GE Flexible Pipeline Solutions
New Technologies to create New Opportunities

Alberto Matucci, CEO Wellstream – Subsea Systems & Drilling
Ray Burke, Product Leader Flexible Pipe
Rusty Justiss, General Manager - RoW
Keith Robertshaw, Commercial Leader Wellstream
Agenda

• Introduction to Wellstream

• Flexible Pipe Solutions: Where GE takes you today

• Integrity management: A New Approach to Risk

• New Frontiers: Where GE takes you tomorrow
What is a Flexible Pipe?
Wellstream Flexible Pipe

A Multi-Layer Pipe made from polymer tubes and wound steel helices – each one has a primary function

- **Carcass**: Prevents collapse under external pressure
- **Fluid Barrier**: Acts as the fluid sealing layer
- **Interlocked Pressure Armour**: Resists internal & external pressure
- **Pair of Contra-wound Tensile Armour Wires**: Provides axial strength
- **Insulating Layer**: Reduces heat loss
- **Outer Sheath**: Marine Barrier - and resists mechanical damage

© 2017 General Electric Company - All rights reserved
Flexible Pipe – Subsea Production, Injection, Export

Combines the strength and durability of steel pipe with the ability to handle wave and wind induced motion; often the only solution for Floating Production Systems

- Transfer lines link floating components
- Risers bring subsea production up to the platform
- Jumpers to connect wells to manifolds, or other structures
- Flowlines: long static lines for gathering or exporting fluids
Production and Delivery
Wellstream Production Facilities

Newcastle, UK
• Operational since 1997
• Capability and experience to manufacture the full range of offshore products from 2” - 16” ID
• Annual production capacity ~300nKm
• Drive to world class EHS and quality standards

Rio & Niterói, Brazil
• Serving Petrobras since the early 1990’s
• Commenced manufacturing in May 2007
• Annual production capacity of ~ 270nKm
• Product range: 2” to 12” ID
• Manufacturing systems replicate Newcastle
Brilliant Factory ... enabler for digital thread

Virtual Manufacturing (Model based Enterprise)
- Optimization of product models MFG process & systems
  - Visualise & Collaborate across disciplines
  - Virtual Validation - Find and Fix Issues Early and Digitally
  - Facilitates Electronic Work Instructions

Sensor Enabled Automation
- Improve utilization of machines, tools & people
  - Enabling Data driven analytics allowing decisions to be made faster
  - Automated Capture of Inspection & Test Data
  - Enables Predix

Factory & Supply Chain Optimisation
- Materials & sourcing optimization across business
  - Machine Connectivity
  - Leveraging 3D data with Product Manufacturing Information being utilised downstream from Engineering

PLM + ERP + MES are the foundations for Digital Thread
Rio Innovation Centre

Full Scale Test Facilities

- Hyperbaric Chamber (7500psi / 1.1m ID / 6m long)
- Dynamic Tension-Tension Test Rig (900tn / H₂S and CO₂ Capability)
- Bending & Tension Dynamic Rig (700tn dynamic / 1250tn Static)
- Burst Pit / Full Scale Corrosion Pit (30,000 psi / H₂S and CO₂ Capability)

Small Scale Test Facilities

- Special Mechanical Tests (Dynamic & Static H₂S and CO₂ Capability)
- Microscopy Lab (Optical / Stereo / SEM)
- Sour Service Testing
- High Pressure Corrosion Tests (H₂S and CO₂ Capability)
Newcastle Innovation Centre

- Dynamic Bending with Tension (DTR),
- Dynamic Tension-Tension
- Mid and Full-scale Thermal Cycle
- Dynamic and static bending
- Small-scale materials testing
- Ultra-high pressure testing
- Material testing laboratory

Recently commissioned full-scale Thermal Cycling with Bending Rig:
Capable of testing two samples at once, at a pressure of 400 bar, cycling temperatures between 130 and minus 25°C, and applying bending cycles to the pipes.

