



(51) International Patent Classification:

E21B 33/04 (2006.01) *B33Y 80/00* (2015.01)
F16J 15/08 (2006.01)

(21) International Application Number:

PCT/US2023/073851

(22) International Filing Date:

11 September 2023 (11.09.2023)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

17/943,993 13 September 2022 (13.09.2022) US

(71) Applicant: **BAKER HUGHES OILFIELD OPERATIONS LLC** [US/US]; 17021 Aldine Westfield, Houston, TX 77073 (US).

(72) Inventors: **WALKER, Laura**; c/o Baker Hughes Oilfield Operations LLC, 17021 Aldine Westfield Road, Houston, TX 77073 (US). **ADAMS, Keith**; c/o Baker Hughes Oilfield Operations LLC, 17021 Aldine Westfield road, Houston, TX 77073 (US). **MUNK, Brian**; c/o Baker Hughes Oilfield Operations LLC, 17021 Aldine Westfield Road, Houston, TX 77073 (US). **VALERA, Lauren**; c/o Baker Hughes Oilfield Operations LLC, 17021 Aldine Westfield Road,

Houston, TX 77073 (US). **MITELMAN, Guy**; c/o Baker Hughes Oilfield Operations LLC, 17021 Aldine Westfield Road, Houston, TX 77073 (US). **CHENG, Samuel**; c/o Baker Hughes Oilfield Operations LLC, 17021 Aldine Westfield Road, Houston, TX 77073 (US).

(74) Agent: **POLLANDER, Laura et al.**; 17021 Aldine Westfield, Houston, TX 77073 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ,

(54) Title: PRINTED ANNULAR METAL-TO-METAL SEAL

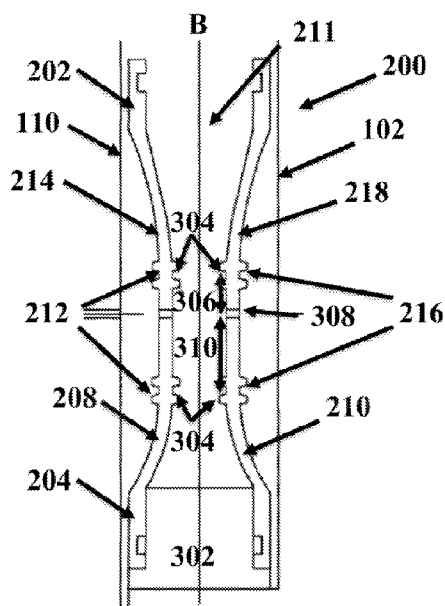


Fig. 3

(57) Abstract: A metal-to-metal seal for sealing an annular space between a well casing and a wellbore. The seal includes an inner portion and an outer portion, each portion including a central seal portion. The central seal portion has a concave shape in a de-energized state which curves towards the centerline of the seal and is capable of flexing radially outward towards surface of the annular space when energized. The central seal portion further includes at least one outer ridge extending outward away from the centerline of the seal and sealingly engages with the outer annular surface when energized.

DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT,
LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE,
SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN,
GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

PRINTED ANNULAR METAL-TO-METAL SEAL

Cross-Reference to Related Applications

[0001] This application is a continuation-in-part of U.S. Patent Application No. 17/587,774,
5 titled “PRINTED ANNULAR METAL-TO-METAL SEAL,” filed January 28, 2022, the full
disclosure of which is hereby incorporated by reference in its entirety for all purposes.

Background

Field of Invention

10 [0002] This invention relates in general to fluid control in annular spaces, and more particularly,
to annular seals to prevent fluid movement through an annular space.

Description of the Prior Art

[0003] Oil and gas field operations typically involve drilling and operating wells to locate and
retrieve hydrocarbons. A completed well typically includes multiple annular spaces between
15 various components. These can include annuli between production tubing and production casing,
between different levels of casing, and finally between the outermost casing and the formation.
The annuli are named starting at the inner-most annulus, which is designated the A-annulus, with
increasing alphabetical designations for each annulus moving outward.

[0004] At times during the life of a well, it can be necessary to plug one or more of the annuli at
20 certain locations both permanently and temporarily. This can be done to prevent fluid
communication in different sections of the well and can be used both for maintenance and
environmental purposes. The annular seals are often placed using a casing hanger system in order
to position them at certain depths of the well.

[0005] Current annular seals have a number of deficiencies which can limit their effectiveness. Exposed sealing ridges can contact both the inner and outer surfaces of the annulus during the process of positioning the seal in the annular space. This can result in damage both to the surfaces of the annular space as well as the sealing ridges which can lead to incomplete sealing upon
5 activation. When in position, current annular seals often require large mechanical forces to energize and seal the annular space. Further, repeated sealing in the same location can cause wear on the inner and outer annular walls. This can result in incomplete sealing at the same location over time.

Summary

10 [0006] One embodiment of the present technology provides for an annular metal-to-metal seal including an inner seal portion and an outer seal portion each seal portion further including a central seal portion. In some embodiments the central seal portion can have a concave shape in a de-energized state that curves towards a centerline of the seal. In other embodiments, the central seal portion can be capable of flexing radially outward upon energization of the seal. In alternate
15 embodiments there can be at least one outer ridge extending radially outward from the central seal portion of the outer portion of the seal away from the centerline of the seal. In some embodiments, the at least one outer ridge can sealingly engage with an outer annular surface when energized.

[0007] In alternate embodiments, there can be at least one inner ridge extending radially outward from the central seal portion of the inner portion of the seal away from the centerline of the seal.

20 In some embodiments, the at least one inner ridge can sealingly engage with the inner annular surface when energized.

[0008] In some embodiments, there can be outer and inner concave central seal surfaces which define a recess between the two central seal surfaces. In other embodiments, there can be at least

one intra-seal ridge extending from the outer concave central seal portion. In some embodiments, the at least one intra-seal ridge can sealingly engage with a plunger when energized.

[0009] In alternate embodiments, there can be at least one central ridge extending from the inner concave central seal portion. In some embodiments, the at least one central ridge can sealingly
5 engage with a plunger when energized.

[0010] In other embodiments, the at least one outer ridge can include a plurality of outer ridges. In some embodiments, the plurality of ridges can be positioned at predetermined locations along the central portion of the seal.

[0011] Some embodiments can provide for a seal for sealing between the outer and inner seal
10 portions. In some embodiments that seal can be a plunger sealing surface, an intra-seal seal, or a tab seal. In certain embodiments, insertion of a plunger can energize the plunger sealing surface or tab seal.

[0012] In other embodiments, the inner seal portion and outer seal portion can be made with additive manufacturing. In some embodiments the ridges can be a different material of
15 construction than the central portion of the seal.

[0013] A second embodiment of the present technology provides for a method for sealing an annular space of a well. The embodiment can provide for selecting an inner seal portion based on the inner diameter of the annular space, and selecting an outer seal portion based on an outer
20 diameters of the annular space. These seal portions can be combined to form a metal-to-metal annular seal in embodiments. In some embodiments, a metal-to-metal annular seal can be inserted into the annular space. In some embodiments, the inner portion can have inner biased concave central sealing surface and the outer portion can have an outer biased concave central sealing surface. In other embodiments, a plunger can be inserted into the first end of the annular seal. In

alternative embodiments, the plunger can energize the inner and outer biased concave central sealing surfaces of the annular seal by pushing the surfaces towards the annular surfaces within the annular space. In some embodiments, this can result in sealing engagement between the inner and outer biased concave central sealing surfaces and the annular surfaces of the annular space.

5 **[0014]** In other embodiments, there can be ridges on the inner and outer biased concave central sealing surfaces. In alternate embodiments these ridges can sealingly engage with the annular surfaces of the annular space. In some embodiments, the seal can be tested after engaging the sealing surfaces to test for a proper seal. In these embodiments, additional sealing surfaces can be engaged if it is determined that the annular space is not properly sealed.

10 **[0015]** Some embodiments can include a step of selecting a sealing system for sealing between the inner and outer seal portions. In some embodiments the plunger can provide sealing engagement between the inner and outer seal portions.

15 **[0016]** A third embodiment of the present technology provides for a method for resealing an annular space. In some embodiments, the plunger can be removed from the first end of the annular metal-to-metal seal and the seal can be removed from the annular space. In other embodiments the an inner seal portion and/or an outer seal portion can be replaced. In alternate embodiments, the seal can be reinserted into the annular space. In some embodiments, the plunger can be inserted into the seal to re-energize the seal.

20 **[0017]** In some embodiments, replacing the seal portions can change the location of a sealing ridge on the seal portion. In other embodiments, the method can further comprise changing a seal type for sealing between the inner and outer seal portions.

[0018] In some embodiments, the seal can be placed in a substantially similar in the annular space both before removal and after re-insertion. In other embodiments, the ridges can engage in substantially different locations before removal and after re-insertion into the annular space.

Brief Description of the Drawings

[0019] The present technology will be better understood on reading the following detailed description of non-limiting embodiments thereof, and on examining the accompanying drawings, in which:

5 **[0020]** Figure 1 is a schematic view of an embodiment of a system that includes a production tubular and injection apparatus.

[0021] Figure 2 is an isometric view of a sample annular metal-to-metal seal.

[0022] Figure 3 is a schematic cross-sectional view of a sample annular metal-to-metal seal prior to the insertion of a plunger.

10 **[0023]** Figure 4A is a schematic cross-sectional view of a sample annular metal-to-metal seal after a plunger has been inserted into the open first end of the seal.

[0024] Figure 4B is a schematic cross-sectional view of a sample annular metal-to-metal seal with plunger fully inserted into the seal.

15 **[0025]** Figure 5A is a schematic cross-sectional view of a sample embodiment of an annular metal-to-metal seal with a tapered plunger partially inserted.

[0026] Figure 5B is a schematic cross-sectional view of a sample embodiment of an annular metal-to-metal seal with a tapered plunger fully inserted.

[0027] Figure 6 is a schematic cross-sectional view of a sample embodiment of an annular metal-to-metal seal with a tapered plunger and additional sealing ridges.

[0028] Figure 7A is a block diagram of steps to seal an annular space using an annular metal-to-metal seal.

[0029] Figure 7B is a block diagram of steps to unseal an annular space using an annular metal-to-metal seal.

5 [0030] Figure 7C is a block diagram of steps to rescal an annular space using the same annular metal-to-metal seal.

