

FULL BORE COMPRESSION SEALING METHOD

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/164,362, entitled "Full Bore Compression Sealing Method", filed on March 27, 2009, which is herein incorporated by reference in its entirety.

BACKGROUND

[0002] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present invention, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present invention. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

[0003] Fluid systems, such as mineral extraction systems (e.g., oil and gas), typically include multiple segments of tubing, valves, and connectors that are sealed together by various seals. These seals are often subjected to harsh environmental conditions, such as corrosive fluids, extreme pressures, and extreme temperatures. Moreover, these seals are often disposed in remote equipment, such as a marine (e.g., sub-sea) wellhead, which can make access and repair difficult and expensive. Over time, these seals tend to lose their memory or shape. When this type of damage occurs, the seals begin to hold pressure less effectively, particularly at high pressures and sub-ambient temperatures. As such, it may be important to ensure that these seals are installed in a manner which minimizes damage (e.g., extrusion) during installation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Various features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with

reference to the accompanying figures in which like characters represent like parts throughout the figures, wherein:

[0005] FIG. 1 is a block diagram illustrating a mineral extraction system in accordance with an embodiment of the present invention;

[0006] FIG. 2 is a partial cross-section of the casing spool and the hanger of FIG. 1;

[0007] FIG. 3A is a partial cross-section of an exemplary annular seal in a non-deformed ("pre-loaded") shape;

[0008] FIG. 3B is a partial cross-section of an exemplary annular seal in a deformed ("loaded") shape;

[0009] FIG. 4 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having a substantially constant axial cross-sectional height from a radially inner face to an axial centerline and a linearly increasing axial cross-sectional height from the axial centerline to a radially outer face;

[0010] FIG. 5 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having a linearly decreasing axial cross-sectional height from the radially inner face to the axial centerline and a substantially constant axial cross-sectional height from the axial centerline to the radially outer face;

[0011] FIG. 6 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having a linearly increasing axial cross-sectional height from the radially inner face to the axial centerline and a linearly decreasing axial cross-sectional height from the axial centerline to the radially outer face;

[0012] FIG. 7 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having a linearly decreasing axial cross-sectional height from the radially inner face to the axial centerline and a linearly

increasing axial cross-sectional height from the axial centerline to the radially outer face;

[0013] FIG. 8 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having a non-linearly decreasing axial cross-sectional height from the radially inner face to the axial centerline and a non-linearly increasing axial cross-sectional height from the axial centerline to the radially outer face;

[0014] FIG. 9 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having a non-linearly increasing axial cross-sectional height from the radially inner face to the axial centerline and a non-linearly decreasing axial cross-sectional height from the axial centerline to the radially outer face;

[0015] FIG. 10 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having an asymmetrical, linearly decreasing axial cross-sectional height from the radially inner face to the axial centerline and an asymmetrical, linearly increasing axial cross-sectional height from the axial centerline to the radially outer face;

[0016] FIG. 11 is a partial cross-section of an exemplary embodiment of an annular seal with a core seal section having more than two varying cross-sectional profile sections; and

[0017] FIG. 12 is another partial cross-section of an exemplary embodiment of an annular seal with a core seal section having more than two varying cross-sectional profile sections.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0018] One or more specific embodiments of the present invention will be described below. These described embodiments are only exemplary of the present invention. Additionally, in an effort to provide a concise description of these exemplary embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the

development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0019] Certain exemplary embodiments of the present invention include systems and methods for using an annular seal configured to expand radially when subjected to an axial force. More specifically, the annular seal may include a top seal section, a bottom seal section, and a core seal section. The core seal section may include non-orthogonal top and bottom faces when in a non-deformed shape. In addition, when in the non-deformed shape, the annular seal may be capable of being run into a wellhead while leaving a gap between the annular seal and inner and outer bodies through which the annular seal is run. This gap may reduce the likelihood of damage, such as extrusion.

[0020] When the axial force is exerted on the annular seal, the core seal section may expand radially, causing the annular seal to form a seal between the inner and outer bodies. In addition, the axial force may also cause the top and bottom faces of the core seal section to be deformed into an orthogonal alignment, causing the annular seal to form a seal between upper and lower bodies above and below the annular seal, respectively. In certain embodiments, the top and bottom seal sections may be configured to urge the top and bottom faces of the core seal section into the orthogonal alignment. For example, the top and bottom seal sections may be formed of harder materials pre-loaded in a manner biased toward orthogonal alignment of the top and bottom faces of the core seal section.

