

THREADED CONNECTOR HAVING METAL-TO-METAL SEAL

Cross Reference to Related Application

The present application claims priority to U.S. Provisional Application Serial No.
5 62/751,987 filed on October 29, 2018 which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates generally to connectors for tubular members and, more particularly, to threaded connectors having metal-to-metal seals.

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BACKGROUND

When a hole is bored into the earth, as for the production of oil and gas, a large diameter pipe known as surface casing may be installed into the upper section of the borehole. Surface casing stabilizes the walls of the borehole near the surface where they are more apt to cave in. On
15 holes drilled in offshore waters from platforms, or jack-ups, the pipe may be extended from the ocean floor to the deck of the drilling structure and is often known as a marine riser. In such case, the riser may be an extension of the surface casing and serves to prevent entry of sea water into the borehole.

Make-up and installation of pipe such as surface casing from floating offshore drilling
20 structures or vessels may be complicated by the actions of waves on the vessel. Various motions of the vessel, of which the most critical are roll and pitch, render the make-up of screw-type connections very difficult. Not only may it be difficult to stab one casing section into another, but it may be difficult also to attain proper alignment during make-up, which can result in destructive cross-threading. While running casing of any kind may be difficult in such hostile environments,
25 it may be particularly difficult for larger casing strings, such as twenty inches or larger. This may be due not only to greater mass of such larger casing but to the decrease in allowable make-up angle for a given pitch thread as the pipe diameter increases.

Maintenance of such pipe may be complicated also by the wave action of the ocean and the motion of the vessel. Wave actions and the motion of the vessel apply tension and bending to
30 the pipes, which in turn applies tension and bending loads on the connectors of the segments of such pipe. If the tension and bending loads on the connectors becomes too great in magnitude, then the loads will cause distortion and damage to the connector, which in turn will cause leakage.

The above problems are exacerbated by the design of pipe connections, which have only limited physical space wherein high contact stresses can be exerted. The limited size increases the

potential of metal-to-metal galling during make-up and breakout of the threaded connection. Also, the limited area of contact stresses increases the risk of leakage due to preexisting damage of surfaces at the metal-to-metal interface. Such issues have caused pipe connection designers to use tight controls on machining tolerances when manufacturing connectors. However, such tight
5 designs can create connectors with higher contact stresses than may be desirable, which can lead to increased make-up torques and potential for galling.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present disclosure and its features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

5 FIG. 1 is a longitudinal cross section of a pin connector in accordance with certain embodiments of the present disclosure;

 FIG. 2 is a longitudinal cross section of a box connector suitable for reception of the pin connector of FIG. 1 in accordance with certain embodiments of the present disclosure;

 FIG. 3 is a partial longitudinal cross section of the box and pin configuration shown in
10 FIGS. 1 and 2 shown in the fully engaged position in accordance with certain embodiments of the present disclosure;

 FIG. 4 is an exploded, isolated view of a region of the threaded connection of FIG. 3 showing a recess in the box connector adjacent to a pin nose in accordance with certain embodiments of the present disclosure; and

15 FIG. 5 is a graph showing the relationship of the nose seal contact pressure as a function of distance from the nose for a sphere-on-cone seal configuration in accordance with certain embodiments of the present disclosure.

DETAILED DESCRIPTION

Illustrative embodiments of the present disclosure are described in detail herein. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous
5 implementation-specific decisions must be made to achieve developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of the present disclosure. Furthermore, in no way should
10 the following examples be read to limit, or define, the scope of the disclosure.

Certain embodiments according to the present disclosure may be directed to threaded connectors having metal-to-metal seals. Threaded connectors may have a male connector (sometimes called a pin) and a female connector (sometimes called a box). Connection may be made by screwing the male connector into the female connector. Additionally, the male connector
15 may have an exterior curvilinear sealing surface and the female connector may have a corresponding interior curvilinear sealing surface. Upon connection, a metal-to-metal seal may be formed by the contacting of the exterior curvilinear sealing surface of the male connector and the interior curvilinear sealing surface of the female connector.