[0031] Figure 8 is a schematic cross-sectional view of a sample embodiment of an annular metal-to-metal seal with a bulbous plunger partially inserted.

10 [0032] Figure 9 is a schematic cross-sectional view of a sample embodiment of a split annular metal-to-metal seal.

[0033] Figure 10A is a schematic cross-sectional view of a sample split annular metal-to-metal seal with plunger sealing locations.

[0034] Figure 10B is a schematic cross-sectional view of a sample split annular metal-to-metal seal with intra-seal seal.

15 [0035] Figure 10C is a schematic cross-sectional view of a sample split annular metal-to-metal seal with an alternative intra-seal seal.

[0036] Figure 11A is a schematic cross-sectional view of a sample split annular metal-to-metal with an unengaged tab seal.

20 [0037] Figure 11B is a schematic cross-sectional view of a sample split annular metal-to-metal with an engaged tab seal.

[0038] Figure 12 is a block diagram of steps to seal an annular space using a split metal-to-metal seal.

Detailed Description

[0039] The foregoing aspects, features and advantages of the present technology will be further appreciated when considered with reference to the following description of preferred embodiments and accompanying drawings, wherein like reference numerals represent like elements. In describing the preferred embodiments of the technology illustrated in the appended drawings, specific terminology will be used for the sake of clarity. The present technology, however, is not intended to be limited to the specific terms used, and it is to be understood that each specific term includes equivalents that operate in a similar manner to accomplish a similar purpose.

[0040] When introducing elements of various embodiments of the present invention, the articles “a,” “an,” “the,” and “said” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. Any examples of operating parameters and/or environmental conditions are not exclusive of other parameters/conditions of the disclosed embodiments. Additionally, it should be understood that references to “one embodiment”, “an embodiment”, “certain embodiments,” or “other embodiments” of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Furthermore, reference to terms such as “above,” “below,” “upper”, “lower”, “side”, “front,” “back,” or other terms regarding orientation are made with reference to the illustrated embodiments and are not intended to be limiting or exclude other orientations.

[0041] Referring initially to Figure 1, there is shown an exemplary wellbore system **100** that includes a wellbore **102** drilled through an earth formation **104** and into a production zone or

reservoir **106**. The wellbore **102** is shown lined with a casing having a number of perforations **108** that penetrate and extend into the formation production zone **106** so that formation fluids or production fluids may flow from the production zone **106** into the wellbore **102**. The wellbore **102** includes a string (or production tubular) **110** that includes a tubular (also referred to as the “tubular string” or “base pipe”) **110** that extends downwardly from a wellhead **122** at surface **124** of the wellbore **102**. An annulus **120** is defined between the string **110** and the wellbore **102**, which may be an open or cased wellbore.

[0042] Injection assembly **126** is positioned at selected locations along the string **110**. Each injection assembly **126** may be isolated within the wellbore **102** by a pair of annular seals **128**.

Although only one injection assembly **126** is shown, any appropriate number of such injection assemblies **126** may be arranged along the string **110**. Annular seals **128** isolate discrete portions of the annulus **120**, thereby enabling pressure manipulation to control fluid flow in wellbore **102**.

[0043] Referring now to Figure 2, an annular metal-to-metal seal **200** is pictured. The seal has a first end **202** and second end **204** and a central portion **206**, as well as an inner generally cylindrical surface **208** and an outer generally cylindrical surface **210**. The seal generally circumscribes a central axis **A**. The outer surface **210** has a greater radius than the inner surface **208**. First end **202** of the seal can define a recess **211** in the central portion **206** between the inner surface **208** and outer surface **210** of the seal. Both the inner **208** and outer **210** surfaces are generally concave, with the outer surface **210** of central portion **206** curving generally inwardly toward the axis **A** of the seal **200** and the inner surface **208** of central portion **206** curving generally outwardly away from the axis **A** of the seal **200** between the first end **202** and the second end **204** of the seal.

[0044] As also shown in Figure 2, the inner surface **208** of the seal can include inner ridges **212**. The inner ridges **212** can be positioned on the inner concave central surface **214** of the central portion **206** of the seal and protrude from the inner concave central surface **214** of the seal toward the central axis **A**. Similarly, the outer surface **210** of the seal can include outer ridges **216**. The outer ridges **216** can be positioned on the outer concave central surface **218** of the central portion **206** of the seal and protrude from the outer concave central surface **218** of the seal away from the axis **A**. This positioning of the ridges **212**, **216** on the concave central surfaces **214**, **218** of the seal helps to protect the ridges **212**, **216** from contacting a casing or other tubular during setting of the seal.

[0045] Figure 3 shows a schematic cross-sectional view of the annular metal-to-metal seal **200**. Figure 3 provides additional detail of the second end **204** of the seal, including a seal cap **302**. The seal cap **302** can help to properly position the seal relative to the plunger (discussed below) and connects the inner surface **208** with the outer surface **210** of the seal **200**. The seal cap **302** can also or alternatively be installed on the first end **204** of the seal. This results in the seal **200** being reversable in the annular space.

[0046] Alternatively, the seal cap **302** can be an integral component of the seal **200** such that it cannot be removed. In this alternative configuration, the seal cap **302** may not be able to be moved to the first end **204** of the seal **200**.

[0047] In Figure 3, the ridges **212**, **216** are also shown in particular axial locations along the concave central surfaces **214**, **218** of the seal, and additional corresponding intra-seal ridges **304** are shown on inner surfaces of the recess **211**. The intra-seal ridges **304** face inward towards a centerline **B** of the recess **211**.

[0048] In the particular embodiment shown in Figure 3, the distance **306** between a centerline **308** of the seal and the ridges **212, 216, 304** located toward the first end **202** of the seal is less than the distance **310** between the centerline **308** of the seal and the ridges **212, 216, 304** located toward the second end **204** of the seal. If the seal is reoriented in the annular space, the distances **306** and **310** may also be reoriented, resulting in different sealing locations upon energization of the seal between the ridge **212, 216** and the string **110** and wellbore **102** than before the reorientation.

[0049] Figure 4A shows the seal in a de-energized state before a plunger **402** energizes the seal. The diameter of the plunger **402** can be substantially equal to the diameter **404** of the recess **211** at the first end **202** of the seal. The generally concave shape of the concave central surfaces **214, 218** of the seal results in a smaller diameter **406** between the concave central surfaces **214, 218** of the seal than the diameter **404** of the plunger **402**. As such, when the plunger **402** moves between the concave central surfaces **214, 218** of the seal, the inner and outer surfaces **208, 210** of the seal are pushed radially outward away from the centerline **B** of the recess **211**. This results in the energization of the seal, shown in Figure 4B.

[0050] The plunger **402** can have a tapered end **408**. The tapered end **408** can result in requiring less force to insert the plunger **402** into the first end **202** of the seal. Additionally, the tapered end **408** can also reduce the energy required to energize the seal as the plunger **402** passes between the concave central surfaces **214, 218** of the seal.

[0051] Figure 4B shows the seal after the plunger **402** energizes the seal. Here, the inner and outer surfaces **208** and **210** have been pushed radially outward relative to the centerline **B** of the recess **211** by the plunger **402**. As the plunger **402** pushes through the seal, intra-seal ridges **304** engage in sealing contact with the surfaces of the plunger **402**. At the same time, ridges **212, 216** have

been pushed by the plunger **402** radially toward the string **110** and wellbore **102** until the ridges **212**, **216** engage in sealing contact with the string **110** and wellbore **102**. In some embodiments, a plunger lip **410** can be provided to prevent the plunger from moving past a predetermined point relative to the first end **202** of the seal. This can help to prevent the plunger **402** from passing
5 through the seal during energization.

[0052] Alternatively, the plunger can enter the seal **200** from below instead of from above as shown in Figure 4A. This can occur when the seal **200** is reorientated in the annular space and has an integral second end instead of a seal cap **302**. In this embodiment, the plunger **402** can energize the seal **200** in the same way as described above. The first end **202**, however, is oriented towards
10 the bottom of the annular space instead of towards the top as shown in Figure 4A.

[0053] When it is desired to de-energize the seal, the reverse process occurs. The plunger **402** is removed from the seal. The central portion **206** of the seal can be biased so that without the plunger **402** the concave central surfaces **214**, **218** return to the generally concave positions shown in Figure 4A. This results in the ridges **212**, **216** moving out of sealing engagement with the string
15 **110** and wellbore **102**. Once the plunger **402** is completely removed from the annular seal and the seal has returned to the position in Figure 4A, the seal can be removed from the annular space. Upon removal of the seal, the ridges **212**, **216** are once again protected from contact with the string **110** and wellbore **102** of the annular space due to the return of the concave central surfaces **214**, **218** to their generally concave positions. Since the seal retains the same shape both before and
20 after sealing an annular space, the seal can be reused multiple times. Reuse in the same location is eased by flipping the seal and positioning in the same location of the annular space, which, as discussed above, results in changed locations of the ridges **212**, **216** relative to the string **110** and wellbore **102**.

[0054] Figures 5A and 5B show an alternate embodiment of an annular seal and plunger configuration. In this embodiment, the ridges **212, 216, 304** located above the centerline **308** and towards the first end **202** of the seal can be smaller than the ridges **212, 216, 304** located below the centerline **308** and towards the second end **204** of the seal. Additionally, the plunger **402** can include a midpoint taper **502** such that the upper end **504** of the plunger **402** can have a greater diameter than the lower end **506** of the plunger **402**. This can result in selective energization of different sealing ridges **212, 216, 304** during insertion of the plunger **402** based on the size of the different ridges **212, 216, 304** and location of the midpoint taper **502** on the plunger.

[0055] Figure 5A shows this alternate embodiment in a semi-energized configuration. In this configuration, the plunger **402** can be partially inserted into the seal such that the midpoint taper **502** has not moved past the ridges **212, 216, 304** above the centerline **308** and toward the first end **202** of the seal. As a result, the plunger **402** has not yet contacted the ridges **212, 216, 304** above the centerline **308** due to the smaller ridge size when compared to the ridges **212, 216, 304** below the centerline **308** and towards the second end **204** of the seal. In this embodiment, the ridges **212, 216, 304** above the centerline **308** of the seal are not sealingly engaged with the plunger **402**, the string **110**, or the wellbore **102**.

