

WELLHEAD ASSEMBLY HAVING A SINUSOIDAL SEALING PROFILE AND A METHOD TO ASSEMBLE THE SAME

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] This invention relates in general to subsea wellheads and, in particular, to a metal sealing system for subsea wellheads and related subsea equipment disposed in the subsea wellhead and a method to assemble the same.

Brief Description of Related Art

[0002] In hydrocarbon production wells, a wellhead housing is located at the upper end of the well. The wellhead housing is a large tubular member having an axial bore extending through it. Casing will extend into the well and will be cemented in place. A casing hanger, which is on the upper end of the casing, will land within the wellhead housing. The exterior of the casing hanger is spaced from the bore of the wellhead housing by an annular clearance which provides a pocket for receiving an annulus seal. Annular spaces within concentric members, such as the wellhead housing and the casing hanger, may be exposed to high pressures downhole that require isolation from within the wellhead housing and/or production tree. One manner of isolation involves setting seals within the annular spaces to form a pressure barrier between the downhole pressure and the ambient pressure to the wellhead housing.

[0003] There are many types of annulus seals, including rubber, rubber combined with metal, and metal-to-metal. One metal-to-metal seal in use has a U-shape, having inner and outer walls or legs separated from each other by an annular clearance. An energizing ring, which has smooth inner and outer diameters, is pressed into this clearance to force the legs apart to seal in engagement with the inner surface of the outer wellhead member and with the exterior of the inner wellhead member.

[0004] Some annular seals utilize wickers. Wickers may be located on the exterior of the inner wellhead member, in the bore of the outer wellhead member, or both. The outer leg of the seal embeds into the wickers of the outer wellhead member while the inner leg of the seal embeds into

the wickers of the inner wellhead member. This provides the function of both locking the annulus seal in place and axial restraint to the inner wellhead member, as well as forming a seal between the outer wellhead member and the inner wellhead member. Lockdown is the term used for the capacity and capability of the inner wellhead member and seal assembly to stay in place vertically in the wellhead when a pressure or other force is applied from below. This force may be, for example, the result of annulus pressure build-up or from thermal growth of the casing attached to a bottom of the hanger or a combination of both. A sufficient lockdown capacity is needed to ensure that the seal integrity is maintained and the inner wellhead member and seal remain static.

[0005] The sealing wickers are machined directly into the bore of the outer wellhead member or landing subs and the neck of the inner wellhead member. The annulus seal is made of a sufficiently deformable metal to allow it to deform against the wickers. The deformation occurs as the wickers "bite" into the annulus seal. In order to cause the seal to deform without damaging the wickers, the annulus seal is made of a metal that is softer than the steel used for the inner and outer wellhead members. The wicker bite resists the lockdown force from the inner wellhead member as a shear resistance. The higher the wicker bite, the higher the lockdown capacity. The lower the wicker bite, the lower the lockdown capacity.

[0006] An energizing ring is pressed into the seal between the inner and outer legs to deform the seal against the wickers. This causes the seal to form in a top down manner, forming sequential sealing bands at progressively lower axial locations as each wicker is engaged by the annulus seal. As these wellhead assemblies are disposed in subsea locations, fluid will fill the annulus into which the annulus seals are disposed prior to setting of the seal. As the sealing bands are formed, fluid may be trapped between each wicker. The trapped fluid builds up pressure quickly due to its high bulk modulus. This pressure buildup causes hydraulic lock that limits total engagement or "bite" between the wickers and the annular seal. The limited engagement of the wickers reduces the total lockdown and damage tolerance capabilities of the annulus seals. Therefore, there is a need for an improved sealing assembly that decreases instances of hydraulic lock, thereby increasing lockdown capacity and damage tolerance of the annulus seals.

SUMMARY OF THE INVENTION

[0007] These and other problems are generally solved or circumvented, and technical advantages are generally achieved, by preferred embodiments of the present invention that provide a wellhead assembly having a sinusoidal sealing profile and a method to assemble the same.