[0021] As will be appreciated, in the present context described herein, when the top and bottom faces of the core seal section are described as non-

orthogonal when in a non-deformed shape, this means that the top and bottom faces of the core seal section do not form perpendicular surfaces relative to radially inner and outer faces of the core seal section. In other words, the top and bottom faces are not flat or parallel to a radial axis of the core seal section. Conversely, when the top and bottom faces of the core seal section are described as being brought into an orthogonal alignment when in a deformed shape due at least in part to the axial force, this means that the top and bottom faces of the core seal section are deformed in such a way that the top and bottom faces form substantially perpendicular surfaces relative to the radially inner and outer faces of the core seal section. In other words, the top and bottom faces become substantially flat and parallel to the radial axis of the core seal section.

[0022] FIG. 1 is a block diagram that illustrates an embodiment of a mineral extraction system 10. As discussed below, one or more seals may be employed throughout the system 10. The illustrated mineral extraction system 10 may be configured to extract various minerals and natural resources, including hydrocarbons (e.g., oil and/or natural gas), from the earth, or to inject substances into the earth. In some embodiments, the mineral extraction system 10 is land-based (e.g., a surface system) or sub-sea (e.g., a sub-sea system). As illustrated, the system 10 includes a wellhead 12 coupled to a mineral deposit 14 via a well 16. The well 16 may include a wellhead hub 18 and a well bore 20. The wellhead hub 18 generally includes a large diameter hub disposed at the termination of the well bore 20 and designed to connect the wellhead 12 to the well 16.

[0023] The wellhead 12 may include multiple components that control and regulate activities and conditions associated with the well 16. For example, the wellhead 12 generally includes bodies, valves, and seals that route produced minerals from the mineral deposit 14, regulate pressure in the well 16, and inject chemicals down-hole into the well bore 20. In the illustrated embodiment, the wellhead 12 includes what is colloquially referred to as a Christmas tree 22 (hereinafter, a "tree"), a tubing spool 24, a casing spool 26, and a hanger 28 (e.g.,

a tubing hanger and/or a casing hanger). The system 10 may include other devices that are coupled to the wellhead 12, and devices that are used to assemble and control various components of the wellhead 12. For example, in the illustrated embodiment, the system 10 includes a running tool 30 suspended from a drill string 32. In certain embodiments, the running tool 30 is lowered (e.g., run) from an offshore vessel to the well 16 and/or the wellhead 12. In other embodiments, such as surface systems, the running tool 30 may include a device suspended over and/or lowered into the wellhead 12 via a crane or other supporting device.

[0024] The tree 22 generally includes a variety of flow paths (e.g., bores), valves, fittings, and controls for operating the well 16. For instance, the tree 22 may include a frame that is disposed about a tree body, a flow-loop, actuators, and valves. Further, the tree 22 may provide fluid communication with the well 16. For example, the tree 22 includes a tree bore 34. The tree bore 34 provides for completion and workover procedures, such as the insertion of tools into the well 16, the injection of various chemicals into the well 16, and so forth. Further, minerals extracted from the well 16 (e.g., oil and natural gas) may be regulated and routed via the tree 22. For instance, the tree 22 may be coupled to a jumper or a flowline that is tied back to other components, such as a manifold. Accordingly, produced minerals may flow from the well 16 to the manifold via the wellhead 12 and/or the tree 22 before being routed to shipping or storage facilities. A blowout preventer (BOP) 36 may also be included, either as a part of the tree 22 or as a separate device. The BOP may consist of a variety of valves, fittings, and controls to prevent oil, gas, or other fluid from exiting the well in the event of an unintentional release of pressure or an overpressure condition.