[0056] The ridges **212, 216, 304** below the centerline **308** can be in contact with the lower end **506** of the plunger **402** since the ridges **212, 216, 304** below the centerline **308** can be larger than the ridges **212, 216, 304** above the centerline **308** of the seal. This contact can cause the concave central surfaces **214, 218** below the centerline **308** to be pushed radially outward relative to the centerline **B** of the recess **211** by the plunger **402**. As a result, the ridges **212, 216, 304** below the centerline **308** of the seal can be sealingly engaged with the plunger **402**, the string **110**, and the wellbore **102**, while the ridges **212, 216, 304** above the centerline **308** of the seal need not be

sealingly engaged with the plunger **402**, the string **110**, or the wellbore **102**. In other words, the shape of the plunger **402**, the position of the plunger **402** in the recess **211**, and the size of the ridges **212**, **216**, **304** can be manipulated to effect sealing engagement between seal surfaces, the plunger **402**, the string **110**, and the wellbore **102** in different ways depending on the requirements of a particular drilling operation.

[0057] In the configuration of Figure 5A, the annular seal can be tested with only the ridges **212**, **216**, **304** below the centerline **308** of the seal sealingly engaged to determine if the configuration is sufficient to seal the annular space. If, upon testing, the annular space is not sealed, or if more assurance of sealing is needed, the plunger **402** can continue into the annular seal to the position depicted in Figure 5B.

[0058] Figure 5B shows the annular seal in a fully energized configuration. The plunger **402** can continue into the seal such that the midpoint taper **502** can pass the ridges **212**, **216**, **304** above the centerline **308** of the seal. This can result in contact between the ridges **212**, **216**, **304** above the centerline **308** and the plunger **402** which can cause the concave central surfaces **214**, **218** above the centerline **308** to be pushed radially outward relative to the centerline **B** of the recess **211** by the plunger **402**. In this way, the ridges **212**, **216**, **304** above the centerline **308** of the seal can be sealingly engaged with the plunger **402**, the string **110**, and the wellbore **102**. At the same time, the ridges **212**, **216**, **304** below the centerline **308** of the seal remain sealingly engaged with the plunger **402**, the string **110**, and the wellbore **102**, similar to Figure 5A. The midpoint taper **502** may not be able to move past the ridges **212**, **216**, **304** below the centerline **308** such that they are similarly engaged as in Figure 5A.

[0059] In configuration of Figure 5B, ridges **212**, **216**, **304** of the seal can be sealingly engaged with the plunger **402**, the string **110**, and the wellbore **102**, thereby sealing the annular space. The annular seal can be de-energized and removed from the annulus by removing the plunger **402** from the first end **202** of the seal. Without the plunger **402**, the concave central surfaces **214**, **218** return to their generally concave positions. This results in the ridges **212**, **216** moving out of sealing contact with the string **110** and wellbore **102**. Once the plunger **402** is completely removed from the annular seal, the seal can be removed from the annular space. The ridges **212**, **216** are once again protected from contact with the string **110** and wellbore **102** of the annular space during removal of the seal due to the generally concave shape of the concave central surfaces **214**, **218**. Since the seal retains the same shape both before and after sealing the annular space, the seal can be reused multiple times.

[0060] Figure 6 shows an alternate embodiment with multiple sets of ridges of variable size on the annular seal, and a tapered or stepped plunger **402** similar to that shown in Figures 5A and 5B. In the example embodiment shown, the seal can include a first set of ridges **602**, a second set of ridges **604**, a third set of ridges **606**, and a fourth set of ridges **608**, although any appropriate number of ridges can be used. Each set of ridges includes inner ridges **212**, outer ridges **216**, and inter-seal ridges **304**. In this embodiment, the first and second set of ridges **602**, **604** are smaller ridges. The third and fourth set of ridges **606**, **608** are larger. The sizes of the individual ridge sets can be varied according to the desired energization sequence of the seal.

[0061] In Figure 6, the seal is currently in a deenergized position as none of the ridge sets **602**, **604**, **606**, **608** have engaged with the plunger **402**. Energization of the first and second ridge sets **602**, **604** can occur when the upper end **504** of the plunger **402** engages with the ridge sets **602**, **604**. Energization of the third and fourth ridge sets **606**, **608** can occur when the lower end **506** of

the plunger **402** engages with the ridge sets **606**, **608**. When fully energized, the embodiment provides for four sets of sealing surfaces with the string **110** and wellbore **102**. Additionally, the plunger **402** can be removed from the annular seal so that the seal can be removed from the annular space when sealing is no longer needed and reused as required.

5 **[0062]** The annular seals can be made using additive manufacturing. Additive manufacturing can allow for the creation of the detailed ridges that form the sealing surfaces of the annular seal that may not be made using traditional machining methods. Additionally, additive manufacturing can result in a biased structure that can deform when energized, yet return to its original shape when deenergized, allowing for the annular seal to be reused multiple times.

10 **[0063]** Additive manufacturing can further allow the seal to be made with mixed materials. In this way, the material used for the sealing surfaces can be different from the material used to construct the body of the seal. For example, the sealing surface can be made of a highly corrosion resistant material while the rest of the seal is not made with highly corrosion resistant material. This can reduce the cost to manufacture the seal by not requiring the entire seal to be made from the more
15 expensive highly corrosion resistant material. Additionally, this can prolong the life of the seal as the sealing surfaces can be more resilient to chemical attacks with the change in materials of construction.

[0064] Figure 7A is a process for temporarily sealing an annular space with a metal-to-metal annular seal. The annular seal can first be placed in the annular space at the desired sealing location
20 in step **700**. Once the annular seal is in place, a plunger is inserted into the open end of the annular seal in step **702**. The open end can either be the first end towards the top of the seal, or the second end from the bottom of the seal. The plunger can continue into the recess or space between the

inner and outer surfaces of the annular seal in step **704**, thereby energizing the seal. The inner and outer surfaces of the annular seal can then be pushed radially outward relative to the plunger, resulting in the generally concave surfaces moving outward towards the walls of the annular space until the surfaces reach a sealed position in step **706**. Ridges on the inner and outer surfaces of the seal can make sealing contact with the string and wellbore of the annular space to seal the annular space in step **708**.

[0065] Figure 7A can be modified for annular seals with multiple sealing locations. A tapered or bulbous plunger can be used to set individual seal sets within the annular seal. With at least one set of seals engaged of the annular seal, the seal can then be tested to ensure that the space is properly sealed. If the annular space is properly sealed, the seal can remain in a partially engaged state. If the annular space is not properly sealed, the method of Figure 7A can be repeated from **704** to engage additional ridge sets on the seal until the annular space is properly sealed.

[0066] Figure 7B is then a process for removing the temporary seal from the annular space. Here, the plunger can first be removed from the space between the inner and outer surfaces in step **710**. Without the plunger pushing the inner and outer surfaces outward, they return to their original, deenergized position in step **712**. This can result in the ridges on the inner and outer surfaces breaking contact with the string and wellbore of the annular space which also breaks the seal on the annular system in step **714**. The plunger can then be fully removed from the first end of the seal in step **718** and the seal can be removed from the annular space in step **718**.

[0067] Figure 7C follows as a process for resealing the same location of the annular space after the seal has been removed. Replacement of the seal in the exact same orientation may not result in proper sealing of the annular space. This is because the ridges of the seal can contact the string and

wellbore of the annular space in the same position. Repeated sealing in the same location can lead to wear on the string and wellbore at the location of contact which can cause incomplete sealing when installed at a later time.

5 [0068] For resealing the space, the end cap can first be removed from the second end of the annular seal and installed on the first end of the annular seal in steps **720** and **722**. The entire seal can then be flipped such that the capped first end is inserted first into the annular space in step **724**. The seal can then be reinserted and resealed in steps **726** through **734**, which are similar to Figure 7A. Reversing the orientation of the seal can result in different sealing locations due to different offsets in the ridges on the inner and outer surfaces of the seal. This results in a complete seal of the
10 annular space even if the seal is installed in the same location as before.

[0069] For a seal with an integral end and no seal cap, steps **720** and **722** can be skipped. Instead, when the plunger is inserted into the reoriented seal in step **728**, the plunger can be inserted into the open first end from below the seal instead of from above the seal. This results in the different sealing locations from reorienting the seal without having to reposition the seal cap.

15 [0070] Alternatively, the seal can be completely replaced with an alternative seal with sealing ridges located at different positions than the original seal. In this embodiment, replacement starts at step **726** with inserting the new seal into the annular space and proceeds according to Figure 7C. This embodiment can be used when the sealing surfaces of the original seal are worn or if the seal has already been reoriented in the annular space.

20 [0071] Figure 8 is an embodiment according to the present technology of a seal **200** with a bulbous plunger **802**. The seal can have upper sets of inner and outer ridges **804** and lower sets of inner

and outer ridges **806**. The plunger **802** in this embodiment can a lower end **808** and an upper end **812** with greater diameters than a center section **810**.

[0072] This configuration of the plunger can allow for the sets of ridges **804** and **806** to be selectively engaged by the bulbous plunger **802**. From the position shown in Figure 8, the plunger
5 can be retracted up the body of the seal **200** towards the first end **202** so that the lower end **808** is located between the upper sets of ridges **804**. This can allow for the selective engagement of the upper ridge sets **804** without engaging the lower ridge sets **806**. Alternatively, the bulbous plunger **804** can be inserted further into the seal **200** towards the second end **204**. In this configuration, the lower set of ridges **806** can be selectively engaged while the upper set of ridges **804** may not
10 be engaged. The shape of the bulbous plunger **802** can allow for partial and selective activation of the seal.

[0073] Other embodiments of the seal can allow for different sequences of engaging sealing surfaces depending on the configuration of the seal and plunger. A tapered plunger of Figure 6, for example, can engage sealing ridge sets located towards the first end **202** of the seal while not
15 engaging sealing ridge sets towards the second end **204** of the seal. Conversely, a bulbous plunger **802** as shown in Figure 8 can engage sealing ridge sets towards the second end **204** of the seal while not engaging sealing ridge sets towards the first end **202** of the seal.