New in-plane bend testing rig:
Fatigue testing of part / full section pipe (without pressure); first 1.5M cycle test complete
Wellstream Capability & Track Record
Global System Analysis
Subsea Risk - Digital Assurance
Integrity Management – Hardware Capability

• Distributed temperature sensing
• Fibre optic fibres embedded within the structure delivering a full thermal history & detection of:
  • presence/location of flooding in the annulus
  • movement/loss of ancillaries (buoyancy/clamps)
  • overheating under the bend stiffener
  • rapid system/flow changes
  • onset wax/hydrate formation

• In-situ stress measurement
• MAPS® stress measurement technology; deployable as a monitor or inspection service for management of the integrity of the load bearing armour wires within the structure – ‘reach’ allows defect detection in otherwise inaccessible regions

© 2017 General Electric Company - All rights reserved
® MAPS is a registered trademark of GE Oil & Gas
Integrity Management in the Digital Environment
Managing risk, Maximising availability

A holistic concept encompassing embedded sensor technology, targeted inspection & operational data, managed within a digital portal for the optimisation of performance through the lifecycle.

Maximize Uptime, Optimise OPEX
Allow Planned Intervention
Support Flow Assurance
Manage Risk, Eliminate High Consequence Events
Provide Analytics for Life Extension
Regulatory – License to Operate

Aligned with a comprehensive service offer to complement the operator’s own integrity management processes.
Technology-Driven Solutions
Technology for Tomorrow

Product Portfolio expansion
- T-Profile pipe – Flip and Flow
- Heated lines – Expanded Capabilities

New HPHT polymers
- Targeting GoM Applications, new capabilities,

Deep Water applications
- Qualifying our pipe design for frontier applications

Composite Pipe
- Disruptive change in Flexible Pipe – Smarter competitive solution for new Frontiers
Anti-Flip Enhanced Flow Solution
Smother Flow & Faster Flow with T-Profile

Dual piece carcass developed to eliminate flow induced resonance in high-speed gas applications. T-profile also reduces head loss in flexible flowlines and risers.

Qualification testing:
• Pigging trials completed
• Dynamic cycling and wear testing
• Full industrialisation in progress
Laser Inspection

The bore of the 11.5-inch pipe was inspected using lasers housed inside the carcass mandrel. Three lasers were used. The lasers scanned the entire length of the manufactured pipe.

Ideal Formed T-profile Geometry

Result – Dramatic reduction in radial “corrugation” inside pipe
Comparing 10” Steel Pipe Flowrate to Flexible

For Methane gas
Inlet conditions; Pressure 16.5 MPa & Temperature 118°C
Mass flow rate = 83.3 kg/s (Based on 1.0215 m³/s flow at inlet)

<table>
<thead>
<tr>
<th>Carcass</th>
<th>API 17B</th>
<th>82x2 Carcass without T-Insert</th>
<th>82x2 with Unwelded T</th>
<th>82x2 with Welded T</th>
<th>Rigid Steel Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe ID (in/mm)</td>
<td>12 (305)</td>
<td>12 (305)</td>
<td>10.9 (277)</td>
<td>10.65 (270)</td>
<td>9.88 (251)</td>
</tr>
<tr>
<td>Inlet Flow Velocity (m/s)</td>
<td>14.0</td>
<td>14.0</td>
<td>17.0</td>
<td>17.8</td>
<td>20.7</td>
</tr>
<tr>
<td>Inlet Reynolds No.</td>
<td>2.02E8</td>
<td>2.02E8</td>
<td>2.22E8</td>
<td>2.27E8</td>
<td>2.45E8</td>
</tr>
<tr>
<td>Roughness (RMS)</td>
<td>1.213</td>
<td>3.201</td>
<td>0.593</td>
<td>0.368</td>
<td>0.0675</td>
</tr>
<tr>
<td>Relative Roughness</td>
<td>0.004</td>
<td>0.0105</td>
<td>0.0021</td>
<td>0.0014</td>
<td>0.0003</td>
</tr>
<tr>
<td>Darcy Friction Factor</td>
<td>0.00710</td>
<td>0.00963</td>
<td>0.00596</td>
<td>0.00530</td>
<td>0.00365</td>
</tr>
<tr>
<td>Pressure drop (MPa/bar)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isothermal Expansion</td>
<td>0.19 (1.9)</td>
<td>0.25 (2.5)</td>
<td>0.25 (2.5)</td>
<td>0.25 (2.5)</td>
<td>0.26 (2.6)</td>
</tr>
<tr>
<td>Adiabatic Expansion</td>
<td>0.19 (1.9)</td>
<td>0.25 (2.5)</td>
<td>0.25 (2.5)</td>
<td>0.25 (2.5)</td>
<td>0.26 (2.6)</td>
</tr>
</tbody>
</table>