[0025] The tubing spool 24 provides a base for the tree 22. Typically, the tubing spool 24 is one of many components in a modular sub-sea or surface mineral extraction system 10 that is run from an offshore vessel or surface system. The tubing spool 24 includes a tubing spool bore 38. The tubing spool bore 38 connects (e.g., enables fluid communication between) the tree bore 34 and the well 16. Thus, the tubing spool bore 38 may provide access to the well

bore 20 for various completion and workover procedures. For example, components can be run down to the wellhead 12 and disposed in the tubing spool bore 38 to seal off the well bore 20, to inject chemicals down-hole, to suspend tools down-hole, to retrieve tools down-hole, and so forth.

[0026] The well bore 20 may contain elevated pressures. For example, the well bore 20 may include pressures that exceed 10,000, 15,000, or even 20,000 pounds per square inch (psi). Accordingly, the mineral extraction system 10 may employ various mechanisms, such as seals, plugs, and valves, to control and regulate the well 16. For example, plugs and valves are employed to regulate the flow and pressures of fluids in various bores and channels throughout the mineral extraction system 10. For instance, the illustrated hanger 28 (e.g., tubing hanger or casing hanger) is typically disposed within the wellhead 12 to secure tubing and casing suspended in the well bore 20, and to provide a path for hydraulic control fluid, chemical injections, and so forth. The hanger 28 includes a hanger bore 40 that extends through the center of the hanger 28, and that is in fluid communication with the tubing spool bore 38 and the well bore 20. One or more seals may be disposed between the hanger 28 and the tubing spool 24 and/or the casing spool 26.

[0027] FIG. 2 depicts a partial cross-section of the casing spool 26 and the hanger 28 of FIG. 1. The hanger 28 includes a seal assembly 42, which may provide the sealing for the hanger 28 against the wellhead 12 (e.g., against the casing spool 26). The casing spool 26 includes a landing assembly 44 that provides for landing of the hanger 28.

[0028] In certain embodiments, the landing assembly 44 may include a bottom landing ring 46, a hanger lockdown ring 48, a lockdown actuation ring 50, and a top landing ring 52. The bottom landing ring 46 may be threaded to the hanger 28. The landing assembly 44 may locate the hanger 28 in place and may be locked into position via the hanger lockdown ring 48 by radially engaging recesses 54 of the wellhead 12 (e.g., the casing spool 26). Once the landing assembly 44 is locked into place, the landing assembly 44 (and the hanger 28)

may be locked by actuation of the lockdown actuation ring 50 such that the hanger lockdown ring 48 is locked radially into the recesses 54 of the wellhead 12. The hanger 28 may be adjusted by rotating the hanger 28 via the threads such that the hanger 28 moves along the bottom landing ring 46.

[0029] The top landing ring 52 may also be threaded to the hanger 28. In certain embodiments, the top landing ring 52 and bottom landing ring 46 may both couple to the hanger 28 via the same outer diameter threads. The top landing ring 52 may also be coupled to the bottom landing ring 46 via a protrusion 56 (e.g., a tongue) that engages a recess 58 of the bottom landing ring 46. As such, the top landing ring 52 may rotate in sync with the bottom landing ring 46 but may not allow load transfer between the top landing ring 52 and the bottom landing ring 46. In other embodiments, the top landing ring 52 may be coupled to the bottom landing ring 46 via a key and keyway, a castellation feature, or any other suitable mechanism. The protrusion 56 may provide a gap 60 between the bottom landing ring 46 and the top landing ring 52. As a result of the engagement between the top landing ring 52 and the bottom landing ring 46, the top landing ring 52 may isolate any vertical movement of the hanger 28 as a result of pressure either below or above the hanger 28 from the bottom landing ring 46. The top landing ring 52 “rides along” with any movement of the hanger 28 without transferring or off-loading any load, thus preventing damage to the hanger lockdown ring 48 and maintaining integrity of the hanger lockdown ring 48.

[0030] In certain embodiments, the seal assembly 42 may include a lower seal body 62, a lower test seal 64, an inner metal seal assembly 66, a middle seal body 68, an outer metal seal assembly 70, an upper seal body 72, an upper test seal 74, an upper seal actuation ring 76, and a carrier nut 78. The lower seal body 62 may abut the top landing ring 52 when the hanger 28 is installed, landed, and sealed in the wellhead 12. The middle seal body 68 may be connected to the lower seal body 62 at seal 80, such that both the lower test seal 64 and the inner metal seal assembly 66 fit between the middle seal body 68 and the lower seal body 62. In certain embodiments, the inner metal seal assembly 66 may include a pair of Canh seals, such as R-Canh or MRD-Canh seals. The upper

seal body 72 may be connected to the middle seal body 68 at seal 82, such that the outer metal seal assembly 70 fits between the upper seal body 72 and the middle seal body 68. Again, in certain embodiments, the outer metal seal assembly 70 may include a pair of Canh seals, such as R-Canh or MRD-Canh seals. In addition, the upper seal body 72 may be connected to the upper seal actuation ring 76 at seal 84, such that the upper test seal 74 fits between the upper seal body 72 and the upper seal actuation ring 76.