In previous designs, the interior and exterior curvilinear surfaces may be essentially the same shape. This, in some embodiments, would allow a male connector and female to have a flush
20 or near flush metal-to-metal seal. For example, previous designs may show both connectors having a frustoconical shape. Thus, in such designs, the frustoconical male connector may have a flush connection with the frustoconical female connector.

It is through the metal-to-metal seal that the male connector may exert contact stresses on
25 the female connector and vice versa. The connectors may be located at the ends of longitudinal members, which may be pipe segments in some embodiments, that can be connected by way of the connectors. Such longitudinal members may exert considerable stress on the metal-to-metal seal in the connection because such a longitudinal member may act effectively as a lever on the connection. For example, the transverse motion of a longitudinal member may apply significant
30 contact stresses to the metal-to-metal seal, potentially causing the seal or connection to deform and create a leak.

The disclosed embodiments address the deficiencies in previous connector designs by providing different shapes for the contacting curvilinear sealing surfaces of the first and second

connecting members, which in some embodiments may be male and female connectors. Unlike previous designs where the male and female connectors may have matching surfaces, the disclosed embodiments here may have mismatched surfaces. For example, in one exemplary embodiment, the male connector may have a frustohemispherical sealing surface while the female connector may have a frustoconical sealing surface. In another exemplary embodiment, the male connector may be frustospherical and the female connector may be frustoconical. In yet another embodiment, the male connector may be frustotoroidal and the female connector may be frustoconical. As those of ordinary skill in the art will appreciate, the surfaces may be reversed, *i.e.*, the male connector may have the frustoconical surface and the female member may have the other surface. In embodiments where the surface is frustotoroidal, the torus may be of the ring, horn, or the spindle type. In such embodiments, the spindle type of torus may be used because it has large radius of curvature on the male connector sealing surface. Generally, the shapes used for the male and female connectors may be any shape if the shape is in the form of a frustum of a three-dimensional geometric object. For example, the shapes used for the male and female connectors may be a shape selected from the group consisting of frustoconical surfaces, frustocylindrical surfaces, frustoellipsoidal surfaces, frustospheroidal surfaces, frustohemispherical surfaces, frustoparabolic surfaces, frustohyperbolic surfaces, frustotoroidal surfaces, and blends thereof.

Additionally, the male connector may have a nose located at the tip of the male connector. In embodiments where the male connector is a pin, this nose may be referred to as a pin nose. The interior surface of the female connector may be designed to engage the nose of the male connector upon connection. In some embodiments, the nose of the male connector may be relatively thin and flexible, thereby allowing the male connector to move slightly in a transverse direction after full connection to the female connector.

The disclosed mismatched male and female curvilinear surfaces, along with the flexible male connector nose, may facilitate a more reliable threaded connection having a metal-to-metal seal. In some embodiments, the flexible nose and mismatched surfaces working together may provide for a wide parabolic distribution of contact stresses along the mating sealing surfaces. Also, in some embodiments, the flexible nose may provide for rapid-pressure energization of the metal-to-metal seal when the connection may be under either internal or external pressure.

During said pressurization, the flexibility of the male connector nose may cause the curvilinear sealing surface of the male connector to rotate or "roll" to a slightly different position on the curvilinear sealing surface of the female connector. In such case, the contact footprint of

the contacting curvilinear sealing surface may widen or generally increase in size significantly. Such increase in the size of the footprint may result in spreading the contact stresses over a larger surface area, the larger surface area being the larger footprint. In addition to a larger contacting footprint, the magnitude of contact pressure increases substantially with increasing internal or external pressure, resulting in a net increase of said contact stresses per unit surface area of the metal-to-metal seal. In short, this pressurization process is caused by the flexibility of the pin nose and the favorable shape of the contact stress profile. This same flexibility of the pin nose and favorable metal-to-metal sealing configuration may also cause the contact stresses to increase and the contact footprint to widen when the connection is subjected to tension and bending loads, also increasing the contact stresses per unit surface area.