*Based on RR calculated using API formula*  *Based on RR calculated using actual carcass RMS*  *Both compressible and incompressible analyses give same conclusion except lower pressure drop for compressible flow*
HPHT Solutions
High Temperature Polymer Development

Product driver

- Higher operating pressures at high temperature require a step change in barrier material.
- Material limits reached at extremes

New CR1404HTP™ Fluoropolymer

- Built from same chemical blocks as PTFE and PVDF.
- Contains no plasticiser so no risk of pressure sheath shrinkage

Benefits

- Reliable operation for design pressures 15kpsi and above
- Excellent crazing resistance & low temp. performance
- Chemical and blistering resistance demonstrate suitability for 150°C duty

Eliminates Crazing for 15,000psi and Above
Ultra – Deep Water Capability
Deepwater Collapse Enhancement

- New carcass machine - 22mm thickness
- Manufactured 18mm carcass to date
- Further profile and tooling under development.
The Drive to Deepwater
Extending the Capability Envelope

- 7½Ø × 1800mwd riser × 500 bar $P_{Op}$ – Gas Injection Riser (R181) – simulated service life testing end of 2017, 1Q 2018.

11"Ø × 2000mwd (R161 Bzl) Carcass Profile – collapse testing to be finished by 3Q 2016.

© 2017 General Electric Company - All rights reserved
Composite Solution
Composite Pipe - Pressure Armour

- High pressure capacity
- Well known and trusted materials
- State of the art manufacturing
- Simplified design
- Optimised material usage
- Flexible and fatigue resistant
- Mature and proven end terminations
Riser System Optimisation

- Top end tension reduction
- Optimise platform capacity vs no. of risers
- Simpler bend stiffener design due to less onerous requirements
- Reduced buoyancy requirements
- Installation time saving
- CPA optimised to meet TDP demands
- Reduction in weight & top tension allows increased free hanging catenary length
- Reduced overall pipe diameter improves dynamic stability

© 2017 General Electric Company - All rights reserved
Next Generation Product Value

Product Features:
- Efficient High Pressure Large Diameter Deepwater Solution
- 30% less weight bringing benefit across value chain
- Simplifies configuration; reduces buoyancy
- Proven Reliable End-fitting technology

Logistics:
- More efficient logistics, more pipe per reel

Installation:
- Cheaper and faster, more pipe per vessel
- Facilitates wider range of construction vessels
Live Case Study: GoM HP Water Injection Riser

Global Analysis for customer to determine benefit of improving flexible pipe solution with GE composite pressure armour

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>15,000 psi</td>
</tr>
<tr>
<td>Water Depth</td>
<td>2150 m</td>
</tr>
<tr>
<td>Temperature</td>
<td>40°C</td>
</tr>
<tr>
<td>Pipe ID</td>
<td>7.5&quot;</td>
</tr>
</tbody>
</table>

Key Technical Impacts

- Riser Total Length: 4400m
- Riser Unit Weight: -30%
- Total Riser Length: -30%
- Buoyancy: -75%

Standard Pipe

Composite Pipe

Riser Total Length: 3000m
Multi-scale Qualification

- Components (full-scale pipe)
- Sub-components (mid-scale pipe)
- Details (wire/composite features)
- Elements (e.g., as mfg. composite)
- Coupons (e.g., flat coupons)

Hoop / Pressure

Flexural/Bending

Generic

Non-generic

Structural Features

Database
Composite Product - Program Timeline

- **GE’s Bonded CPA concept conceived**
- **Coupon properties and RPSEA Award**
- **Static testing and manufacturing results OTC 2013 24160**
- **Compression and TDP analysis OMAE 2014 23579**
- **Ageing and RGD completed OTC-2014 25393**
- **Defect detection monitoring system developed IHTEC 2014**
- **Mid-scale testing completed OTC 2015 25753**
- **DTR and TCR sample testing**
- **First full-scale ATL manufacturing module procured**
- **Full-scale ATL module commissioned**
- **Full-scale testing and qualification completed**

- **Completed**
- **In progress**
- **Final Target**
Wellstream
A Global Supplier of Unique Solutions

Composite pipe – Lighter Deeper Smarter Faster Riser solution

High-Pressure High-Temperature Materials (15-20ksi, ≈150ºC)

T-Profile carcass smoother flows at higher velocities – more for less …

Integrity Management: Smart Pipe, MAPS inspection embedded sensors