[0074] Figure 9 is an embodiment according to the present technology of a split annular metal-to-metal seal. In this embodiment, the seal **200** can comprise an inner portion **902** and an outer portion
20 **904**. The inner and outer portions **902**, **904** can further comprise an inner base portion **906** and an outer base portion **908**. The base portions **906**, **908** can be shaped complementary to each other

such that an annular metal-to-metal seal **200** can be formed from the two portions **902**, **904** by combining the complementary two base portions **906**, **908**.

[0075] The inner and outer portions **902**, **904** can be manufactured independently and can be combined according to the annular space to be sealed. Inner and outer ridges **212**, **216** can be located in various positions on the inner and outer portions **902**, **904**. This can allow for replacement of one of the two portions **902**, **904** to replace worn ridges **212**, **216** or to change the sealing location within the annular space without moving the seal. Different sized portions **902**, **904** can be configured for various inner and outer diameters of the annular space. This configuration can allow for the selection of an inner portion **902** according to the inner diameter of the annular space and an outer portion **904** according to the outer diameter of the annular space.

[0076] Figure 10A is an embodiment according to the present technology for sealing between the two portions **902**, **904** of a split seal **200**. In the present embodiment, the plunger **402** can further comprise plunger sealing surfaces **1002**. The plunger sealing surfaces **1002** can be configured to engage the base portions **906**, **908** when the plunger **402** is fully inserted into the seal **200**. In this position, the plunger sealing surfaces **1002** can seal with the base portions **906**, **908** to prevent fluid flow through any gap between the two portions **902**, **904**.

[0077] Figures 10B and 10C are embodiments according to a present technology of an intra-seal seal **1004** within the base portions **906**, **908**. The seal **1004** can be positioned within the inner base portion **906** as shown in Figure 10B, within the outer base portion **908** as shown in Figure 10C or both base portions. The seal **1004** can be located on a vertical surface of the base portions **906**, **908** as shown in Figure 10B, a horizontal surface of the base portions **906**, **908** as shown in Figure 10C

or both. The seal **1004** can be an elastomer seal, a metal-to-metal seal, a spring-loaded seal, or any other kind of appropriate seal. In other embodiments, a seal may not be provided.

[0078] Figure 11A is an embodiment of the present technology with a tab seal **1102** for sealing between the portions **902**, **904**. In the embodiment, a tab seal **1102** can extend from an outer base portion **908** such that the tab seal **1102** can overlap the inner base portion **906**. In alternate
5 embodiments, the tab seal **1102** can extend from an inner base portion **906** and overlap the outer base portion **908**. As shown in Figure 11A, the tab seal **1102** can be in an initially position such that it is not engaged in sealing contact.

[0079] Figure 11B is an embodiment of the present technology where the tab seal **1102** can be in
10 sealing contact with the inner base portion **906**. Here, the plunger **402** can contact the tab seal **1102** such that sealing contact results. Removal of the plunger **402** can result such that the sealing contact is broken at the tab seal **1102**.

[0080] Figure 12 is a process for temporarily sealing an annular space with a split metal-to-metal annular seal. This process begins by selecting the inner and outer portions in steps **1200** and **1202**.
15 These can be selected according to the inner and outer diameter of the annular space to be sealed. Selection can also be determined by the position of the ridges on the inner an outer portions for sealing with the annular space. Next a system for sealing between the two portions can be selected in step **1204**. In some embodiments, the sealing system can be selected simultaneously as the portion selection of steps **1200** and **1202** for portions with integral seals such as those shown in
20 Figures 10A, 10B, 10C, and 11B. In other embodiments, a sealing system may not be selected. The method can then proceed with step **700** of Figure 7A for sealing the annular space.

[0081] To replace a portion of the seal, the seal can first be removed according to Figure 7B followed by selection replacement portions according to steps **1200** and **1202** for the inner portion, outer portion, or both portions. The seal can then be reinserted according to figure 7A. The replacement portions can have ridges in substantially different positions than the replaced inner and outer portions. This can result such that the annular space is sealed in substantially different locations on either the inner surface, outer surface or both. This can occur even with the metal-to-metal seal positioned in a similar location prior to replacing a portion of the seal.

[0082] Although the technology herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present technology. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present technology as defined by the appended claims.

That claimed is:

1. A metal-to-metal seal for sealing between a pair of annular surfaces, the seal comprising:
an inner seal portion and an outer seal portion, each seal portion comprising a central seal
5 portion the central seal portion having a concave shape in a de-energized state such that the central
portion curves toward a centerline of the seal, the central portion capable of flexing radially
outward toward the pair of annular surfaces upon energization of the seal; and
at least one outer ridge extending from the central portion of the seal radially outward away
from the centerline of the seal so that when the seal is energized the at least one outer ridge
10 sealingly engages an outer annular surface of the pair of annular surfaces.
2. The seal of claim 1, further comprising at least one inner ridge extending from the central
portion of the inner portion of the seal radially outward away from the centerline of the seal so that
when the seal is energized the at least one inner ridge sealingly engages an inner annular surface
of the pair of annular surfaces.
- 15 3. The seal of claim 1, wherein the outer seal portion comprises an outer concave central seal
surface and the inner seal portion comprises an inner concave central seal surface, the outer
concave central seal surface and inner concave central seal surface separated from one another and
defining a recess therebetween, the seal further comprising at least one intra-seal ridge extending
from the outer concave central seal surface into the recess so that when the seal is energized by a
20 plunger inserted into the recess, the at least one intra-seal ridge extending from the outer concave
central seal portion sealingly engages the plunger.
4. The seal of claim 3, further comprising and at least one intra-seal ridge extending from the
inner concave central seal surface into the recess so that when the seal is energized by the plunger,

the at least one intra-seal ridge extending from the inner concave central seal surface sealingly engages a plunger.

5. The seal of claim 3, wherein the at least one outer ridge comprises a plurality of outer ridges.

5 6. The seal of claim 1 further comprising:
at least one seal positioned to seal between the outer seal portion and the inner seal portion.

7. The seal of claim 6, wherein the at least one seal is a plunger sealing surface, an intra-seal seal, or a tab seal.

8. The seal of claim 7 wherein insertion of a plunger into the recess energizes the plunger
10 sealing surface or the tab seal.

9. The seal of claim 1 wherein the inner seal portion and the outer seal portion are made via an additive manufacturing process.

10. The seal of claim 1 wherein the at least one ridge comprises a different material of construction than the central portion of the metal-to-metal seal.

15 11. A method for sealing an annular space of a well comprising:
selecting an inner seal portion according to an inner diameter of the annular space;
selecting an outer seal portion according to an outer diameter of the annular space;
inserting the combined inner and outer portions as a metal-to-metal annular seal= into the
annular space, the inner portion having an at least one inner biased concave surface and the outer
20 portion having at least one outer biased concave central seal surfaces;
inserting a plunger into a first end of the annular seal;
energizing the seal by pushing the at least one inner and outer biased concave central seal
surfaces toward proximate annular surfaces in the annular space; and

sealingly engaging the at least one inner and outer biased concave central seal surfaces with annular surfaces in the annular space.

12. The method of claim 11 further comprising:

providing at least one intra-seal ridge and ridges on the inner and outer biased concave

5 central seal surfaces; and

sealingly engaging the at least one intra-seal ridge with the plunger and the ridges with the annular surfaces in the annular space.

13. The method of claim 11 further comprising:

sealingly engaging at least one additional inner and outer biased concave central seal

10 surfaces with annular surfaces in the annular space.

14. The method of claim 11 further comprising:

selecting a sealing system for sealing between the inner seal portion and the outer seal portion.

15. The method of claim 14 wherein the plunger sealingly engages the sealing system for

15 sealing between the inner seal portion and the outer seal portion.

16. A method of resealing an annular space comprising:

removing a plunger from a first end of a metal-to-metal annular seal to de-energize the metal-to-metal annular seal;

removing the metal-to-metal annular seal from the annular space;

20 replacing an inner seal portion and/or an outer seal portion;

reinserting the seal into the annular space; and

inserting the plunger into the metal-to-metal annular seal to re-energize the metal-to-metal annular seal.

17. The method of claim 16 wherein replacing the inner seal portion and/or the outer seal portion changes a location of a sealing ridge on the inner and outer seal portions.

18. The method of claim 16 further comprising:

changing a seal type between the inner seal portion and outer seal portion

5 19. The method of claim 16 wherein the seal is in a substantially similar location in the annular space before removal and after re-insertion.

20. The method of claim 19 wherein the ridges engage the surfaces of the annular space in a substantially different locations before removal and after re-insertion.

