Friction Grip in Wellheads: An Innovative Approach to Load Support & Sealing

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Introduction to Plexus Ocean Systems

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Who is Plexus?

- Plexus Ocean Systems Limited rents and sells wellhead products and associated equipment to a number of major oil & gas operators.

- Plexus products utilize patented POS-GRIP technology to “grip” tubular components.
Plexus Today

• Offices in Aberdeen, London, & Malaysia
• Publicly traded on London AIM
• 70+ worldwide employees
• In year ending 30 June 2009:
  • 14% increase in turnover to £15.1m
  • Profit before tax of £1.8m
  • Less than 2% of global wellhead market share
Introduction to Conventional Wellhead Technology

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The Wellhead Industry

- The wellhead industry is mature, large, and regulated
  - Global market for wellhead equipment is over £1 billion / annum
  - Major wellhead suppliers include Cameron, Dril-Quip, FMC, GE Oil & Gas (Vetco), Wood Group.
  - Standard wellhead design regulated by API 6A & API 17D
What is a Wellhead?

- A wellhead is the pressure-containing end connection of a well which:
  - Provides a connection point for the Blowout Preventer (BOP) equipment while drilling a well
  - Provides a connection point for the X-mas Tree equipment while producing a well
  - Seals the annulus between casing strings
  - Suspends multiple casing strings
Conventional Wellhead Hanger Support Technology

Mandrel Wellhead
- Casing supported by hanger landed on shoulder
- Fixed landing point
- Casing hanger can be run through BOP stack
- Enables use of high-grade metal-to-metal seals

Slip & Seal Wellhead
- Casing support through slips
- Adjustable landing point
- Requires BOP stack to be lifted to cut casing
- Resilient seals only
Wellhead Location

This presentation will focus on surface wellheads

Exploration well  OR  Production well

Surface wellhead

OR

Subsea wellhead
Drilling from Jack-up Rigs w/ Mudline Suspension

Surface Wellhead:
- Supports little casing weight
- Seals annulus
- Provides BOP interface

Mudline Suspension:
- Supports most casing weight

Fixed distance means space-out is required
Development of POS-GRIP Exploration Wellheads

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  • The Future (POS-GRIP subsea & connectors)
The idea: an adjustable surface wellhead for use above mudline suspension systems on jack-up drilling rigs
Existing Adjustable Wellheads

- Slip & Seal Wellhead
- Adjustable Shoulder Wellhead
- Adjustable Casing Sleeve
POS-GRIP Friction-grip Wellhead Concept

‘Type 1’

‘Type 2’
POS-GRIP Friction-grip Wellhead Concept

‘Type 1’

‘Type 2’
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‘Type 2’
POS-GRIP Wellhead Technology

POS-GRIP is a method of supporting oil field tubulars with an externally activated radial friction grip. In wellheads, POS-GRIP replaces the conventional casing slips or landing shoulders.

Contact Stress at interface: $Q$

Coefficient of friction at interface: $\mu$

Contact Area at interface: $A$

Load Capacity = $Q \times \mu \times A$
Materials in a POS-GRIP System

- **Wellhead Housing Body Requirements**
  - Low Young’s Modulus
  - Corrosion resistance & NACE compliance

- **Compression Ring Requirements**
  - High Young’s Modulus & high strength

- **Compression Collar Requirements**
  - Little distortion when split

- **Hanger Requirements**
  - High Young’s Modulus & high strength
  - Corrosion resistance & NACE compliance

- **General Requirements**
  - Cost, availability, etc.
• Consider load-supporting friction interface
  • Need as high a static coefficient of friction as possible
  • WH bore or POS-GRIP element surface kept ‘smooth’
  • Hanger OD should be ‘rough’ to maximize friction: many potential options exist
Small-scale friction testing

• Which ‘rough’ hanger surface to use?
  • Test & assess several profiles in small-scale testing
  • Test multiple samples of each potential profile
  • Measure load capacity & ‘bite’

Shear Load

Normal Load

Measure block travel
Hanger Design: Friction Profile Selected

• Design hanger outer diameter:
  • Biased tooth profile selected as ‘standard’
  • Incorporate flutes through the toothed area so fluid returns can flow past hanger when it is being run
  • Annulus seal profile above gripping section
Grip Coefficient

• Rough profile ‘bites’ into smooth profile:
  • Grip coefficient ($\Phi$); not coefficient of friction ($\mu$)
  • Frictional load support & shear strength combined
  • Values must be determined empirically
  • Local plastic deformation in WH / POS-GRIP element bore
Load Capacity Calculation Method

Load Capacity = Grip Coefficient \times \text{Contact Stress} \times \text{Contact Area}

- Contact stress determined by various engineering methods
- **External** pressure at friction interface **decreases** contact stress
Load Capacity Calculation Method

Load Capacity = Grip Coefficient \times \text{Contact Stress} \times \text{Contact Area}

- Contact stress determined by various engineering methods
- **Internal** pressure at friction interface **increases** contact stress
Tolerance Study

• 3 critical interfaces, over 6 critical dimensions in load path
• Strong dependence of load capacity on tolerance stack-up
• Must ‘over-design’ to have sufficient capacity in worst-case tolerance stack-up

Compression ring / collar interface

Compression collar / WH body interface

WH body / hanger interface
POS-GRIP Activation

• Activation applied via hydraulic stud tensioners
• ‘Load control’ could ‘eliminate’ tolerance stack-up, but...
• ‘Distance control’ is operationally far easier
• ‘Distance control’ with feedback?
Physical Test w/ FEA Correlation