[0008] In accordance with an embodiment of the present invention, a wellhead assembly is disclosed. The wellhead assembly includes an outer tubular wellhead member with a bore having an axis and a sealing surface extending an axial distance along an inner diameter surface of the bore. Wickers are formed in the sealing surface, the wickers circumscribing the bore along an axially undulating path. The wellhead assembly also includes an inner tubular member in the outer tubular wellhead member, and a seal element between the inner tubular wellhead member and the outer tubular wellhead member. The seal element may be urged against the wickers to form a sealing interface.

[0009] In accordance with another embodiment of the present invention, a wellhead assembly is disclosed. The wellhead assembly includes an outer tubular wellhead member with a bore having an axis and a sealing surface extending an axial distance along an inner diameter surface of the bore. Wickers are formed in the sealing surface and circumscribe the bore along an axially undulating path. Partial wickers are also formed in the sealing surface. Each partial wicker extends along a portion of the circumference of the bore and follows an axially undulating path. The wellhead assembly also includes an inner tubular member in the outer tubular wellhead member, and a seal element between the inner tubular wellhead member and the outer tubular wellhead member. The seal element may be urged against the wickers to form a sealing interface.

[0010] In accordance with yet another embodiment of the present invention, a method of forming a wellhead assembly is disclosed. The method provides an outer tubular wellhead member having a bore, an axis, and an inner surface of the outer tubular wellhead member having wickers that circumscribe the bore and vary axially in position around the circumference of the bore. The method inserts an inner tubular wellhead member in the outer tubular wellhead member and an annular seal in an annulus between the outer tubular wellhead member and the inner tubular wellhead member. The method urges the seal against the wickers so that the wickers deform the seal and create a barrier in the annulus.

[0011] An advantage of a preferred embodiment is that it provides a wellhead assembly that may seal with multiple independent sealing surfaces with reduced risk of hydraulic lock. This is accomplished by providing a flowpath for fluid residing between wickers to move out of the wicker area during setting of the wellhead assembly. In addition, the disclosed embodiments provide increased lockdown capacity by the seal, thereby limiting instances of upward movement of a casing hanger sealed to a high pressure housing or wellhead. Still further, the disclosed embodiments provide a wellhead assembly with increased tolerance for wellbore damage when installing the wellhead assembly in subsea locations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] So that the manner in which the features, advantages and objects of the invention, as well as others which will become apparent, are attained, and can be understood in more detail, more particular description of the invention briefly summarized above may be had by reference to the embodiments thereof which are illustrated in the appended drawings that form a part of this specification. It is to be noted, however, that the drawings illustrate only a preferred embodiment of the invention and are therefore not to be considered limiting of its scope as the invention may admit to other equally effective embodiments.

[0013] Figure 1 is a sectional view of a high pressure housing of a subsea wellhead in accordance with an embodiment of the present invention.

[0014] Figure 2 is an enlarged sectional view of a plurality of wickers of the high pressure housing of Figure 1 in accordance with an embodiment of the present invention.

[0015] Figure 2A is an enlarged view of a portion of the plurality of wickers of the high pressure housing of Figure 2, in accordance with an embodiment of the present invention.

[0016] Figure 3 is a sectional view of the high pressure housing of Figure 1 having additional components of a subsea wellhead assembly disposed therein in accordance with an embodiment of the present invention.

[0017] Figure 4 is a schematic sectional view of a portion of the wellhead assembly of Figure 3, illustrating a seal assembly in an unenergized or unset position between the high pressure housing and a casing hanger in accordance with an embodiment of the present invention.

[0018] Figure 5 is a schematic sectional view of the portion of the wellhead assembly of Figure 4, illustrating the seal assembly in an energized or set position between the high pressure housing and the casing hanger in accordance with an embodiment of the present invention.

[0019] Figure 6 is a schematic view of a portion of the plurality of wickers of Figure 2, illustrating fluid movement during energization of the seal assembly of Figures 4 and 5 in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0020] The present invention will now be described more fully hereinafter with reference to the accompanying drawings which illustrate embodiments of the invention. This invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

[0021] In the following discussion, numerous specific details are set forth to provide a thorough understanding of the present invention. However, it will be obvious to those skilled in the art that the present invention may be practiced without such specific details. Additionally, for the most part, details concerning wellhead placement, construction, operation, and the like have been omitted inasmuch as such details are not considered necessary to obtain a complete understanding of the present invention, and are considered to be within the skills of persons skilled in the relevant art. As used herein, terms such as above and below are used to describe relative position of components of the invention as illustrated and are not intended to limit the disclosed embodiments to a vertical or horizontal orientation.

