LEAK-PROOF WELLHEADS - A MATTER OF CONTROL

Ben van Bilderbeek, CEO of Plexus Holdings plc.

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Background

For more than two hundred years the oil and gas industry provided the energy to enable three industrial revolutions, which have given the world the prosperity it enjoys today.

Despite today’s necessary growth of alternative and renewable energy sources, hydrocarbons for practical and economic reasons will continue to play a significant role for generations to come. However, things must change, to respond to urgent questions from the environmental lobby and activist investors, who have real concerns about the future role of the oil and gas industry and investment therein.

From the perspective of the well site, it is imperative for the reputation of natural gas in a decarbonizing world, to credibly demonstrate during this early phase of the energy transition, that near zero methane emissions are achievable. This is a competitive differentiator for operating companies.

For wellheads, today’s focus is on technical solutions that help reduce emissions at the wellsite, aiming at a ‘net zero’ target, with sound and verifiable technologies, that positively impact the supply chain.

There is no doubt that conventional technologies have served our industry well, developing amazing solutions for production, under the most challenging conditions imaginable. However, technological improvements must continue to be made, particularly bearing in mind genuine concerns about the negative impact of hydrocarbons on the environment.

In the case of wellheads and their sealing capabilities, a new method of engineering has been developed, which applies for both surface and subsea well applications. The technology is based on sealing principles as derived from Hertzian Stress Theory, which was introduced by Heinrich Hertz in 1882, with the publication of the paper "On the contact of elastic solids".

This development is particularly relevant for natural gas, which is still considered the cleanest hydrocarbon to combust in terms of CO2 emissions and a major contributor in the effort to reduce the greenhouse effect. This, until recently, accepted norm about the green credentials of natural gas has recently been placed under the microscope by those promoting a more rapid conversion to renewables.

The challenge is clear. Although natural gas is cleaner when it burns by emitting only half the level of CO2 as compared to oil and coal, the process of extracting and delivering gas along the supply chain involves leakage of un-combusted methane, which even at relative low levels wipes out its cleaner burning advantage.
Introduction

The phrase “leak-proof by design” conveys that if well-known and long-established engineering principles are used, then life-cycle integrity for metal-to-metal wellhead seals is possible, which eliminates uncertainty and lowers Totex (i.e., Capex + Opex).

Because a major cost component for wellheads during their life cycle, is associated with maintenance and the resulting loss of production, scientific solutions targeted at delivering “Net-Zero” supply chain emissions can deliver unexpected dividends, by reducing life-cycle cost.

Lower Totex is a key incentive for operators and helps justify the disruption that inevitably comes from change, as the scale of global drilling and production activity continues to expand, to meet demand from economic growth and decarbonisation efforts. Indeed, tens of thousands of new wells are added every year around the world.

The resulting scaling up of natural gas as the largest decarbonisation opportunity on the planet, will however demand the minimisation of methane leaks from the supply chain. It has been forecast that, in part because of the need to clean up the environment, that the global demand for natural gas should treble by 2050, a prospect that must not be derailed by quite manageable fugitive emissions.

More demand for natural gas translates into more demand for production wellheads, and greater focus on minimising methane leaks, to deliver “net-zero” solutions for every exposed component of the supply chain.

More wellheads, more leaks, more intervention, more Totex, all adding to the challenge of controlling 3 million abandoned wells in the US alone!
As wellheads, firmly cemented into the ground and through which natural gas is produced, are the permanent fixtures in the supply chain, they are not readily replaced and therefore require remedial procedures that can be implemented without disturbing cash flow. Such external intervention, conducted in situ, is for natural gas and particularly small methane molecules, a temporary fix, which substantially impacts Opex and which exposes the environment to the risk of catastrophic failure, where wellheads can become ‘super emitters’, such as the recently reported gas leak in the US, and of course the GOM incident of 2010.