In some embodiments, the flexibility of the pin nose may be facilitated by an annular groove on the surface of the pin and near the pin nose. The thinness of the pin, near the pin nose, due to the annular groove may allow the pin nose to flex. Additionally, the annular groove may contain an O-Ring, which may form a seal against an interior surface of the box connector, which in turn may serve as a secondary seal to prevent leakage. In embodiments where there is no annular groove near the pin nose, the pin nose may be stiff or rigid and not be able to flex in the manner above described.

The higher contact stresses per unit surface area under tension, bending, and pressure loads is an advantage over previous designs wherein lower contact stresses per unit surface area resulted when a tension or bending force was applied to the connection. In such previous designs, the lower contact stresses per unit surface area may have an increased risk of leakage due to insufficient contact pressures or preexisting damage of the curvilinear sealing surfaces at the metal-to-metal seal. In previous designs, to overcome the lowering of contact stresses resulting from loading of the connection, the contact stresses at make-up are normally made to be initially higher by increasing the interference between the pin and box sealing surfaces. This may create an increased risk of galling of the curvilinear sealing surfaces at the metal-to-metal seal during make-up and breakout of the threaded connection, which too can create leakage. In previous designs, creation of such higher contact stresses by increased seal interference may require higher make-up torques, which also may create an increased risk of galling. Also, previous designs creating high contact stresses over limited areas may require connectors to be manufactured with tight controls on machining tolerances.

The above disclosure has the advantage of having a wider area of lower contact stresses at make-up and breakout, which may significantly reduce the propensity for galling during make-

up and breakout of the threaded connection. Also, the wider area of contact stress decreases the risk of leakage at the sealing interface due to preexisting surface damage. Lower contact stresses at make-up leads to reduced or eliminated galling potential and lower make-up torques. The above disclosure has the further advantage that applied tension loads further increase and widen the contact footprint. The above disclosure has the further advantage that the flexibility of the pin nose and the favorable shape of the contact stress profile allow significant loosening of machining tolerances, reducing both manufacturing cost and rejection rates.

One skilled in the art would recognize that the shapes of the male connector and female connector sealing surfaces could be reversed and still provide similar benefits.

Turning now to the drawings, referring to FIGS. 1 and 2, a connector assembly in accordance with the present disclosure is shown generally by reference number 10. The assembly 10 includes a first connector member, which may be a male connector in some embodiments, and a second connector member, which may be a female connector in some embodiments. In one exemplary embodiment, the male connector may be a pin 12 and the female connector may be box 13. In FIGS. 1 and 2, pin 12 is shown generally in alignment with and ready for insertion into a box 13.

Referring to FIG. 1, pin 12 may be attached to a longitudinal member 14. Longitudinal member 14 may be tubular in shape and may have a bore 18. Pin 12 may also be tubular and may have a bore 20 which may be an extension of bore 18 of longitudinal member 14, which in turn may be cylindrical for casing applications. An external makeup shoulder 24 may have a larger diameter than longitudinal member 14. Following makeup shoulder 24 may be a cylindrical upper guide section 26. Guide section 26 may provide a flat surface (when viewed in longitudinal cross section) and may serve to guide pin 12 into a female connector, which may be a box 13, in a manner hereinafter described.

Near the bottom of pin 12 may be a section 28 having a multiplicity of threads 30 cut thereon. In some embodiments, section 28 may be tapered such that threads 30 taper from upper base 32 down toward lower base 34. As those of ordinary skill in the art will appreciate, any suitable taper may be used. In any case, section 28 may be tapered or shaped to permit threaded section 28 to travel substantially into the mating threaded section in box 13 (described below) before thread engagement begins.