[0031] The upper test seal 74 and the lower test seal 64 may generally be retracted radially while the hanger 28 is run into the wellhead 12, and expanded radially once the hanger 28 is landed and sealed in the wellhead 12. For example, FIGS. 3A and 3B depict partial cross-sections of an exemplary annular seal 86 in a non-deformed ("pre-loaded") shape and a deformed ("loaded") shape, respectively. The annular seal 86 may, for instance, be either the lower test seal 64 or the upper test seal 74, illustrated in FIG. 2. The annular seal 86 may be located between a radially outer body 88, an upper radially inner body 90, and a lower radially inner body 92. In addition, the upper inner body 90 and the lower inner body 92 may be separated by another seal 94. For instance, if the annular seal 86 is the upper test seal 74 of FIG. 2, the outer body 88 may be the casing spool 26, the upper inner body 90 may be the upper seal actuation ring 76, and the lower inner body 92 may be the upper seal body 72. However, if the annular seal 86 is the lower test seal 64 of FIG. 2, the outer body 88 may be the casing spool 26, the upper inner body 90 may be the middle seal body 68, and the lower inner body 92 may be the lower seal body 62. Furthermore, although illustrated in FIGS. 3A and 3B as being installed between the outer body 88, the upper inner body 90, and the lower inner body 92, the annular seal 86 described herein may be installed within any combination of radially inner and outer bodies and axially upper and lower bodies.

[0032] The annular seal 86 may have a cross-sectional composition generally comprised of three sections, e.g., a core seal section 96, a top seal section 98, and a bottom seal section 100. As illustrated, the core seal section 96 is axially between the top and bottom seal sections 98 and 100. The core seal section 96

may be comprised of an elastomer or rubber material while the top seal section 98 and bottom seal section 100 may be comprised of harder materials, such as fabric and certain metals. In particular, the top seal section 98 and the bottom seal section 100 may be configured to urge top and bottom faces of the core seal section 96 into an orthogonal alignment, which may form a seal with the upper inner body 90 and the lower inner body 92. In other words, the top seal section 98 and the bottom seal section 100 may urge the top and bottom faces of the core seal section 96 into a substantially parallel alignment with respect to a radial axis of the core seal section 96 to close the gap of the bore. For instance, the top seal section 98 and the bottom seal section 100 may be pre-loaded in a manner which may tend to urge top and bottom faces of the core seal section 96 toward an alignment which is substantially perpendicular to radially inner and outer faces of the core seal section 96 across the entire surface of the top and bottom faces. In addition, in certain embodiments, the annular seal 86 may include one or more radially inner grooves 102 and one or more radially outer grooves 104 for increasing the sealing volume.

[0033] As described above, while the hanger 28 is being run into the wellhead 12, the annular seal 86 may be retracted radially. In other words, the annular seal 86 may be configured such that when in a non-deformed ("pre-loaded") shape, the annular seal 86 has a cross-section with non-orthogonal top and bottom faces and the radial width of the cross-section of the annular seal 86 is approximately equal to the radial width W_{UIB} between a radially inner face 106 and a radially outer face 108 of the upper inner body 90, leaving a gap W_{gap} between the annular seal 86 and the outer body 88. In other words, the total radial width W_{total} between the radially inner face 106 of the upper inner body 90 and the outer body 88 may be equal to the radial width W_{UIB} between the radially inner face 106 and the radially outer face 108 of the upper inner body 90 plus the gap W_{gap} . Since there is a gap W_{gap} between the annular seal 86 and the outer body 88 while the hanger 28 is being run into the wellhead 12, the annular seal 86 may be less susceptible to extrusion while, for instance, running through the BOP 36. As such, the annular seal 86 may remain capable of creating tighter

seals over the life of the annular seal 86 since damage from extrusion during installation is minimized.