1/18

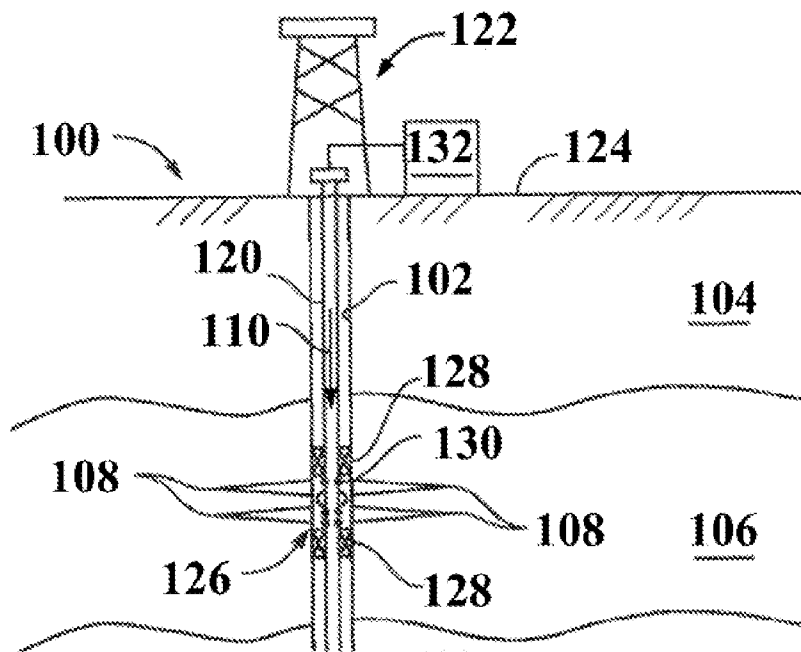


Fig. 1

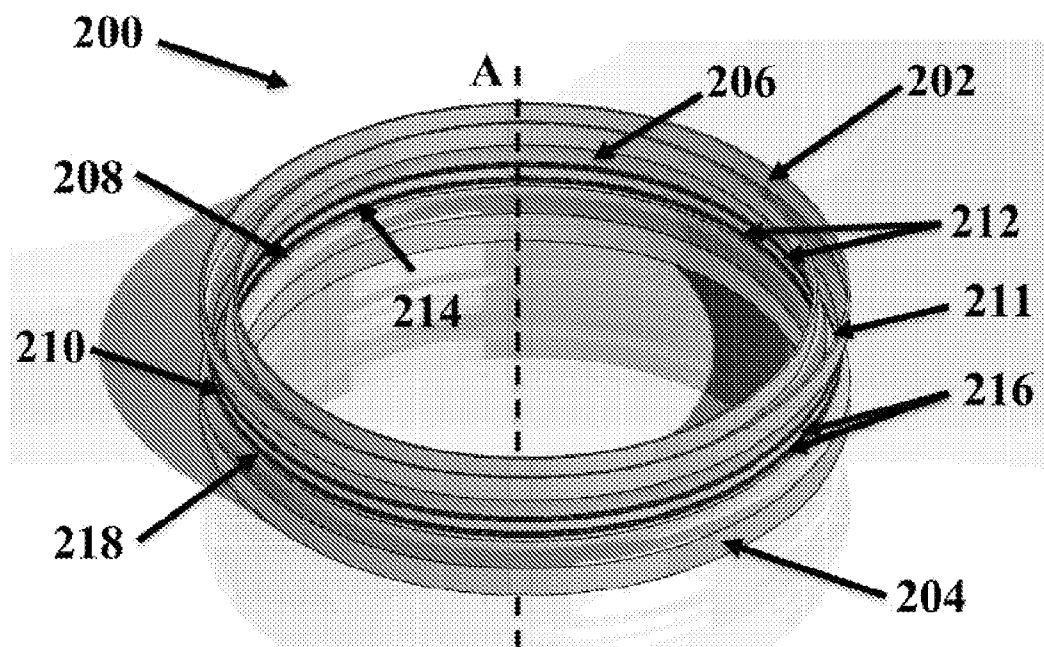


Fig. 2

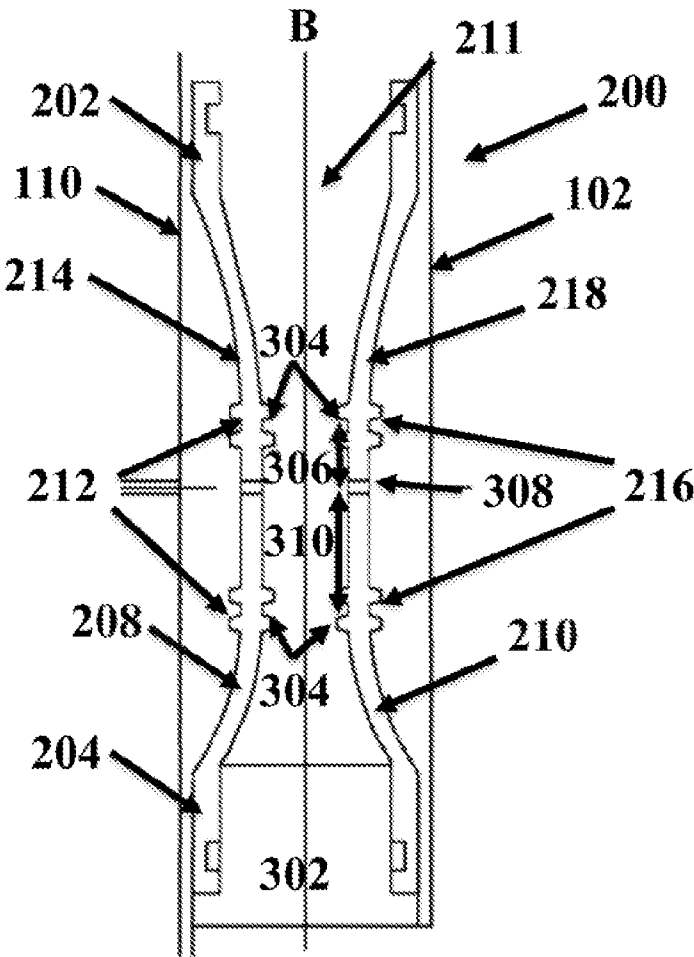


Fig. 3