Nearest the lower end of pin 12 may be a pin curvilinear sealing surface 36, followed by a pin nose 38. Make up is limited by the external pin shoulder 24 contacting box external shoulder 75. Pin curvilinear sealing surface 36 may be of a three-dimensional shape that may facilitate a

more reliable threaded connection by way of a metal-to-metal seal with the box curvilinear sealing surface 74 (described herein below).

Referring now to FIG. 2, a box 13 for threaded mating with pin 12 of FIG. 1 is shown. Now describing the exterior of box 13 in detail, generally from the bottom to the top of the drawing, box 13 may be attached to a longitudinal member 52. Longitudinal member 52 may be tubular in shape and may have a bore 62. Box 13 may also be tubular and may have a bore 66 which may be an extension of bore 62 of longitudinal member 52, which in turn may be cylindrical for casing applications

Extending to the upper end of box 13 may be a tubular end section 56 which may be larger in diameter than longitudinal member 52. Section 56 may have, in its interior, threads for mating with threads 30 of pin 12 (described hereinafter below). The transition from longitudinal member 52 to end section 56 may define an annular shoulder 60, which may be useful in supporting the longitudinal member 52, and other like members connected thereto, when a tubular string may be being made up, for example.

Now describing the interior of box 13, generally from the bottom to the top of the drawing, longitudinal member 52 may have a bore 62. Bore 62 may be in communication with a bore 66 in box 13. Near longitudinal member 52, bore 66 may be defined by a wall 68 and a curvilinear sealing surface 74.

Toward the bottom end of box 13 may be a box curvilinear sealing surface 74. A shoulder 73 may connect the wall 72 with the box curvilinear sealing surface 74. Shoulder 73 may be located beneath box curvilinear sealing surface 74. During makeup, pin nose 38 may not contact shoulder 73. Instead, the distance that pin nose 38 may travel into box 13 may be limited during makeup by contact between external pin shoulder 24 and box shoulder 73. Box curvilinear sealing surface 74 may provide a surface for receiving pin curvilinear sealing surface 36 on pin 12 and may be of a three-dimensional shape that may facilitate a more reliable threaded connection by way of a metal-to-metal seal with the pin curvilinear sealing surface 36 (described below).

Toward the upper end of box 13 may be an opening 80 which may be defined by a wall having a multiplicity of threads 81, the purpose of which may be to allow the pin to enter the box, thereby allowing for make-up of the pin and box. Threads 81 may be of the same pitch as threads 30 on threaded section 28 on pin 12. Threaded opening 80 may be also tapered or shaped to matingly receive threaded section 28 of pin 12. In an exemplary embodiment, threaded opening 80 may have a smaller-diameter lower base 82 adjacent to a recess 83 and may have a larger-

diameter upper base 84 toward the top end of box 13. Recess 83 may be a threaded-relief groove that also functions as a stress redirection groove.

Nearest the top end of box 13 may be an internal opening 85 defined by wall 86 and having a beveled lip 87 that is sized to receive upper guide section 26 of pin 12. The combination of guide section 26 and wall 86 acts to guide the threaded section 28 on pin 12 and threaded opening 80 on box 13 together without cross-threading. Similar guidance on the opposite end of threaded section 28 and threaded opening 80 may be provided by the combination of pin curvilinear sealing surface 36 and box curvilinear sealing surface 74.

The threads 30 on threaded section 28 of pin 12 and threads 81 in threaded opening 80 in box 13 may have a pitch of about four threads per inch. As those of ordinary skill in the art will appreciate, any suitable pitch may be utilized. On pin 12, the lower side 90 of each thread 30 may be beveled downwardly. On pin 12, the upper thread side 92 may be also beveled downwardly and inwardly. The box threads 81 may be complementary to the pin threads 30, so that the two sets of threads mesh with back-slanted mating surfaces 92 of the pin threads on back-slanted mating surfaces 94 of the box threads and beveled lower side 90 on beveled upper edge 96. When such threads are fully engaged, the wedge shapes may provide thread security not only down the length of the joint but also across the width of the joint. This may prevent the joint from failing due to expansion of the box diameter during stress, a condition known as "bellling."

