard</td>
</tr>
<tr>
<td>2014</td>
<td>Development of 8-12” OD connectors for HPHT (15K-20K) applications</td>
</tr>
<tr>
<td>2014</td>
<td>GMC actively pursuing connected opportunities</td>
</tr>
<tr>
<td>2015</td>
<td>Award of Deepstar project for 15K Sour service DVT</td>
</tr>
<tr>
<td>2015</td>
<td>Award of North Sea Caisson replacement projects</td>
</tr>
<tr>
<td>2016</td>
<td>Installation of Moho Nord TLP – Zero LTI, Zero NPT</td>
</tr>
<tr>
<td>2016</td>
<td>Awarded 3rd North Sea Caisson replacement.</td>
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</table>
Features: Pin & Box Mechanical Connector

Competitive Key Features
- Concentrically Threaded (No Torque Connector)
- Multiple Metal-to-Metal Nib Seals
- Highly Fatigue Resistant (> DNV-C1)
- Fast Make-break Cycles & Recoverable
- Wide Range of Sizes (8” to >60”)

Distinguishing GMC Features
- Qualified to ISO 21329.
- ID & OD Preloaded Contact Shoulder
- Excellent Torsional Slip Resistance
- HPHT Ready
GMC Connector Make-up Process

https://vimeopro.com/gmcltd/gmc-limited/video/153877688
Patented Improvements to GMC Connector

- Elimination of ID Gap.
- Preload at both ID and OD.
- Reduced Stress Concentration
- Increased Fatigue Resistance
- More Sealing Redundancy
- Improved Torsional Resistance
ISO 21329 Qualification Process

DNV ‘Statement of Conformity’ to ISO 21329 “Petroleum and Natural Gas Industries – Pipeline Transportation Systems – Test Procedure for Mechanical Connectors

GMC Achieves Key Milestone: January 2010
The first mechanical connector to conform to ISO 21329:2004
Connector Qualification Parameters

- Pipe - 20” OD x 1.00” WT – API 5L X65 PSL 2 DSAW pipe
- Design Pressure - 2,250 psi (3,375 psi hydrostatic test)
- Connector – AISI 4130 (90ksi min. yield) GMC spec.
- DNV - C1 (RP-C203) class connector to pipe weld (double sided welds ground flush ID and OD.
- Fatigue test stress ranges
  - Low: 120 MPa
  - Medium: 148 MPa
  - High: 196 MPa
- Six sets of connectors tested at low, medium and high stress range (two at each)
- #2 (low stress range) and #3 (high stress range) had internal pressure of 2,250 psi
- Connector size (20in) for qualification selected based on target applications in SCRs, oil offloading lines and median range in the size scalability per ISO 21329 recommendations.
## Test Samples and Confidence Level

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Confidence Level</th>
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<tr>
<td></td>
<td>Normal</td>
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<tr>
<td><strong>Number of Test Samples</strong></td>
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<tr>
<td>Make, break and torque tests</td>
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<tr>
<td>Repeated make-up and breakout</td>
<td>1 to 4</td>
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<tr>
<td>Final make-up</td>
<td>All</td>
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<tr>
<td>Reverse torque</td>
<td>1 to 4</td>
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<tr>
<td><strong>Service load tests</strong></td>
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<tr>
<td>Installation tests</td>
<td>1 to 4</td>
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<tr>
<td>Hydrostatic pressure tests</td>
<td>1 to 4</td>
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<tr>
<td>Operational unrestrained tests</td>
<td></td>
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<tr>
<td>Total number of cycles, (N_c)</td>
<td>1, 3, 20, 100</td>
</tr>
<tr>
<td>Operational restrained tests</td>
<td></td>
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<tr>
<td>Total number of cycles, (N_c)</td>
<td>2, 4, 20, 100</td>
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<tr>
<td><strong>Limit load tests</strong></td>
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<tr>
<td>Pressure-to-failure test</td>
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<tr>
<td>Compression-to-failure test</td>
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<tr>
<td>Bending-to-failure test</td>
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<tr>
<td>Tension-to-failure test</td>
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<tr>
<td><strong>Fatigue tests</strong></td>
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<tr>
<td>Bending fatigue-to-failure test</td>
<td>2, 9</td>
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<tr>
<td>SL (Low Stress)</td>
<td>10, 11</td>
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<tr>
<td>SM (Med. Stress)</td>
<td>3, 12</td>
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<tr>
<td>SH (High Stress)</td>
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</table>
# ISO 21329 - Connector Test Matrix