[0022] Figure 1 illustrates a partial sectional view of a high pressure housing 13 of a subsea wellhead assembly 11. Subsea wellhead assembly 11 may be any suitable wellhead assembly disposable in a subsea environment to drill and produce fluid from a subsea location. In the illustrated embodiment, high pressure housing 13 provides a pressure vessel interface between a blowout preventer (not shown) and well casing (not shown) disposed in high pressure housing 13. High pressure housing 13 may include one or more of the following: a dual seal profile at the wellhead connector interface, a blowout preventer isolation test tool seal area, a running tool cam profile, and one or more hanger seal profiles 15. Seal profiles 15 may be formed in a bore 17 of high pressure housing 13. Bore 17 and high pressure housing have a common axis 19. A person skilled in the art will recognize that one or more casing hangers and associated casing strings as well as one or more tubing hangers and associated tubing strings may be disposed within high pressure housing 13. In some embodiments, a lockdown bushing or lockdown hanger may be disposed within high pressure housing 13 to provide additional pressure capacity for the system. A person skilled in the art will also recognize that a

separate seal profile 15 may be formed in bore 17 for every hanger or bushing expected to be disposed within high pressure housing 13. A person skilled in the art will understand that other equipment, such as subsea trees and the like, may include sealing profiles 15 as described herein.

[0023] Figure 2 illustrates a detailed view of seal profile 15 of high pressure housing 13. Seal profile 15 may be formed of a plurality of wickers 21. As shown in Figure 2, wickers 21 are grooves formed in bore 17 of high pressure housing 13. Referring to Figure 2A, each wicker 21 may have a triangular cross sectional profile having a crest 23, an upper flank 25, and a lower flank 27. In an embodiment, crests 23 of adjacent wickers 21 are separated by a distance 29. In an embodiment, distance 29 may be approximately one-eighth of an inch. A person skilled in the art will understand that distance 29 may vary as needed for the particular application to which high pressure housing 13 is put to use. For example, distance 29 may be increased or decreased as needed to increase or decrease lockdown capacities and damage tolerance capabilities of wellhead assembly 11. Upper flank 25 and lower flank 27 of adjacent wickers 21 join at a valley 31. A person skilled in the art will recognize that valleys 31 may be spaced by a distance equivalent to distance 29 and may vary as needed for the particular application of high pressure housing 13. Each wicker 21 may have a depth 33 from crest 23 to valley 31. In the illustrated embodiments, depth 33 is uniform for any given axial cross section of high pressure housing 13. Similarly, distance 29 may be uniform for any given axial cross section of high pressure housing 13. In an embodiment wickers 21 are machined into bore 17 of high pressure housing 13 with a computer numerical controlled lathe or a cam driven manual machine. In other embodiments, high pressure housing 13 may be cast with wickers 21. A person skilled in the art will understand that any suitable method may be used to form wickers 21.

[0024] Each crest 23 circumscribes bore 17 so that a crest 23 may be traced from a circumferential location, around bore 17 to return to the circumferential location where the trace began. For example, each crest 23 may form a continuous line around the circumference of bore 17 so that the trace starts and finishes at the same axial height and radial position as it started. Similarly, upper flank 25, lower flank 27, and valley 31 of each wicker 21 may be traced from a circumferential location, around bore 17 to return to the circumferential location where the trace began. Crests 23 of each wicker 21 may vary axially around the circumference of bore 17 as shown in Figure 2. For example, if location 22 is designated as a baseline height for the upper most wicker 21 of the