Referring to FIG. 3, pin 12 and box 13 are shown in a fully engaged position. On the lower end of pin 12, pin curvilinear sealing surface 36 may be received by box curvilinear sealing surface 74. In some embodiments, curvilinear sealing surface 36 is a frustospherical surface and curvilinear sealing surface 74 is a frustoconical.

In some embodiments, the pin 12 may contain an annular groove 78 that comprises a ring of empty space due to the removal of material from the pin. In such embodiments, the presence of the annular groove 78 creates a section of the pin 12, near the pin nose 38 in FIG. 4, that is thinner than surrounding sections. This thinness allows the pin nose 38 to be flexible and thus provide for the rapid-pressure energization of the metal-to-metal seal as described above.

The annular groove 78 may function also to receive therein a backup O-ring seal 76 that is sized to fit groove 78. The O-ring seal 76 in groove 78 may serve as a back-up seal to the primary metal-to-metal seal between surfaces 36 and 74. Groove 78 may be dove-tailed to hold the backup O-ring 76 in place. The depth of annular groove 78 may be slightly less than the diameter of the backup O-ring cross section so that the backup O-ring 76 will provide a pressure seal against surface 79 of pin 12. The backup O-ring 76 is a backup seal that engages the

cylindrical surface 79 in the box above the box's frustoconical metal sealing surface 74. In a particular embodiment, the primary seal against internal pressure is provided by the metal-to-metal contact between the frustohemispherical surface 36 on the pin and the frustoconical surface 74 on the box. This metal-to-metal seal configuration provides a gas-tight and water-tight seal. Locking engagement of threads 30 on pin 12 with threads 81 on box 13 may be provided by the wedging of the upper faces 92 of threads 30 with the lower faces 94 of threads 81. The mutual engagement of these wedge-shaped threads may prevent box 13 from expanding and thereby may prevent thread disengagement due to such expanding of the box since any tendency of the box to expand results in the pin threads pulling radially inwardly on the box threads.

As stated previously, recess 83 may be a threaded-relief groove that also functions as a stress redirection groove. Shoulder 73 may be located beneath box curvilinear sealing surface 74. Also, in some embodiments, a second O-ring 108 may be located in groove 110 to exclude external pressure. For example, such O-ring 108 may serve as a seawater exclusion seal. However, second O-ring 108 is not required for the disclosed embodiments to operate as intended.

Referring to FIG. 4, which is a close up of the connection illustrated in FIG. 3, pin curvilinear sealing surface 36 is shown forming a metal-to-metal seal with box curvilinear sealing surface 74. As described above, the main limitation on the travel of pin 12 into box 13 may be the seating of the pin end against the box internal shoulder 73. This leaves a gap 990 between pin nose 38 and box shoulder 73. The pin contacts internal shoulder 73, thus closing gap 990, only under conditions of high compressive loads. The size of gap 990 between the end of the pin and shoulder 73 may be chosen in order to maximize the compressive load capacity of the connection.

It is through the metal-to-metal seal between surfaces 36 and 74 that the male connector may exert contact stresses on the female connector or vice versa. In some embodiments, said contact stresses may result from movement by longitudinal member 14 and/or longitudinal member 52 (See FIG. 1 and FIG. 2). In some embodiments, longitudinal members 14 and 52 may be pipe segments connected by way of pin 12 and box 13. Such contact stresses, if large enough in magnitude, can cause deformation in the components of first and second connecting members, which in some embodiments may be pin 12 and box 13. Said deformation may result in fluid leaks through the connection.