[0034] Once the hanger 28 is landed and sealed in the wellhead 12, the annular seal 86 may expand radially as the annular seal 86 deforms into a deformed (“loaded”) shape having a cross-section with substantially orthogonal top and bottom faces. In other words, the top and bottom faces may be deformed into being substantially parallel to a radial axis of the annular seal 86. This is due at least in part to the force of the axial load F_{axial} that is distributed between the upper inner body 90 and the lower inner body 92 once the hanger 28 is landed in the wellhead 12. The axial force F_{axial} is created at least in part by the weight of the components above the annular seal 86. As the axial force F_{axial} is applied to the annular seal 86, the core seal section 96 of the annular seal 86 may deform (e.g., axial compression) such that the radial width of the annular seal 86 increases to the total radial width W_{total} between the radially inner face 106 of the upper inner body 90 and the outer body 88 (e.g., radial expansion). More specifically, portions of the core seal section 96 may deform from the top and bottom of the core seal section 96, decreasing the height (e.g., axial compression) of the core seal section 96 but increasing the radial width (e.g., radial expansion) of the core seal section 96. The degree of radial expansion of the core seal section 96 may vary based on the particular geometries used, materials used for the core seal section 96, the amount of the axial force F_{axial} , and so forth. However, in certain embodiments, the core seal section 96 may expand radially by 5-10% or more of the radial width of the annular seal 86. As the radial width of the annular seal 86 increases, the annular seal 86 may gradually apply a radial force F_{radial} between the radially inner face 106 of the upper inner body 90 and the outer body 88, creating a seal between the bodies. Also, as illustrated in FIGS. 3A and 3B, the two grooves 102, 104 may slightly deform under the stresses caused by F_{axial} and F_{radial} , increasing the sealing volume.

[0035] The particular cross-sectional profile of the core seal section 96 of the annular seal 86 may vary between embodiments. FIGS. 4 through 12 illustrate

exemplary embodiments of the annular seal 86 with varying core seal section 96 profiles. For instance, FIG. 4 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having a substantially constant axial cross-sectional height (e.g., axial distance) from a radially inner face 110 of the core seal section 96 to an axial centerline 112 of the core seal section 96 and a linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the axial centerline 112 to a radially outer face 114 of the core seal section 96. In other words, a top face 116 and a bottom face 118 of the core seal section 96 may be characterized as having a substantially orthogonal (e.g., perpendicular to the axial centerline 112 and parallel to a radial centerline 120) section between the radially inner face 110 and the axial centerline 112 and an outwardly angled (e.g., diverging) section between the axial centerline 112 and the radially outer face 114. More specifically, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may be substantially constant from the radially inner face 110 to the axial centerline 112 and may increase linearly from the axial centerline 112 to the radially outer face 114.

[0036] Conversely, FIG. 5 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having a linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to the axial centerline 112 of the core seal section 96 and a substantially constant axial cross-sectional height (e.g., axial distance) from the axial centerline 112 to the radially outer face 114 of the core seal section 96. In other words, the bottom face 116 and the top face 118 of the core seal section 96 may be characterized as having an inwardly angled (e.g., converging) section between the radially inner face 110 and the axial centerline 112 and a substantially orthogonal (e.g., perpendicular to the axial centerline 112 and parallel to a radial centerline 120) section between the axial centerline 112 and the radially outer face 114. More specifically, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may decrease linearly from the radially inner face 110 to the axial

centerline 112 and may be substantially constant from the axial centerline 112 to the radially outer face 114.

[0037] FIG. 6 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having a linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to the axial centerline 112 of the core seal section 96 and a linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the axial centerline 112 to the radially outer face 114 of the core seal section 96. In other words, the bottom face 116 and the top face 118 of the core seal section 96 may be characterized as having an outwardly angled (e.g., diverging) section between the radially inner face 110 and the axial centerline 112 and an inwardly angled (e.g., converging) section between the axial centerline 112 and the radially outer face 114, with the high point 122 of the profile occurring generally at the axial centerline 112. More specifically, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may increase linearly from the radially inner face 110 to the axial centerline 112 and may decrease linearly from the axial centerline 112 to the radially outer face 114.