plurality of wickers 21, locations 24, 28, and 30 may all have different axial positions relative to location 22. In this example, a trace of the upper most wicker 21 beginning at location 22 would be continuous around bore 17 and return to location 22. As shown, some locations of uppermost wicker 21 may be positioned axially higher relative to location 22. For example locations 28 and 30 have higher axial positions in bore 17 relative to location 22. Similarly, some locations of upper most wicker 21 may be positioned axially lower than location 22. For example location 24 has a lower axial position in bore 17 than location 22. Still further, some locations may be positioned at the same axial height as location 22. For example, location 26 is has an equivalent axial height as location 22. In the illustrated embodiment, crests 23 have multiple locations both axially higher and axially lower than location 22 while maintaining a continuous line circumscribing bore 17. In the illustrated embodiment, the axial variation of crests 23 of wickers 21 oscillates in a sinusoidal manner. Thus, the axial position of crest 23 varies with an equivalent amplitude both axially above and axially below initial location 22. Similarly, upper flanks 25, lower flanks 27, and valleys 31 vary axially around the circumference of bore 17 with crest 23 as described above. In this manner, each wicker 21 may have locations of higher, lower, and equivalent axial position relative to an initial position selected at an arbitrary circumferential location of wickers 21. Optionally, wickers 21 may follow a path of approximately any waveform, whether or not the waveform is sequential, symmetric, or curved. A person skilled in the art will understand that axial location of a particular wicker or plurality of wickers 21 may vary with a variety of different shapes and patterns to vary the height of a seal band formed by seal profile 15 as described in more detail below.

[0025] As shown in Figure 2, sealing profile 15 may include partial wickers 32. Partial wickers 32 are formed in bore 17 so that wickers 21, 32 substantially populate a total height 34 of sealing profile 15. Partial wickers 32 have a similar depth 33, pitch or height 29, and component parts, upper flanks 25, lower flanks 27, crests 23, and valleys 31 as each wicker 21. Partial wickers 32 may only be partially formed so that a trace of a partial wicker 32 is not continuous around the circumference of bore 17. Partial wickers 32 may vary in height axially in a manner similar to wickers 21 creating partial fluid channels for the flow of fluid described in more detail below. In the example of Figure 2, partial wickers 32 each extend a distance less than the circumference of bore 17 and are spaced apart from each adjacent partial wicker 32. Although shown as being substantially equidistant, partial wickers 32 can have varying lengths and be space apart at regular or irregular distances.

[0026] Illustrated in a side sectional view in Figure 3 is one example of a wellhead assembly 35 and a running tool 37 inserted in wellhead assembly 35. Running tool 37 includes an inner mandrel 39, having a threaded upper end for connection to a raising and/or lowering device, such as a drill pipe (not shown). The drill pipe, which in an example depends downward from a drilling platform (not shown), can be used for raising, lowering, and operating running tool 37. Wellhead assembly 35 of Figure 3 includes high pressure housing 13, also referred to as an outer annular wellhead housing. Running tool 37 is shown landing a casing hanger 41 within high pressure housing 13. After landing casing hanger 41 in high pressure housing 13, an annular space is formed between respective portions of casing hanger 41 and high pressure housing 13. Additional hangers of similar configurations are illustrated coaxially within high pressure housing 13 and below casing hanger 41. The additional hangers include, a bridging hanger 43 and another casing hanger 45 beneath the bridging hanger 43. Seal assemblies 47 are illustrated set in the annular spaces between each of the hangers 41, 43, 45 and high pressure housing 13 as described in more detail below. At each seal assembly 47 location, a sealing profile 15 may be formed in high pressure housing 13.

[0027] Referring to Figure 4, high pressure housing 13 is a large tubular member located at the upper end of a well, such as a subsea well. Casing hanger 41 is a tubular conduit secured to the upper end of a string of casing (not shown). Casing hanger 41 has an upward facing shoulder 51 on its exterior. An exterior wall 53 of casing hanger 41 is parallel to the wall of bore 17 but spaced inwardly. This results in an annular pocket, clearance, or annulus 52 between casing hanger exterior wall 53 and bore 17. Wickers 55 are located on exterior wall 53 of casing hanger 41. Wickers 55 are similar to wickers 21 of Figures 2-2A adapted to circumscribe exterior wall 53 of casing hanger 41. Wickers 55 may have a similar sinusoidal axial positional variation. When disposed in high pressure housing 13, wickers 55 of casing hanger 41 may be radially adjacent to wickers 21 of high pressure housing 13.