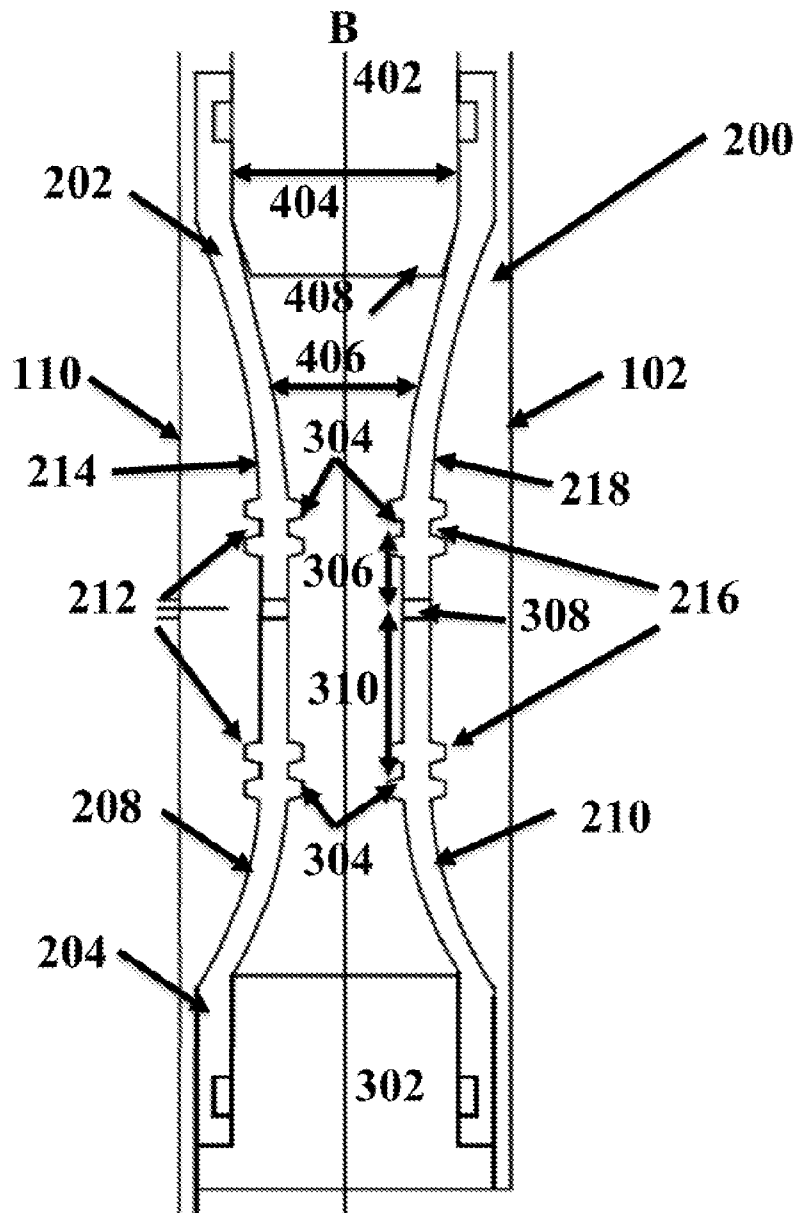


Fig. 4A

5/18

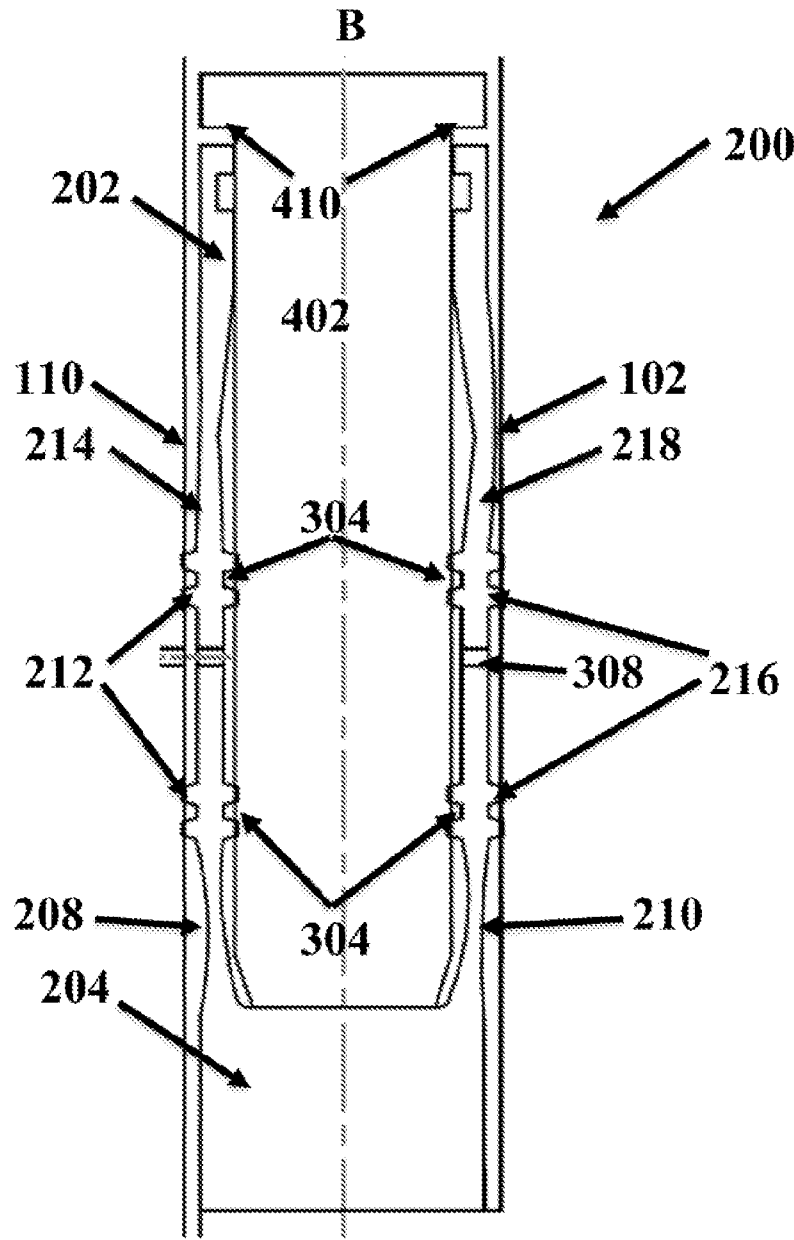


Fig. 4B

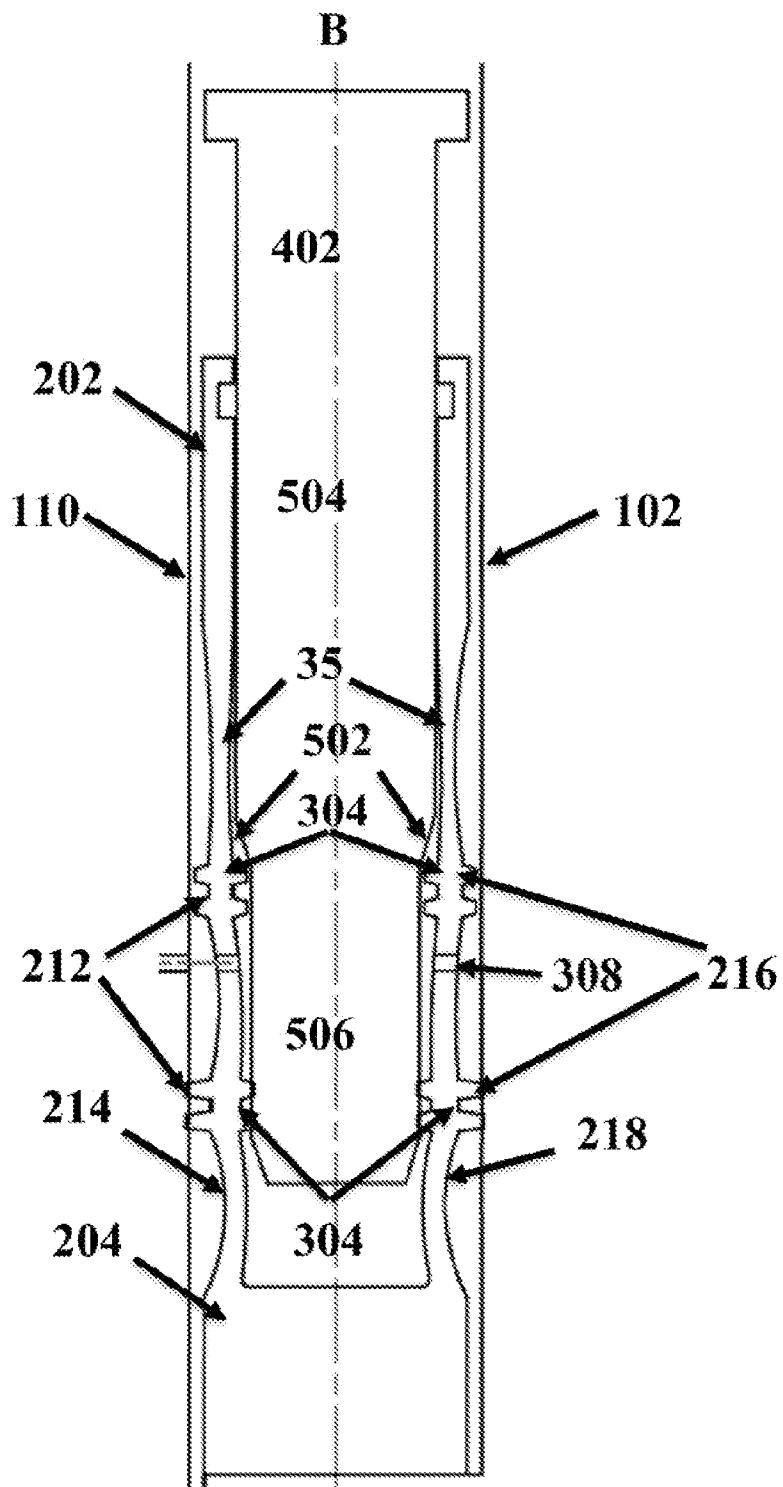


Fig 5A

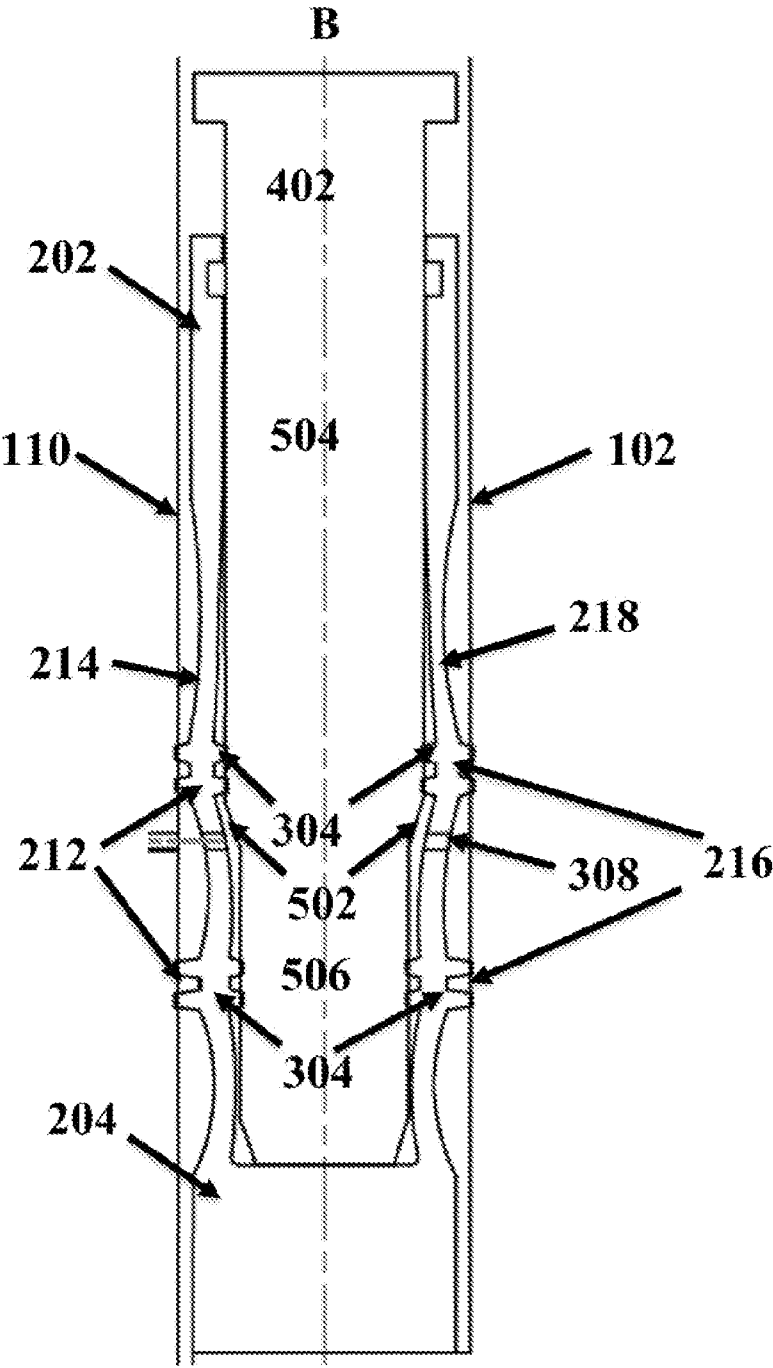