• Verify 6 million pound load capacity of 18-3/4” system
• Test in several different configurations, under several different loadings
• Compare strain gauge data to 3D FEA results
• Designed for up to 15 ksi exploration wells (short-term, high-pressure)
• Between 45 & 72 hours saved compared to conventional equipment for 18-3/4” size (up to 2 BOP lifts eliminated)
• First installed 1998
• Through end of 2009:
  • Over 70 13-5/8” 10K systems installed
  • Over 25 18-3/4” 15K systems installed
Development of ‘HG’ Production Wellhead

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    (POS-GRIP subsea & connectors)
New Market: Long-Term Use in Production Wells

The aim: Re-engineer the existing systems for use on production wells

- 1997: POS-GRIP patented in UK
- 1998: First 13-5/8” 10 ksi WH installed
- 2000: Design exercise f/ 18-3/4” 15 ksi WH’s initiated
- 2004: First 18-3/4” 15 ksi WH’s installed in North Sea
New Materials

• Long-term production life makes the requirement for corrosion resistant alloys (CRA’s) common
• Hanger body materials most affected
• Most common CRA, Alloy 718, is:
  • Slower to machine
  • Requires plasma ion nitriding instead of gas nitriding
  • Reduced grip coefficient
• Biased teeth limit lockdown capability; Therefore change to symmetrical tooth profile
• Test grip coefficient to verify capacity of new profile
Fatigue Study

- Fatigue testing in conjunction with the University of Aberdeen
- Study fatigue performance of unbiased tooth profile:
  - 2 samples each at 2 separate contact stresses
  - Cycled between 40% & 80% of static failure load
  - 1 million cycles at 3Hz frequency
  - 1 test sample in each contact stress taken to static failure after cycles

\[ F_{\text{max}} = 80\% \text{ of static load capacity} \]
\[ F_{\text{min}} = 40\% \text{ of static load capacity} \]
Fatigue Study Results

• No degradation of applied load / movement profile over cycles
• Static failure test after fatigue tests produces grip coefficient result no less than result achieved in static conditions.
POS-GRIP ‘HG’ Sealing

• Takes advantage of already-present high-contact stress, forced-concentric bore, & rigid lockdown
• Built into outer diameter of hanger, so a seal is only needed at one interface (instead of two)
‘HG’ Seal Qualification

- Test program designed to simulate temperature (250 deg. F) / pressure (15 ksi) cycles expected over field life
- Standard API 6A Appendix F test cycle + 10 temperature cycles + another API 6A Appendix F test cycle
‘HG’ Production WH

•Designed for up to 15 ksi production wells (long-term)
•Available in 13-5/8” & 18-3/4” sizes
•Utilizes 15 ksi-rated metal-to-metal ‘HG’ seals
•First installed 2005
•Nine installed through 2009
Development of 18-3/4” 20 ksi Wellhead

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The aim: Take the proven 18-3/4” 15 ksi production system & adapt it for use in a 20 ksi environment

- 1997: POS-GRIP patented in UK
- 1998: First 13-5/8” 10 ksi WH installed
- 2000: Design exercise f/ 18-3/4” 15 ksi WH’s initiated
- 2004: First 18-3/4” 15 ksi WH’s installed in North Sea
- 2005: 15 ksi ‘HG’ seal qualification testing complete
- 2005: First ‘HG’ wellhead installed in North Sea

**Extended Seal Qualification**

- ‘HG’ seal to be requalified to 20,000 psi, 0 – 350 deg F
- Extended field-life service, similar to 15,000 psi qualification
- New test arrangement allows heating & cooling of test fixture internally, to best simulate real-world conditions
Additional FEA – High-Pressure Concerns

• Confirmed static component stresses & contact stresses in new design

• Planned consideration of dynamic aspects of loading by performing:
  • Limit load FEA
  • Elastic shakedown
  • Fracture mechanics FEA
States of Stress: No Internal Pressure

States of stress in a POS-GRIP wellhead are fundamentally different to those in a conventional wellhead.

<table>
<thead>
<tr>
<th>von Mises equivalent stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 psi</td>
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</table>

Pressure in WH bore = 0 psi

Compression rings in Tension

WH Body in Compression

Mandrel Wellhead

POS-GRIP Wellhead
States of stress in a POS-GRIP wellhead are fundamentally different to those in a conventional wellhead.

**States of Stress: Internal Pressure**

**Mandrel Wellhead**
- Large Change in State of Stress, WH in tension
- Pressure in WH bore > 0 psi

**POS-GRIP Wellhead**
- Little Change in State of Stress
- WH Body remains in Compression
- Pressure in WH bore > 0 psi
Plexus 20 ksi rated Surface Production Wellhead

- Designed for 20 ksi production wells (long-term, high-pressure)
- Initial design / proof of concept complete
- 20 ksi ‘HG’ metal-to-metal seal qualification in progress
Future POS-GRIP Applications

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The Aim: Extend POS-GRIP’s use into still more challenging environments

1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

1997: POS-GRIP patented in UK
1998: First 13-5/8” 10 ksi WH installed
2000: Design exercise for 18-3/4” 15 ksi WH’s initiated
2004: First 18-3/4” 15 ksi WH’s installed in North Sea
2005: 15 ksi ‘HG’ seal qualification testing complete
2005: First ‘HG’ wellhead installed in North Sea
2008: Contract awarded for design of 20 ksi WH
The Future: M2S Subsea Conversion

• First use of POS-GRIP subsea
• First system installed in 2008
• With full metal-to-metal production casing string sealing, converted mudline suspension to 13-5/8” 5 ksi subsea wellhead
The Future: HPHT Subsea TB

• Subsea connector to allow tieback to pre-drilled HPHT well
• Metal-to-metal ‘HG’ seals
• Joint-industry partnership kicking off in 2010
Any Questions?

Thanks for your time

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