The disclosed embodiments address these deficiencies by providing different shapes for the disclosed curvilinear sealing surfaces, which in some embodiments may be the pin curvilinear sealing surface 36 and box curvilinear sealing surface 74. Unlike previous designs where the male and female connectors may have matching surfaces, the disclosed embodiments here may have

mismatched surfaces. For example, a male connector, shown in one embodiment in FIG. 4 as pin 12, may have a frustohemispherical sealing surface 36 while a female connector, shown in one embodiment in FIG. 4 as box 13, may have a frustoconical sealing surface 74. In another exemplary embodiment, the male connector may be frustospherical and the female connector may be frustoconical. In yet another embodiment, the male connector may be frustotoroidal and the female connector may be frustoconical. As those of ordinary skill in the art will appreciate, the surfaces may be reversed, *i.e.*, the male connector may have the frustoconical surface and the female member may have the other surface profiles discussed above. In embodiments where the surface is frustotoroidal, the torus may be of the ring, horn, or spindle type. In such embodiments, the spindle type of torus may be used because it has large radius of curvature on the male connector sealing surface. Generally, the shapes used for the male and female connectors may be any shape if the shape is in the form of a frustum of a three-dimensional geometric object.

FIG. 4 also depicts pin nose 38. In some embodiments, pin nose 38 may be relatively thin and flexible, thereby allowing the male connector, here shown in an embodiment as pin 12, to move slightly in a transverse direction after full connection to the female connector, here shown in an embodiment as box 13. In some embodiments, the flexible nose may provide for rapid-pressure energization of the metal-to-metal seal when the connection may be under either internal or external pressure (described herein below).

FIG. 4 also depicts a recess 100 in box 13 adjacent to box shoulder 73 and engaged pin nose 38. In the drawing, recess 100 may be located below box curvilinear sealing surface 74 and pin curvilinear sealing surface 36. Recess 100 is an undercut radius in the box shoulder 73 that reduces the stress in this corner.

FIG. 5 is a graph 120 showing the results of an analysis performed on a pin and box connection in accordance with the present disclosure. Graph 120 serves as an exemplary mathematical description of the rapid-pressure energization of the metal-to-metal seal that may be caused by the mismatched sealing surfaces and a flexible pin nose. Graph 120 shows the contact pressure 122 in a metal-to-metal seal as a function of distance 124 from the pin nose 38 for a particular embodiment where the exterior curvilinear surface of a male connector is frustospherical and interior curvilinear surface of a female connector is frustoconical. The multiple trend lines 136 illustrate the wide parabolic distribution of contact stresses along the mating frustospherical and frustoconical surfaces. The results of the test illustrated in graph 120 show a wide parabolic range of contact stresses. As disclosed above, one can see from the graph that if contact pressure increases (illustrated by the height of the inverted parabola), then the contact footprint increases

in size (illustrated by the width of the inverted parabola).

Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the following claims.

WHAT IS CLAIMED IS:

1. A connector assembly comprising:
 - a first connector member having an exterior curvilinear sealing surface;
 - 5 a second connector member having an interior curvilinear sealing surface;
 - wherein the first connector member is adapted to be received by the second connector member, allowing a connection to be formed; and
 - wherein the exterior curvilinear sealing surface and the interior curvilinear sealing surface have portions with non-complementary surface shapes.
- 10 2. The connector assembly of claim 1 wherein:
 - the interior and exterior curvilinear surfaces are selected from a group consisting of frustoconical surfaces, frustocylindrical surfaces, frustoeffipsoidal surfaces, frustospheroidal surfaces, frustohemispherical surfaces, frustoparabolic surfaces, frustohyperbolic surfaces,
 - 15 frustoroidal surfaces, and blends thereof; and
 - wherein one of the curvilinear sealing surfaces is selected from the group and the other of the curvilinear surfaces is selected from the remaining members of the group.
3. The connector assembly of claim 1 wherein:
 - 20 the first connector member further comprises tapered external threads disposed on a section of the first connector member adjacent to the exterior curvilinear sealing surface; and
 - the second connector member further comprises tapered internal threads disposed on a section of the second connector member adjacent to the interior curvilinear sealing surface,
 - wherein the tapered external threads are complementary to the tapered internal threads.
- 25 4. The connector assembly of claim 3 wherein:
 - the interior curvilinear sealing surface of the second connector member contains a recess adjacent to a nose of the first connector member when the first connector member is seated in the second connector member.