Recently commentators predicted that the oil and gas industry will find that anti-fossil fuel campaigns will dwarf those suffered by the tobacco industry.

Consequently, scientifically justifiable solutions that promote “net-zero” targets and which can demonstrate real results, deserve to be recognized, no matter what their scale of impact on the overall leakage volume. As time passes and more components are improved, the inconvenient emitters will become a greater part of the remaining problem and should not be held back.

Wellheads, which cannot be readily removed to fix leaks, are examples of inconvenient “net-zero” targets, deserving design solutions that “prevent rather than cure”.

**Friction-grip technology**

The friction-grip method of engineering for wellheads is a relatively new method of engineering, which can also be used for many types of leak-proof connections.

POS-GRIP®, as Plexus has named the technology, is based on the natural and timeless flexibility of material. By squeezing a cylindrical body inward, internal hanger bodies or connector pins are physically gripped, until the assembly becomes rigid. If the process is conducted within the elastic limits of the material, a permanent, yet reversible engagement occurs of such a large capacity that for all practical purposes the connection behaves as if two parts have become one.
The squeezing process, which is accurately calibrated and controlled by hydraulic force, delivers verifiable and repeatable results, which can be monitored to stay within specified stress limits. This makes the technology reversible, which is important for wellhead hanger and tubing head applications.

**Net-zero target**

Nearly twenty years of experience in the field, and with more than 400 wells drilled around the world, the friction-grip method of wellhead engineering has been proven to be the safest and most convenient solution on some of the most difficult wells ever drilled.

Now it turns out that friction-grip technology also provides a convenient means to help wellheads meet ‘net-zero’ targets, for the natural gas supply chain.

Although wellheads are by no means ‘the major factor’ in respect of methane leakage volumes, it is the case that annular seals are internally fitted to a device that is permanently cemented into the ground. This differentiates annular seals from more readily accessible and therefore replaceable components in the supply chain, resulting in ‘getting it right’ first time as essential.

Replacing annular seals during production is clearly very disruptive and therefore unaffordable, especially in terms of lost production. Therefore, the oil and gas industry rely on ineffective externally applied intervention solutions to repair internal seals, which for natural gas production are at best just a placebo.

In the following sections it is explained what makes a long-term, leak-proof metal annular seal, fit for use for natural gas and methane containment.

**The making of a Metal Seal**

For metal seals to maintain integrity over time, several basic scientific principles apply.

- Distribute contact stress equally
- Control interface stress within limits
- Maintain rigid interface conditions
- Eliminate dissimilar materials, where possible
- Provide redundancy

It is well known that metal seals only function properly if they are installed under strictly controlled conditions, which must involve monitoring and verification of shallow level plastic deformation at the seal interface.

This is for example what our industry does when installing and testing long casing strings, consisting of hundreds of threaded joints of pipe. Smart tools are used to control and monitor assembly procedures, which are carefully recorded for each connection.

Casing or tubing hangers are in terms of integrity no less important than every pipe coupling in the well architecture. To have different standards for these components makes no sense in respect of risk analysis.
It is therefore a matter of concern that the qualification standards for casing hangers and annular seals are far below those expected from tubular couplings, which in addition to a much higher number of cycles are also tested under ‘real world’ system-based conditions, with simulated external force cycling incorporated.

Although today’s conventional wellhead seals meet current qualification standards, these standards, which are often historically configured to meet common denominators, are not specifically designed to prove long-term integrity under field conditions and therefore may not strictly function as true metal-to-metal contact seals.

**Distribute contact stress equally**

To make a metal seal work for gas throughout repeated pressure and temperature cycles, a mixture of shallow-layer yielding and deeper-layer flexibility, must be achieved every time.

Job one is to make sure that seal members are assembled in a concentric fashion, so that the interface stress is equalised around the contact perimeter of the metal seal body.

This is very difficult, if not impossible to achieve using conventional methods of engineering, which must rely on assembly tolerances, to enable metal components to enter the seal bore.