<table>
<thead>
<tr>
<th>Test Article Identification &amp; Documentation</th>
<th>Test Article 01</th>
<th>Test Article 02</th>
<th>Test Article 03</th>
<th>Test Article 04</th>
<th>Test Article 05</th>
<th>Test Article 06</th>
<th>Test Article 07</th>
<th>Test Article 08</th>
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<th>Test Article 10</th>
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<th>Test Article 12</th>
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<tr>
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<td>Torque Resistance</td>
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<td>Hydrostatic + Bending</td>
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<tr>
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<tr>
<td>Limit Load Tests</td>
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<tr>
<td>Operation Unrestrained</td>
<td>Internal Compression</td>
<td>Axial Compression</td>
<td>Bending</td>
<td>Axial Tension</td>
<td>Internal Compression</td>
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<tr>
<td>Fatigue Tests</td>
<td>Fatigue Test Low Stress</td>
<td>Fatigue Test High Stress</td>
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<td>Fatigue Test High Stress</td>
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Make–Break & Torque Testing

Make–Break Testing

- Five sets of make and breaks per connector set
- A total of more than 60 make/break operations were performed with no galling or tooth damage

Torque Testing

Test Torque = 158.2 ft. kips

Test Torque = 158.2 ft. kips
Installation & Hydrostatic Load Testing

**Hydrostatic Testing:** Internal pressure (3,375 psi) with bending (1,328 ft. kips)

**Installation Test:** Bending - with/without external pressure (2,916 psi)
Operational Load Testing

Operational Unrestrained Loads
- 20 Load Cycles (bending + axial tension)
- Temperature Cycles
- Pressure Cycle (5 cycles)

Operational Restrained Loads
- 20 Load Cycles (axial compressive)
- Temperature Cycle
- Pressure Cycle (5 cycles)
Limit Load Testing

**Internal Pressure to Failure**
- pipe burst at 8,487 psi

**Axial Tension to Failure**
- Pipe failure at 4,337 kips & 1,934 psi (IP)

**Bending to Failure**
- Peak Bending Load of 2,200 ft. kips
Connected Pipeline – Advantages

- Significant increase in fatigue life (~10 times increase compared with field welded pipe)
- Enables use of higher strength pipe which enables reduction in pipe weight/top tension.
- Onshore pipe fabrication as opposed to offshore welding
- Faster, safe, reliable and high quality connections offshore.
- Reduced project duration, quicker field development.
- Use of cost effective installation assets
  - A vessel of opportunity can be used to reduce installation costs.
    - DP2 vessels with modular lay equipment
    - Existing S-lay or J-lay vessels
    - Well intervention vessels
    - Drill ships
- Reduced Project Risk
  - Weather
  - HSEQ
- Reduced Project CAPEX (>30% possible)
Questions with PiP

Connector wall thickness – close to 2"
- increases annular gap/outer pipe (ITP systems: $U=1 \text{ W/(m}^2\cdot\text{K)}@ \frac{1}{2}\text{“gap}$)
- impact of local heat leak path (flow assurance)

How to anchor inner and outer pipes together
- bulkheads are needed every so often @ 1 km spacing (typ)
  For J-lay – tensioning is possible (complex operation)
  For S-lay - (probably) requires welding of half-shells