[0038] Conversely, FIG. 7 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having a linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to the axial centerline 112 of the core seal section 96 and a linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the axial centerline 112 to the radially outer face 114 of the core seal section 96. In other words, the bottom face 116 and the top face 118 of the core seal section 96 may be characterized as having an inwardly angled (e.g., converging) section between the radially inner face 110 and the axial centerline 112 and an outwardly angled (e.g., diverging) section between the axial centerline 112 and the radially outer face 114, with the low point 124 of the profile occurring generally at the axial centerline 112. More specifically, the axial distance between the top and bottom faces 116, 118 and the radial

centerline 120 of the core seal section 96 may decrease linearly from the radially inner face 110 to the axial centerline 112 and may increase linearly from the axial centerline 112 to the radially outer face 114.

[0039] FIG. 8 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having a non-linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to the axial centerline 112 of the core seal section 96 and a non-linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the axial centerline 112 to the radially outer face 114 of the core seal section 96. More specifically, the bottom face 116 and the top face 118 of the core seal section 96 may be characterized as having a concave profile from the radially inner face 110 to the radially outer face 114, with the low point 124 of the concave profile occurring generally at the axial centerline 112. As such, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may decrease non-linearly from the radially inner face 110 to the axial centerline 112, consistent with the concave profile of the top and bottom faces 116, 118. Similarly, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may increase non-linearly from the axial centerline 112 to the radially outer face 114, consistent with the concave profile of the top and bottom faces 116, 118.

[0040] Conversely, FIG. 9 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having a non-linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to the axial centerline 112 of the core seal section 96 and a non-linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the axial centerline 112 to the radially outer face 114 of the core seal section 96. More specifically, the bottom face 116 and the top face 118 of the core seal section 96 may be characterized as having a convex profile from the radially inner face 110 to the radially outer face 114, with the high point 122 of the convex profile occurring generally at the axial centerline

112. As such, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may increase non-linearly from the radially inner face 110 to the axial centerline 112, consistent with the convex profile of the top and bottom faces 116, 118. Similarly, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may decrease non-linearly from the axial centerline 112 to the radially outer face 114, consistent with the convex profile of the top and bottom faces 116, 118.

[0041] FIG. 10 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having an asymmetrical, linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to the axial centerline 112 of the core seal section 96 and an asymmetrical, linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the axial centerline 112 to the radially outer face 114 of the core seal section 96. More specifically, in the illustrated embodiment, the top face 116 of the core seal section 96 may be characterized as having a substantially orthogonal (e.g., perpendicular to the axial centerline 112 and parallel to the radial centerline 120) section between the radially inner face 110 and the axial centerline 112 and an outwardly angled (e.g., diverging) section between the axial centerline 112 and the radially outer face 114. However, conversely, the bottom face 118 of the core seal section 96 may be characterized as having an inwardly angled (e.g., converging) section between the radially inner face 110 and the axial centerline 112 and a substantially orthogonal (e.g., perpendicular to the axial centerline 112 and parallel to the radial centerline 120) section between the axial centerline 112 and the radially outer face 114. As such, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may decrease linearly from the radially inner face 110 to the axial centerline 112 and may increase linearly from the axial centerline 112 to the radially outer face 114.

[0042] Although FIGS. 4 through 10 illustrate the core seal section 96 have two sections about the axial centerline 112, the axial centerline 122 may actually be any axial datum along the radial width of the core seal section 96. In other words, the transition between sections of the core seal section 96 between the radially inner face 110 and the radially outer face 114 may occur at other locations along the top and bottom faces 116, 118. For example, a transition may occur at a point 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, or 95% of the radial distance between the radially inner face 110 and the radially outer face 114. Indeed, transitions may occur at any point along the top and bottom faces 116, 118. In addition, in certain embodiments, more than one transition may occur along the top and bottom faces 116, 118, creating more than two varying cross-sectional profile sections.