Although casing and tubing hangers land on tapered shoulders, there is no effective means of guaranteeing concentricity. Consequently, annular seals are designed to adjust to a variable annulus, resulting in stress variations around the seal perimeter.

In practice conventional metal seals, are stretched or compressed in situ, involving highly stressed sliding action. Thereafter and throughout field-life, the loose nature of lock-down devices adds to intermittent movement between stressed metal surfaces, induced by pressure...
and temperature variations. This movement, known as fretting, is particularly destructive to the integrity of metal seals.

To be able to live with such movement under stress, conventional metal annular seals use sophisticated lubricating coating techniques as protection. This however effectively sets a ‘lubricant seal’, rather than a shallow-layer plastically deformed metal interface seal, which cannot be allowed to slide.

Over time, and after multiple pressure and temperature cycles, these lubricants wear out, potentially resulting in a loss of integrity, which can only be temporarily restored by external intervention of a pliable injection material.

**Control interface stress within Hertzian limits**

The objective for true metal sealing, is to accurately deliver and maintain an equal amount of contact interface stress around each point of the full perimeter of a metal seal, within a carefully prescribed set of limits.

Hertzian Stress Theory, as published 1882, has been effectively used by industry for hundreds of years.

The oil and gas industry have used Hertzian Stress Theory for high-performance permanent metal sealing flange connectors and a variety of tubular products. In these applications, accessibility allows the deployment of smart installation tools that control, monitor, verify and record every assembly procedure.

Hertz’ theory helps to ensure sealing at a molecular level, whilst maintaining the flexibility needed for long-term performance, under varying operational conditions, and the key is rigidity at all cost!
As explained above, conventional wellhead technologies require assembly tolerances, which when stacked to one side, will cause eccentricity. This in turn results in certain parts of a metal seal interface to be stressed beyond specified limits. Such high local stress may cause deep-layer plastic deformation on one side of a seal and sub-yield areas opposite, limiting long-term integrity.
Only since the introduction of friction-grip technology and its remotely controlled installation techniques, has it been possible to introduce aspects of Hertzian Stress Theory to wellhead engineering, for the benefit of maintenance-free, long-term, leak-proof performance, for all applications.

The image below highlights the effect on interface stress if a seal is not correctly energised. On the tight side of seal pockets, contact stress exceeds allowable limits, causing elasticity to be lost, whilst on the loose side under-activation occurs, allowing the seal to leak.

It is also the case that only with interface stress above yield, can the microscopic gaps between seal surfaces be eliminated, so that small molecules, such as methane, can be contained.
The challenge is to find a way to achieve 100% yield for shallow-layer plastic deformation, whilst at the same time keeping the bulk of the seal area elasticity, thereby enabling the system to withstand temperature and pressure changes and resist forces induced by cyclical loading, throughout the life of a well.

In view of the above it should be noted that for practical reasons conventional wellhead technologies offer minimal verification capability. There is no effective way to control or monitor seal actuation forces, particularly in remote applications. Subsea annular seals are not even tested from below and are therefore generally accepted as a “weak link” in the well architecture.

Now however, the recognition of the need for long-term integrity for gas production wellheads is gaining momentum. New technical solutions are now in demand, in the first place for higher pressure and higher temperature (‘HPHT’) applications, but eventually for most wellheads, as activist investors clamour for safer operating practices.

The ability to control, verify and equalize stress are however not the only issues hampering conventional wellhead designs as explained below.

**Maintain rigid interface conditions**

When casing hangers undergo dimensional change during pressure testing, the geometry of the wellhead and hanger bodies inexorably forces them to expand and move, thereby dragging highly stressed metal seals up and down against seal areas in the wellhead bore. The scale of movement, as shown in the chart below, is quite significant and certainly will destroy shallow yielded surfaces, which are essential to contain methane. This together with the linear
movement allowed under basic lock-rings, results in a very loose assembly, in which metal seals struggle to survive long-term.