Mechanical interactions inner/outer pipes&connectors
Cost (two sets of connectors/joint)
PiP is fabricated with compartmented annulus

Outer pipe is welded to inner pipe at every joint (single/double/quad)

Only one offshore weld/joint (or connector)
Offshore assembly – principle & process

Fast-curing resin
FJ sleeve
Pre-fabricated double or quad joint
2 min curing
ready to go

Sliding sleeve
Single offshore Weld
Integration of connector into PiP

Connector is compatible with interpipe weld spacing
Connector wall thickness compatible with sleeve sliding
No thermal effect of connector

Added benefits

- Sleeve protects against external impacts
- Resin in Field Joints locks connector against rotation

Two options for construction
Construction options

- Two welds on connector
  - Most compact design
  - Requires PWHT on both welds
  - Repairs are costly (discard)

- One weld on connector
  - Longer FJ / longer sleeve
  - Pipe-to-connector welds done off-site/different location
## FE analysis

<table>
<thead>
<tr>
<th></th>
<th>Connector</th>
<th>Cutback (mm)</th>
<th>Sleeve length (mm)</th>
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<tbody>
<tr>
<td>1</td>
<td>Butt weld</td>
<td>reduced</td>
<td>2000</td>
</tr>
<tr>
<td>2</td>
<td>Butt weld</td>
<td>700 mm</td>
<td>2400</td>
</tr>
<tr>
<td>3</td>
<td>GMC</td>
<td>reduced</td>
<td>2000</td>
</tr>
<tr>
<td>4</td>
<td>GMC</td>
<td>reduced</td>
<td>2400</td>
</tr>
<tr>
<td>5</td>
<td>GMC</td>
<td>700 mm</td>
<td>2400</td>
</tr>
</tbody>
</table>
- Efficiency on inner pipe: 156/128 = 1.22 (stress is higher in FJ than on inner pipe)

- Efficiency on outer pipe: 156/173 = 0.90 (stress is lower in FJ than on outer pipe)
- Efficiency on inner pipe: $\frac{132}{128} = 1.02$

- Efficiency on outer pipe: $\frac{132}{173} = 0.73$

  - Lowers FJ stresses (more bending moment carried by sleeve)
FE analysis – Connector - short sleeve

- More complicated stress map
- Efficiency on inner pipe: 1.8 -2.1 (high stresses in connector region)
- Efficiency on outer pipe: 1.2 – 1.5
  - High stresses but note material strength X100 (X65 in pipe main run)
- Efficiency on inner pipe: 1.1 - 1.3 (slightly higher stresses in connector region)

- Efficiency on outer pipe: 0.8 – 0.97
  - Longer sleeve alleviates stress concerns
- Efficiency on inner pipe: 1.3 - 1.8 (slightly higher stresses in connector region)

- Efficiency on outer pipe: 1 – 1.6
### FE analysis

- If FJ stresses were compared to inner pipe, stress ratios increase 35%
- Stronger sleeves favored, but all designs are workable with parent material X100

<table>
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<tr>
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<td>reduced</td>
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<td>1.2-1.5</td>
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<td>4</td>
<td>GMC</td>
<td>reduced</td>
<td>2400</td>
<td>0.8-0.97</td>
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<td>5</td>
<td>GMC</td>
<td>700 mm</td>
<td>2400</td>
<td>1-1.6</td>
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</tbody>
</table>
Pipe make-up is 5’ against 10-15’ welding arc time
No NDT – 5’
No High Integrity Coating (sandblasting+induction heating+coating) – 15’

Savings ~30’/joint (in single station J-lay)

Less crewing required
Other vessels possible (drilling rigs, heavy lift,…) → dayrate reductions
Mechanical connectors can be integrated into PiP Field Joints

There are little (no) changes to onshore PiP construction process

The FJ sleeve locks the connector against rotation and protects against bending and external impacts

The offshore installation rates can be significantly increased

Sizes range from 8" and up
Conclusion

Thank you!

Contacts

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