Designing Safe and Reliable HPHT Subsea Wellhead Systems

New Technology to Accommodate a System Approach to Verification Analysis and Validation Testing

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Outline

• HPHT Systems Requirements and Challenges

• Wellhead System Overview
  - System Verification Analysis
  - System Validation Testing – New Horizontal Test Machine

• New HPHT Wellhead System Design Concept

• Advanced Product Quality Planning (APQP)

• Conclusions
HPHT Subsea Systems

- **Requirements**
  - Pressure > 15 Ksi (103.4 MPa) and/or Temperature > 350°F (176.7°C)
  - Higher Structural Load Capacity Requirements
  - Longer Fatigue Life Requirements
  - Need for Next Generation HPHT Equipment

- **Challenges**
  - Uncertainties with Environmental Effects on Material Properties
  - Lack of HPHT Material Properties at Different Environments
  - More Stringent Regulatory Requirements for Verification Analysis and Validation Testing
  - New Tools and Technology Needed
The Wellhead is the topmost component of a well, suitable for the life of the well, non-retrievable, and provides:

- External Load Resistance
- Pressure Containment
- Pressure Controlling Interfaces
- Hanging Interface & Weight Support
- Fatigue/Cyclic Load Resistance
- Barrier to Environment
Verification Analysis

- Traditional (Hand Calculations, Equivalent Tension, 2D FEA)
- Advanced (3D FEA)
Equivalent Tension/Compression

CAPACITY CHART: INTERNAL PRESSURE VS. BENDING WITH TENSION/COMPRESSION

Limitations
- Equivalent Radius
- Compression Side of Bending
- Combined Load Effects
- Non-Axisymmetric Features (dog segments, etc.)
- Two capacity points determined with hand calculation cover all combined loads.
- Etc.

Selection of equivalent radius can affect calculated capacity by approximately 40%
3D FEA Capacity Chart

INTERNAL PRESSURE VS. BENDING WITH TENSION/COMPRESSION AND PRESSURE END LOAD

- Tension
- Compression
- Rated
- Extreme
- Survival

W/O PEL
W/ PEL

Pressure End Load (kips)
Internal Pressure (ksi)
Bending Moment (ft-lbf)

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Wellhead System Global Analysis

- **Loading Conditions**
  - Mechanical Preload
  - External Loads
  - Pressure
  - Pressure End Load (i.e. shear rams closed)
  - Casing Program & Weights
  - Thermal Loads
  - Cyclic Loads

- **3D FEA Model**
  - 200 ft Below Mudline
  - Non-linear Geometry Behavior
  - Over 1 Million Elements
  - No Tied Constraints
  - Modeled with Cement
  - Soil Properties
  - Installation sequence closely mimics field conditions

- **Static and Fatigue Evaluation**
Wellhead System
- Assembly:
  - Wellhead Connector
  - Low Pressure Housing
  - High Pressure Housing
- Process:
  - Preloaded System
  - 6MM lbf. Casing Weight
  - Apply Loads per Capacity Chart
  - Results Comparison
  - Inspection
  - Third Party Witness

Horizontal Test Machine Load Capacity
- $20 \times 10^6$ ft-lbf ($27 \times 10^6$ N•m) Bending
- $13 \times 10^6$ lbf ($57.8 \times 10^6$ N) Tension/Compression
- $6 \times 10^6$ lbf ($26.7 \times 10^6$ N) Simulated Casing Loads
- Combined Loads
Wellhead System Post-Test Inspection

Compression

Connector Hub Face and Load Shoulders

High/Low Pressure Housing Bending Reaction Ring

Tension

Connector Load Shoulders

High/Low Pressure Housing Load Shoulder Interface

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20Ksi Wellhead Connector

- 35” OD Wellhead Mandrel.
- ~Twice Rated Capacity of the 15ksi Connector
- ~10 Times More Fatigue Life than Traditional 15ksi Connector
- 20 Ksi (137.9 MPa) Rated Pressure
- > 20×10^6 ft•lbf (27×10^6 N•m) Survival Bending Capacity
Advanced Product Quality Planning

APQP Process

- **Voice of the Customer / Critical to Quality (CTQ)**
- **Design**
- **Process Flow Diagram**
- **Process Failure Mode Effect Analysis (PFMEA)**
- **Process Control Plan (PCP)**
- **Design Failure Mode Effect Analysis (DFMEA)**
- **Design Failure Modes**
- **Process Failure Modes**

- “What” are the product requirements? Specified by customer.
- “How” do we address the product requirements? Specified by Dril-Quip.

How do we produce the product?

How does the process fail to produce the product as designed?

How does the design fail to satisfy the key product characteristics & not reduce failures?

How do we manufacture the product?

How does the process fail to satisfy the key product characteristics & not reduce failures?

How do we guarantee the process meets the critical product characteristics?

What happens if design & process risk assessment tasks are not done?
Conclusions

• A wellhead system verification analysis and validation test has been successfully completed and provided better understanding of the wellhead system performance.

• System validation testing provided critical information needed to make proper adjustments to the verification analysis methodology.

• Knowledge obtained from this test program is being applied for HPHT development work of 20 Ksi (or higher) subsea systems.

• A new 35” wellhead system/connector design concept is presented with structural capacity and fatigue resistance characteristics expected to meet the HPHT industry needs for the next decades.

• APQP implementation is key for safe and reliable equipment at HPHT environments.
Thank You!

Questions?
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