A further issue is the need to control the effects of ballooning of a pressure vessel. This can be done by pre-loading and pre-stressing a housing with additional structures. Such compound pressure vessels then act in a non-linear fashion, so that movement at the seal interface is significantly decreased, thereby facilitating stresses that can be kept within prescribed Hertzian limits.
A convenient by-product of the friction-grip method of wellhead engineering is that external load rings, used to squeeze the wellhead body onto casing or tubing hangers, act as a composite structure, by pre-stressing the wellhead housing.

In this way the effect of ballooning in a POS-GRIP wellhead is reduced to be within manageable proportions, whilst friction-grip technology also eliminates assembly gaps, so that there is no space for hangers to expand into.

**Eliminate dissimilar materials where possible**

The life cycle of metal wellhead annular seals begins on installation.

Many conventional systems involve metal seals driven along tapered hanger surfaces, to be plastically stretched or compressed as contact lips or bumps engage seal contact areas.

Such assembly procedures involve a highly loaded sliding action, which requires lubrication to prevent brinelling of seal surfaces. Such conventional designs can never be compatible with Hertzian Stress Theory.

To protect non-retrievable components in a wellhead, conventional metal seals are often made of softer steel, which can be the cause for bi-metal corrosion.

Conversely, the principle feature of friction-grip technology is that the gripping action that secures hangers in the wellhead bore and which actuates integral metal annular seals, occurs without linear movement at the seal interface.

The vertical wall of the wellhead housing is physically moved inwards towards multiple integral bump seals and teeth on the hanger body, which are then engaged without sliding
action. It is therefore not necessary to work with softer and dissimilar materials, a major consideration when working in corrosive environments.

**Provide redundancy**

A further feature of activation by lateral movement is that multiple gallery seals can be energised at once to provide redundancy. This allows tailoring of a wellhead system to resist corrosion, “by design”.

The hanger surface image below shows a series of metal gallery seals. The technology can also be used for channelling control lines through the wellhead wall section.

![Image of metal gallery seals](image.jpg)

**One-Design fits all**

POS-GRIP technology is simple engineering, which uses few components, so that little can go wrong.

The technology can be used on a variety of oil and gas applications and has been successfully installed on ultra-high pressure and temperature projects, up to 20,000 psi, at 375 F.

A single POS-GRIP wellhead design has recently been qualified first time to Annex F standard, from -75 to 400 degrees F. This achievement highlights the potential scope for improving the integrity of the natural gas supply chain.

Standard Plexus HG® metal-to-metal seals are as easy to use on low pressure oil applications as on high-pressure methane gas service projects, either on the surface or subsea.
This “ONE DESIGN” aspect of friction-grip technology is readily seen in the illustrations below.

**Standardization**

Standardization delivers life-cycle savings for all applications, but particularly for critical service conditions. As the graph suggests, the one-design aspect of friction-grip technology, leads to a linear cost increase, as pressures get higher and BOPs get larger.

This compares to exponential price differentials between low pressure and high-pressure applications for conventional wellheads, on land and offshore.
Simplicity pays dividends
Particularly when Corrosion Resistant Alloys (‘CRAs’) are used, the simplicity of friction-grip technology pays dividends, not only in terms of integrity, but importantly also in terms of cost!

Conclusion
For the wide adoption of “net-zero” wellhead technology, stress management techniques must be used and mind sets must change. Equipment providers must be persuaded to embrace new methods of engineering without fear of disruption, in the knowledge that true metal-to-metal wellhead seals can play a full part in achieving emissions targets over the coming years.

CONTACT DETAILS:
Plexus Ocean Systems Ltd.
Burnside House, Burnside Drive
Dyce, Aberdeen
AB21 0HW
UK

+44 (0)1224 774 222
info@plexusplc.com
www.plexusplc.com