17TR8 – HPHT Design Guideline for Subsea Equipment

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In the Beginning...

**API 6HP** – primarily focused on burst before leak and 25k BOP equipment being too heavy – $1.5 \times RWP$ vs. $1.25 \times RWP$? External hydrostatic pressure to compensate?

Next was **API PER 15K** to identify all wellbore issues and challenges associated with HPHT (anything above 15k RWP) from sand face to pipeline – looked at things holistically

But PER 15K points to the problems that each API Subcommittee needs to address – never intended to “solve” them… *it is not a design guideline*

**API 17TR8** is Subsea’s attempt at providing some of the guideline solutions.
Holistic View – 1PER15K-1
Tells you what to be looking out for...

Figure 1—System Analysis Specification Breaks (Completion)

Figure 2—System Analysis Specification Breaks (Drilling)
How is HPHT Defined? What Code Rules?

Source: OTC 17927, 23943, 25376
When is a Pressure Vessel Thin or Thick-Walled?

Lamé decided that a pressure vessel should be considered ‘Thick-Walled’ if \( t/d > 0.05 \)

As a very rough guide Lamé’s criteria makes pressure vessels up to 5000 psi are Thin-Walled and most pressure vessels greater than 5000 psi are Thick-Walled.

ASME decided that a pressure vessel should be considered ‘Thick-Walled’ if \( r/t \leq 4 \)

As a very rough guide ASME’s criteria makes pressure vessels up to 10000 psi are Thin-Walled and most pressure vessels greater than 10000 psi are Thick-Walled.
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**Thin-Walled Pressure Vessel Model – Leak Before Burst**
Division 2

**Thick-Walled Pressure Model -Fast Fracture Failure**
Division 3

Lamé July 22, 1795 - May 1, 1870
15k to 25k a design transition zone

Thicker wall sections changes the “pressure vessel model”, but where? Don’t know where leak before burst ends and fast fracture failure begins.

Source: OTC 23621
17TR8: The HPHT Method

- Design Methodology – roadmap for transition from Div 2 to Div 3
- Populate oil field material data sheets at elevated temperatures
  - Establish physical properties and QA lists
- Establish HPHT validation tests
  - Extended function testing standard
  - Guidance for project specific testing
17TR8: HPHT Design Flow Chart

Note 1: Maximum temperature = 550°F
Note 2: - Ref. Section 5.4.1
   - Based on ASME Div. 2 Section 5.5.2 or equipment's functional specifications

“All codes are created equal: some more equal than others”
17TR8: HPHT Design Flow Chart

API 6A/6X, 17D

1.5xRWP

ASME Div 2

ASME Div 3

Path selected determines: Test pressure, Design margins, QA

“All codes are created equal: some more equal than others”

Note 1: Maximum temperature = 550°F
Note 2: Based on ASME Div. 2 Section 5.5.2 or equipment’s functional specifications
Quality and Qualification Requirements

“Buckets” to capture physical properties and performance tests:

PSL 5 to address tighter QA requirements in material strength (± range), ovality, cross section thinning, chemistry, prolongations, stress relaxation properties, etc.

PR 3 to address extended functioning component at HPHT conditions; gas test medium, blow down safety, more temperature cycles, etc.

PR 4 to address cyclic loading, fracture mechanics S-N fatigue, criticality and project specific cyclic design life
17TR8: HPHT Materials Properties

Design Properties *

- **Mechanical Properties**
  - Tensile Properties (including tensile modulus)
  - Fracture Toughness ($K_{1c}$) ***
  - Crack Growth Rate (da/dN)***
  - Fatigue S-N curve***

- **Physical Properties**
  - Thermal conductivity
  - Specific heat capacity
  - Density
  - Thermal expansion
  - Poisson Ratio
  - NACE Test (2% or defined strain limit)
  - Stress Relaxation

Quality Control **

- **Chemistry / Composition Requirements**
- **Mechanical Properties**
  - Tensile Properties (tight range)
  - Charpy, CTOD
  - Hardness

- **Microstructure and Grain Size**
  - NDE
  - Minimum Crack Size

- **Process Control**
  - Melting, Forging
  - Heat Treatment, QTC Prolongation Testing
  - Dimensional – Ovality, Thinning

* For discrete temperatures 75, 350, 450, 550, 650 F
** For QC temperatures defined by ASME VIII, Div 3
*** at H2S, CO2, seawater conditions
17TR8: Seals and Fasteners

- Stress Relaxation defeat seal contact force?
- Thermal growth changes seal pocket geometry and different thermal expansion rates between seal and base material (seal pocket) may defeat or fatigue seal
- Corrosion (H₂S - CO₂, etc.) environment masks fatigue failures; need to investigate separately
Fatigue Assessment:

• Determine if equipment is fatigue sensitive
  ▪ ASME fatigue screening criteria (ASME Div. 2 Section 5.5.2)
    ▪ internal – pressure/temperature; external – mechanical

• Fatigue analysis:
  ▪ S-N approach
  ▪ Fracture Mechanics (FM) approach

• May require:
  ▪ Load-monitoring
  ▪ NDE method capability and its probability of detection (PoD) to identify flaws
  ▪ Multiple flaws assessment

Non-uniform stress field – gray “above yield”
Autofrettage Effect
Source: OTC 23063, 23621
• Both Leak or Burst are catastrophic events because it’s hard to turn off a reservoir.
• Need a different differentiator
• Oil industry has “two barrier” rule for safe operation.
• Locations where a fatigue failure could compromise primary barrier are critical and more detailed analysis – fracture mechanics
17TR8: HPHT Validation

- Can define within a “standard”
- Additional Function Testing
  - Extended testing at Temperature

- Can’t define within a “standard”
- Fatigue Design Requirements
  - S-N Curve for machined parts, welds, notches, etc.
  - Fracture Mechanics
    - Define crack size, material toughness
  - Define cycle life and cyclic testing
- FMECA of Critical Components
  - Additional project specific tests
Future of 17TR8

- First edition to be balloted for publication in 2014
  - Get the word out on HPHT Materials Properties at temperature
- Second edition - work still to be done in 2014 - 15
  - Welding and cladding and associated crack design issues
  - Refine cyclic and fatigue analysis
  - Add Sensors and Monitoring for cycle life
  - Systems engineering of spec breaks and interfaces
  - Work with ASME Div 3 to submit a “code case”
Thank You / Questions

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