Fig 5B

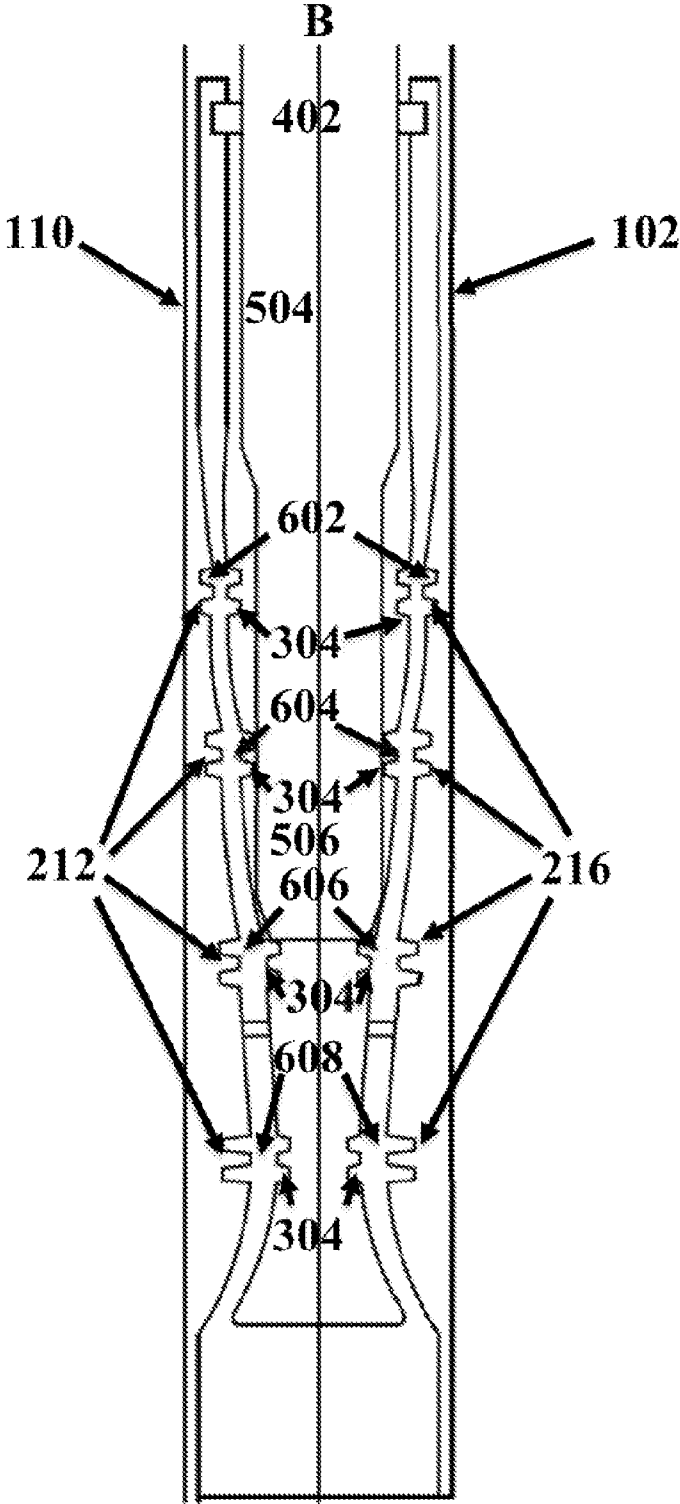
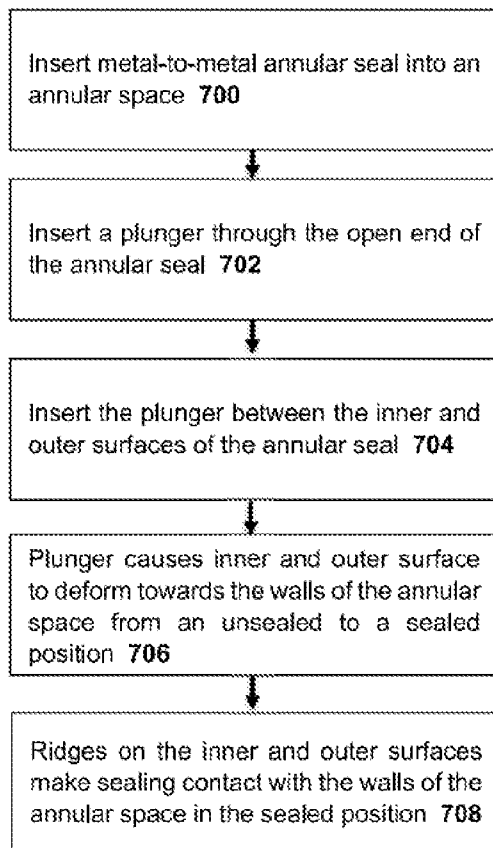
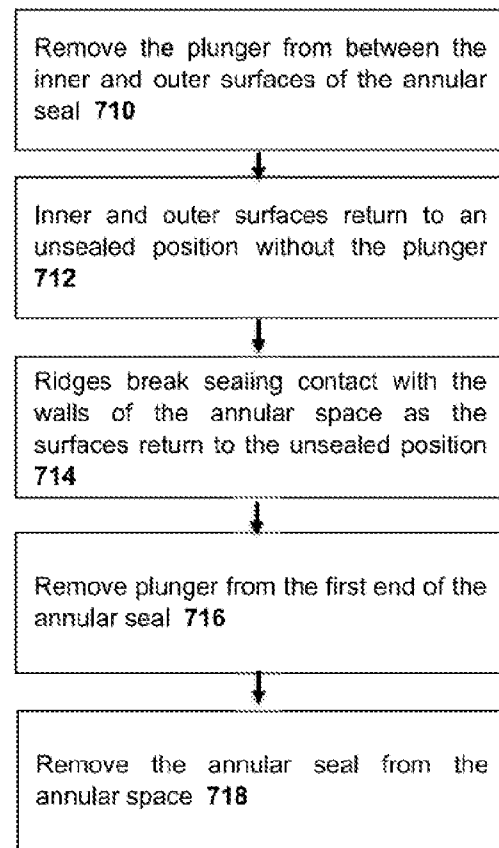
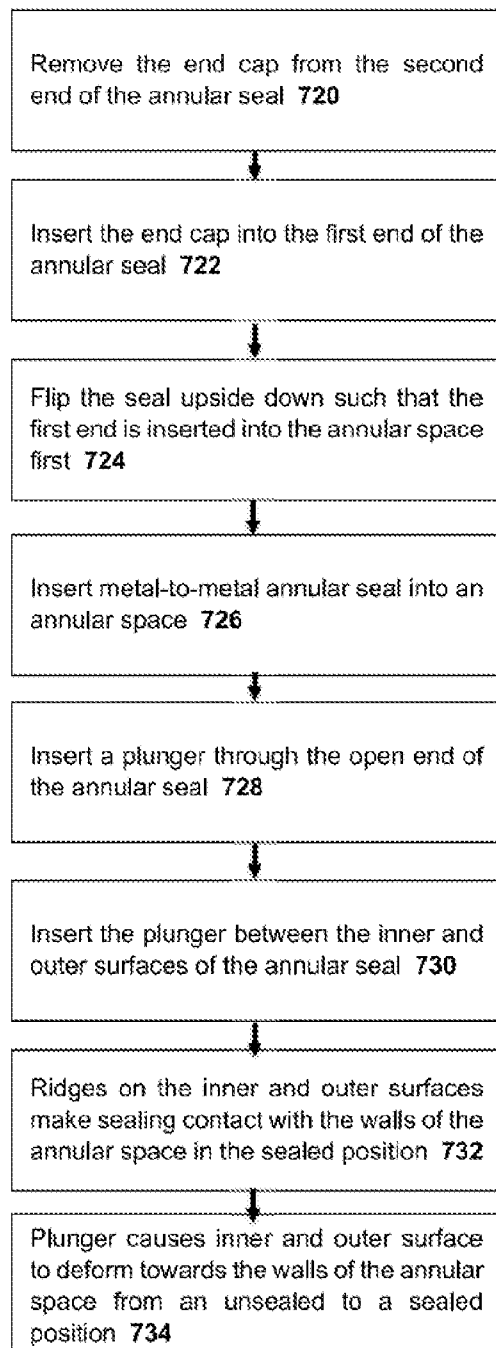