[0028] Seal assembly 47 lands in annulus 52 between casing hanger exterior wall 53 and bore 17. Seal assembly 47 may be made up entirely of metal components. These components may include a generally U-shaped seal member 57. Seal member 57 has an outer wall or leg 59 and a parallel inner wall or leg 61, the legs 59, 61 being connected together at the bottom by a base and open at the top. The inner diameter of outer leg 59 is radially spaced outward from the outer diameter of inner leg 61.

This results in an annular clearance 63 between legs 59, 61. The inner diameter and the outer diameter are smooth cylindrical surfaces parallel with each other. Similarly, the inner diameter of inner leg 61 and the outer diameter of outer leg 59 are smooth, cylindrical, parallel surfaces.

[0029] An energizing ring 65 is employed to force legs 59, 61 radially apart from each other and into sealing engagement with wickers 21, 55 as shown in Figure 5. Wickers 55, 21 bite into inner leg 61 and outer leg 59, respectively, of seal assembly 47 as energizing ring 65 forces outer and inner legs 59, 61 against wickers 21, 55. Energizing ring 65 has an outer diameter that will frictionally engage the inner diameter of outer leg 59. Energizing ring 65 has an inner diameter that will frictionally engage the outer diameter of inner leg 61. The radial thickness of energizing ring 65 is greater than the initial radial dimension of the clearance 63.

[0030] In the illustrated embodiments, bore 17 may be filled with fluid during running, landing, and setting of casing hanger 41 and seal assembly 47. As energizing ring 65 moves axially downward into clearance 63, so that the seal is formed by engaging wickers 21 from top to bottom of sealing profile 15. Upper wickers 21 such as wicker 21A of Figure 6 bite into and deform the sealing surface of seal member 57 to create a sealing band at wicker 21A. As U-shaped seal member 57 engages successive wickers 21_{1-n} , 55_{1-n} , circumferential seal bands may be formed at each wicker 21, 55 sequentially from an upper end of seal member 57 to a lower end of seal member 57. U-shaped member 57 engages each wicker 21, 55 proximate to an inflection point 67 where the wickers change direction, illustrated in Figure 6. Continued axial downward movement of energizing ring 65 causes U-shaped seal member 57 to engage successively more of each wicker 21, 55, deforming seal member 57 into valleys 31. As this occurs, fluid residing between adjacent crests 23 of each wicker 21, 55, for example between crest 23_1 and crest 23_2 of wickers 21_2 and 21_2 , respectively, flows from inflection points 67 toward inflection points 69 where wickers 21, 55 change direction opposite inflection point 67 as shown by arrows 71. For example, as shown in Figure 6, fluid may flow from higher relative locations 26, 28, and 30 toward location 24. In some embodiments, a portion of the fluid residing between adjacent crests 23 flows out of wickers 21, 55. In this manner, the volume of fluid that may be trapped by U-shaped seal member 57 between adjacent wickers 21, 55 may be reduced. Reduction of fluid volume between U-shaped seal member 57 and wickers 21, 55 increases engagement between U-shaped seal member 57 and wickers 21, 55, deforming more of U-shaped

seal member 57 into wickers 21, 55 to create higher lockdown capacities and reduce instances of hydraulic lock during seal setting. Curving the wickers increases their effective length and thus their total volume.

[0031] Accordingly, the disclosed embodiments provide numerous advantages. For example, the disclosed embodiments provide a wellhead assembly that may seal with multiple independent sealing surfaces with reduced risk of hydraulic lock. This is accomplished by providing a flowpath for fluid residing between wickers to move out of the wicker area during setting of the wellhead assembly. In addition, the disclosed embodiments provide increased lockdown capability by the seal, thereby limiting instances of upward movement of a casing hanger sealed to a high pressure housing or wellhead. Still further, the disclosed embodiments provide a wellhead assembly with increased tolerance for wellbore damage when installing the wellhead assembly in subsea locations.