5. The connector assembly of claim 3 wherein:
the first connector member has a flexible nose that will allow the first connector member to rotate into a different orientation while seated inside of the second connector member.
- 5 6. The connector assembly of claim 5 wherein:
the different orientation creates a new contact area between the interior curvilinear sealing surface and exterior curvilinear sealing surface; and
surface contact stresses are exerted by a metal-to-metal seal in the contact area.
- 10 7. The connector assembly of claim 6 wherein:
the different orientation causes a rapid pressure-energization of the metal-to-metal seal when the connection is under either internal or external pressure; and
wherein during the pressure-energization, the new contact area widens and the surface contact stresses increase in magnitude.
- 15 8. The connector assembly of claim 1 wherein:
the first connector member comprises a pin; and
the second connector member comprises a box.
- 20 9. The connector assembly of claim 1 wherein:
the first connector member is a pin connector comprising a pin nose and an annular groove on the exterior surface of the pin connector proximate the pin nose; and
the second connector is a box connector.
- 25 10. The connector assembly of claim 1 wherein:
a gap in a direction parallel to an axis of the first and second connector members is present between an end of the first connector member and a shoulder of the second connector member.

11. A method comprising:

receiving a first connector member into a second connector member;

wherein the first connector member has an exterior curvilinear sealing surface and the second connector member has an interior curvilinear sealing surface; and

5 wherein the exterior curvilinear sealing surface and the interior curvilinear sealing surface have portions with non-complementary surface shapes.

12. The method of claim 11 wherein:

10 the interior and exterior curvilinear surfaces are selected from a group consisting of frustoconical surfaces, frustocylindrical surfaces, frustoellipsoidal surfaces, frustospheroidal surfaces, frustohemispherical surfaces, frustoparabolic surfaces, frustohyperbolic surfaces, frustoroidal surfaces, and blends thereof; and

wherein one of the curvilinear sealing surfaces is selected from the group and the other of the curvilinear surfaces is selected from the remaining members of the group.

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13. The method of claim 11 wherein:

the first connector member further comprises tapered external threads disposed on a section of the first connector member adjacent to the exterior curvilinear sealing surface; and

20 the second connector member further comprises tapered internal threads disposed on a section of the second connector member adjacent to the interior curvilinear sealing surface, wherein the tapered external threads are complementary to the tapered internal threads.

14. The method of claim 13 wherein:

25 the interior curvilinear sealing surface of the second connector member contains a recess adjacent to a nose of the first connector member when the first connector member is seated in the second connector member.

15. The method of claim 13 further comprising:

30 allowing the first connector member to rotate into a different orientation while seated inside the second connector member via a flexible nose of the first connector member.

16. The method of claim 15 further comprising:

creating a new contact area between the interior curvilinear sealing surface and exterior curvilinear surface via the first connector member rotating into the different orientation; and exerting surface contact stresses via a metal-to-metal seal in the new contact area.

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17. The method of claim 16 further comprising:

causing a rapid pressure-energization of the metal-to-metal seal when the connection is under either internal or external pressure; and

during the pressure-energization, widening the new contact area and increasing a magnitude of the surface contact stresses.

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18. The method of claim 11 wherein:

the first connector member comprises a pin; and

the second connector member comprises a box.

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19. The method of claim 11 wherein:

the first connector member is a pin connector comprising a pin nose and an annular groove on the exterior surface of the pin connector proximate the pin nose; and

the second connector is a box connector.

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20. The method of claim 11 wherein:

a gap in a direction parallel to an axis of the first and second connector members is present between an end of the first connector member and a shoulder of the second connector member