[0043] For instance, FIG. 11 illustrates an exemplary embodiment of an annular seal 86 with a core seal section 96 having more than two varying cross-sectional profile sections. In particular, FIG. 11 depicts an annular seal 86 with a core seal section 96 having a linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to a first axial datum 126 of the core seal section 96, a substantially constant axial cross-sectional height (e.g., axial distance) from the first axial datum 126 to a second axial datum 128 of the core seal section 96, and a linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the second axial datum 128 to the radially outer face 114 of the core seal section 96. In other words, the bottom face 116 and the top face 118 of the core seal section 96 may be characterized as having an outwardly angled (e.g., diverging) section between the radially inner face 110 and the first axial datum 126, a substantially orthogonal (e.g., perpendicular to the first axial datum 126 and the second axial datum 128 and parallel to the radial centerline 120) section between the first axial datum 126 and the second axial datum 128, and another outwardly angled (e.g., diverging) section between the second axial datum 128 and the radially outer face 114. More specifically, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the

core seal section 96 may increase linearly from the radially inner face 110 to the first axial datum 126, may be substantially constant from the first axial datum 126 to the second axial datum 128, and may increase linearly from the second axial datum to the radially outer face 114.

[0044] FIG. 12 illustrates another exemplary embodiment of an annular seal 86 with a core seal section 96 having more than two varying cross-sectional profile sections. In particular, FIG. 12 depicts an annular seal 86 with a core seal section 96 having a linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the radially inner face 110 of the core seal section 96 to the first axial datum 126 of the core seal section 96, a linearly increasing (e.g., diverging) axial cross-sectional height (e.g., axial distance) from the first axial datum 126 to the second axial datum 128 of the core seal section 96, and a linearly decreasing (e.g., converging) axial cross-sectional height (e.g., axial distance) from the second axial datum 128 to the radially outer face 114 of the core seal section 96. In other words, the bottom face 116 and the top face 118 of the core seal section 96 may be characterized as having an inwardly angled (e.g., converging) section between the radially inner face 110 and the first axial datum 126, an outwardly angled (e.g., diverging) section between the first axial datum 126 and the second axial datum 128, and another inwardly angled (e.g., converging) section between the second axial datum 128 and the radially outer face 114. More specifically, the axial distance between the top and bottom faces 116, 118 and the radial centerline 120 of the core seal section 96 may decrease linearly from the radially inner face 110 to the first axial datum 126, may increase linearly from the first axial datum 126 to the second axial datum 128, and may decrease linearly from the second axial datum to the radially outer face 114.

[0045] Therefore, as illustrated in FIGS. 3 through 12, the specific cross-sectional geometries of the core seal section 96 may vary between embodiments. However, all of the embodiments illustrated are characterized by substantially non-orthogonal (e.g., not substantially parallel to the radial centerline 120) top and bottom faces 116, 118. As such, as illustrated in FIG. 3B, as the axial force

F_{axial} is applied to the top and bottom faces 116, 118 of the core seal section 96, the core seal section 96 may expand radially while the top and bottom faces 116, 118 are forced into a substantially orthogonal (e.g., substantially parallel to the radial centerline 120) shape between the upper inner body 90 and the lower inner body 92. As the core seal section 96 expands radially, a radial force F_{radial} is gradually created between the outer body 88 and the upper inner body 90, creating a seal between these bodies.

[0046] While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

CLAIMS

1. A system, comprising:
an annular seal configured to mount between tubular components of a mineral extraction system, wherein the annular seal comprises:
a first layer;
a second layer; and
a core disposed axially between the first and second layers, wherein the core is made of a material softer than the first and second layers, and the first and/or second layers are configured to axially compress and radially expand under an axial load to cause radial expansion of the core.
2. The system of claim 1, wherein the first and/or second layers comprise geometries which are angled and/or curved at least partially non-orthogonal to the axial load.
3. The system of claim 1, wherein the first and/or second layers comprise convex and/or concave surfaces.
4. The system of claim 1, wherein the first and/or second layers comprise angled surfaces having an angle at least greater than about 10 degrees relative to a radial direction of the radial expansion, and the angled surfaces extend along at least about 10 percent of a radial width of the annular seal.
5. The system of claim 1, wherein the first and/or second layers comprise zigzagging surfaces.
6. The system of claim 1, wherein the first and/or second layers are configured to radially expand by at least about 5 percent of a radial width of the annular seal in response to the axial compression caused by the axial load.