[0032] It is understood that the present invention may take many forms and embodiments. Accordingly, several variations may be made in the foregoing without departing from the spirit or scope of the invention. Having thus described the present invention by reference to certain of its preferred embodiments, it is noted that the embodiments disclosed are illustrative rather than limiting in nature and that a wide range of variations, modifications, changes, and substitutions are contemplated in the foregoing disclosure and, in some instances, some features of the present invention may be employed without a corresponding use of the other features. Many such variations and modifications may be considered obvious and desirable by those skilled in the art based upon a review of the foregoing description of preferred embodiments. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

CLAIMS:

1. A wellhead assembly comprising:

an outer tubular wellhead member with a bore having an axis and a sealing surface extending an axial distance along an inner diameter surface of the bore;

wickers in the sealing surface circumscribing the bore along an axially undulating path;

an inner tubular member in the outer tubular wellhead member; and

a seal element between the inner tubular wellhead member and the outer tubular wellhead member and urged against the wickers to form a sealing interface.

2. The wellhead assembly of Claim 1, wherein the axial position of each wicker varies sinusoidally.

3. The wellhead assembly of Claim 1 or Claim 2, wherein each wicker of the plurality of wickers is substantially parallel to adjacent wickers.

4. The wellhead assembly of any preceding Claim, wherein the wickers are equidistantly spaced from each adjacent wicker.

5. The wellhead assembly of any preceding Claim, further comprising wickers in a sealing surface on an outer diameter surface of the inner tubular member, the wickers circumscribing the inner tubular member along an axially undulating path.

6. The wellhead assembly of any preceding Claim, further comprising partial wickers in the sealing surface, wherein each partial wicker extends along a portion of the circumference of the bore and follows an axially undulating path.

7. The wellhead assembly of any preceding Claim, wherein partial wickers are proximate axial ends of the sealing surface.

8. The wellhead assembly of any preceding Claim, wherein each of the partial wickers are substantially similar.
9. The wellhead assembly of any preceding Claim, wherein adjacent partial wickers are equidistantly spaced from each other.
10. A wellhead assembly comprising:
 - an outer tubular wellhead member with a bore having an axis and a sealing surface extending an axial distance along an inner diameter surface of the bore;
 - wickers in the sealing surface circumscribing the bore along an axially undulating path;
 - partial wickers in the sealing surface, wherein each partial wicker extends along a portion of the circumference of the bore and follows an axially undulating path;
 - an inner tubular member in the outer tubular wellhead member; and
 - a seal element between the inner tubular wellhead member and the outer tubular wellhead member and urged against the wickers to form a sealing interface.
11. The wellhead assembly of any preceding Claim, further comprising wickers in a sealing surface on an outer diameter surface of the inner tubular member, the wickers circumscribing the inner tubular member along an axially undulating path.
12. The wellhead assembly of any preceding Claim, further comprising partial wickers in the sealing surface on the outer diameter surface of the inner tubular member, wherein each partial wicker extends along a portion of the outer diameter surface and follows an axially undulating path
13. The wellhead assembly of any preceding Claim, wherein the axial position of each wicker varies sinusoidally.

14. The wellhead assembly of any preceding Claim, wherein each wicker of the plurality of wickers is substantially parallel to adjacent wickers.
15. A method of forming a wellhead assembly comprising:
- (a) providing an outer tubular wellhead member having a bore, an axis, and an inner surface of the outer tubular wellhead member having wickers that circumscribe the bore and vary axially in position around the circumference of the bore;
 - (b) inserting an inner tubular wellhead member in the outer tubular wellhead member;
 - (c) inserting an annular seal in an annulus between the outer tubular wellhead member and the inner tubular wellhead member; and
 - (d) urging the seal against the wickers so that the wickers deform the seal and create a barrier in the annulus.
16. The method of Claim 15, wherein step (a) further comprises providing each wicker with a sinusoidally varying axial position.
17. The method of Claim 15 or Claim 16, wherein step (a) further comprises providing wickers on an outer circumference of the inner tubular wellhead member.
18. The method of any of Claims 15 to 17, wherein step (a) further comprises providing partial wickers on the outer tubular wellhead member, wherein the partial wickers extend along a portion of the circumference of the bore.
19. A wellhead assembly substantially as herein before described with reference to the accompanying drawings.
20. A method of forming a wellhead assembly substantially as herein before described with reference to the accompanying drawings.