Fig 6

9/18

**Fig 7A****Fig 7B**

10/18

**Fig 7C**

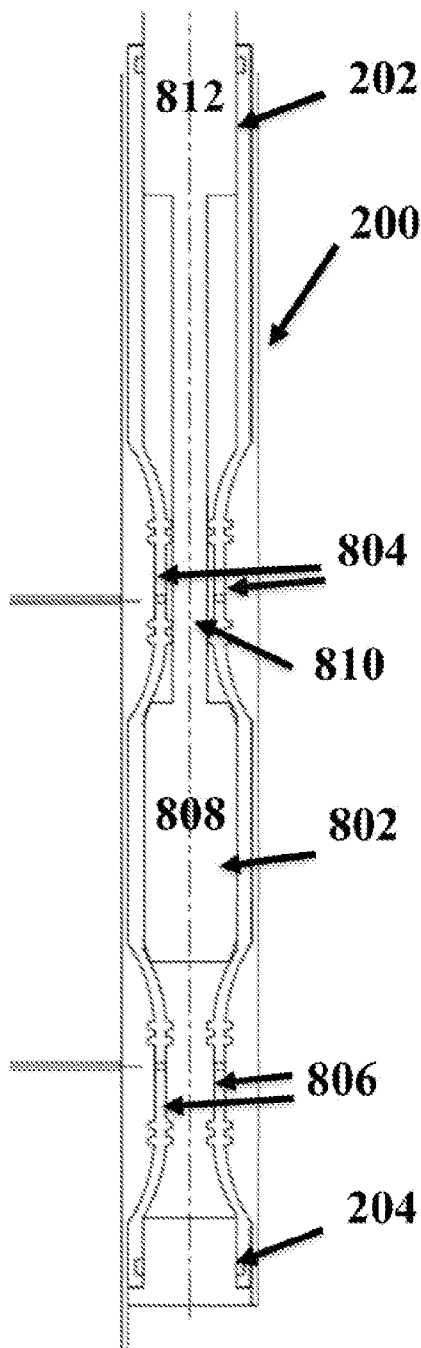


Fig. 8

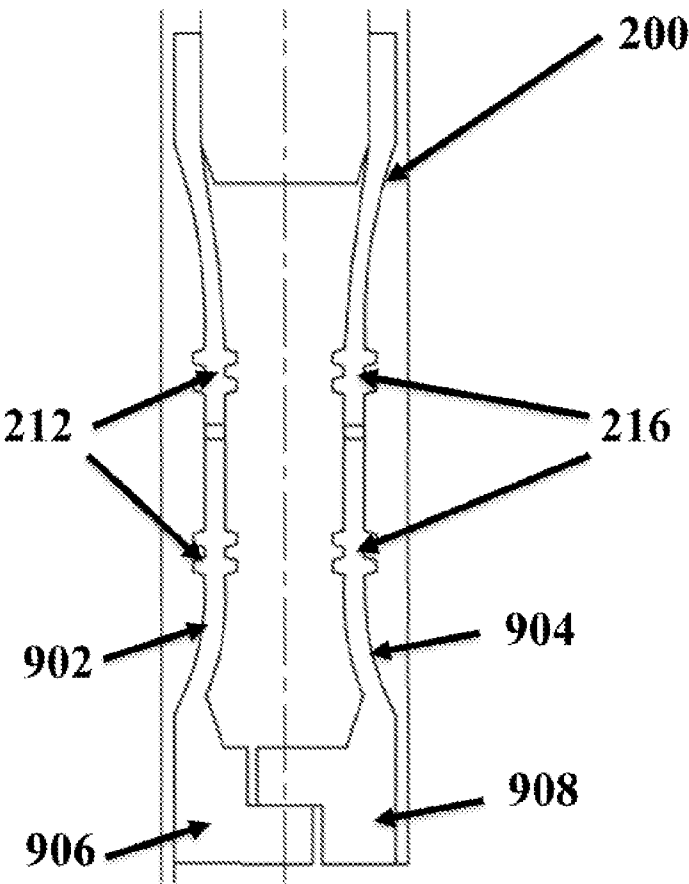


Fig. 9

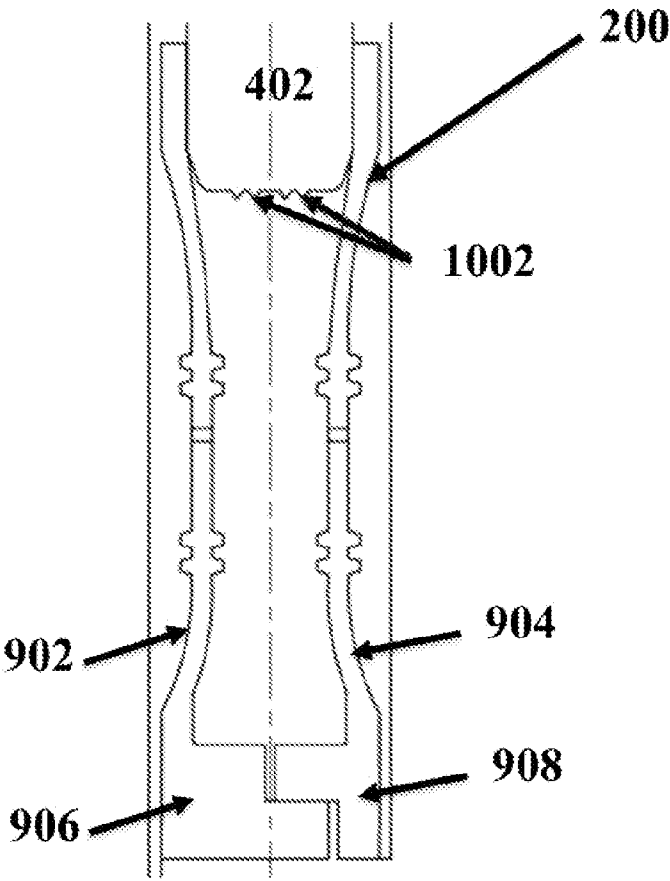


Fig. 10A

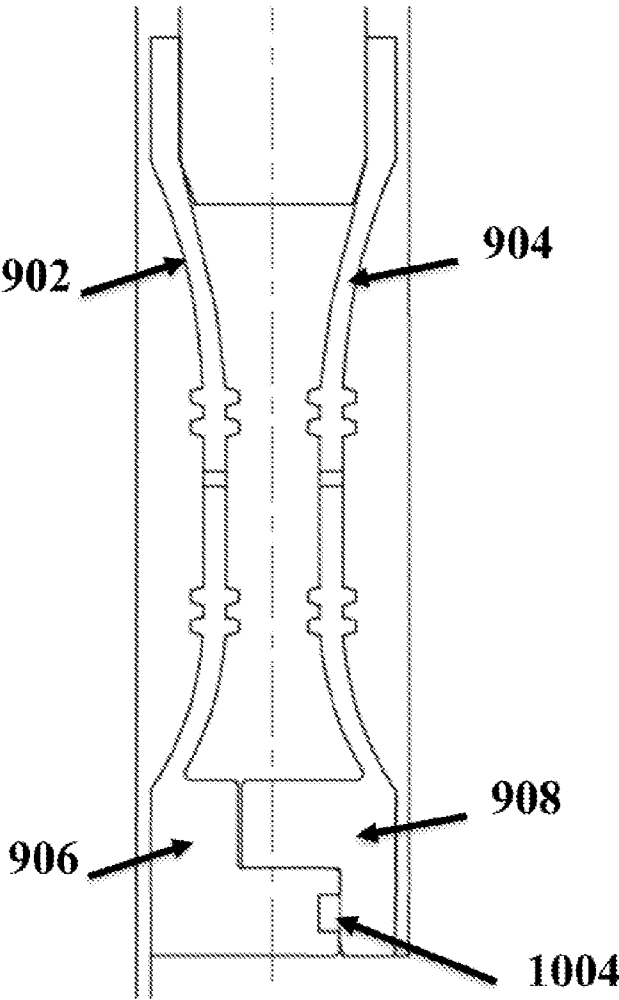


Fig. 10B

15/18

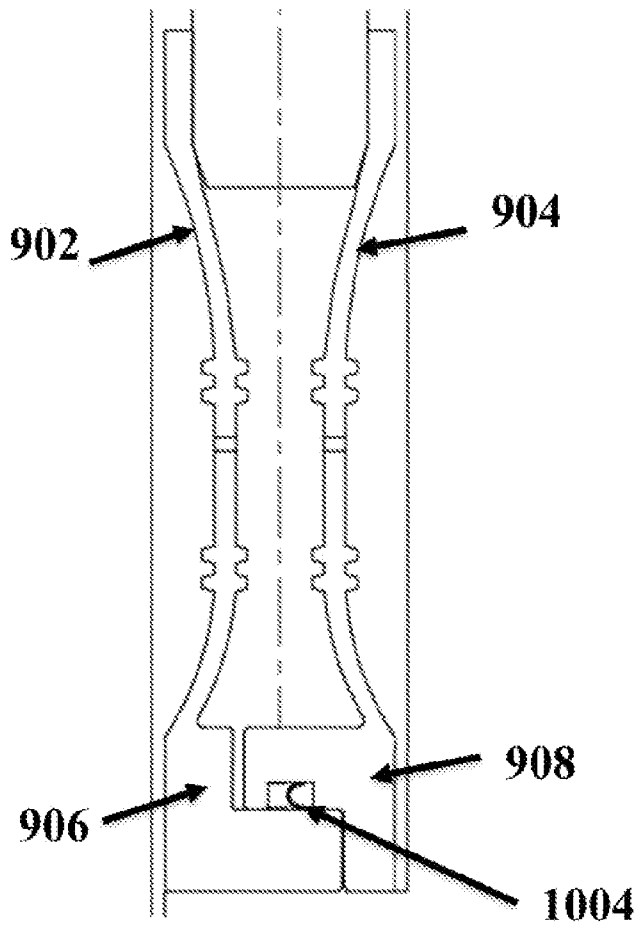


Fig. 10C

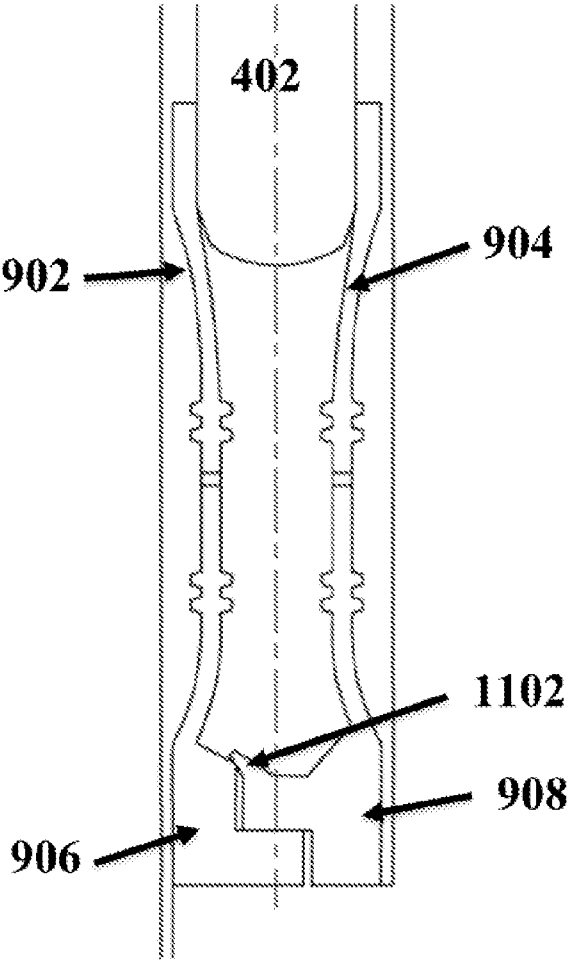


Fig. 11A

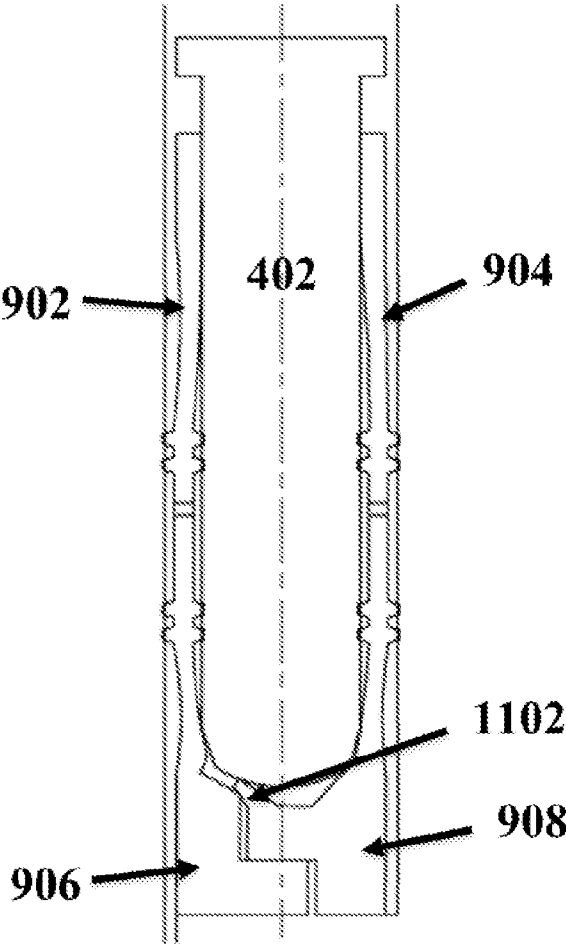
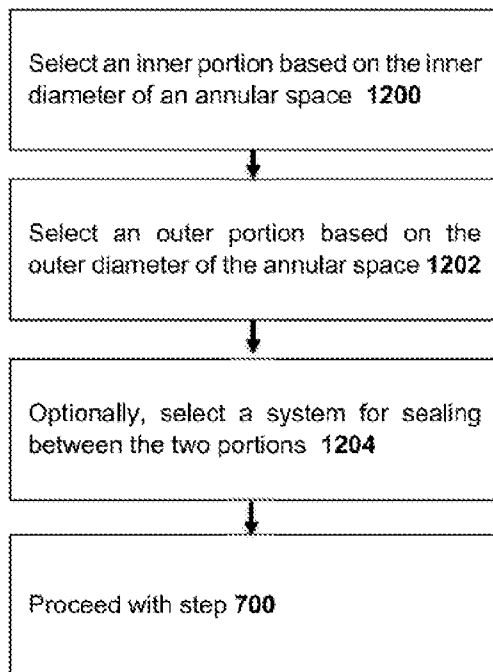


Fig. 11B

18/18

**Fig 12**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2023/073851

A. CLASSIFICATION OF SUBJECT MATTER**E21B 33/04(2006.01)i; F16J 15/08(2006.01)i; B33Y 80/00(2015.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B 33/04(2006.01); E21B 33/03(2006.01); E21B 33/043(2006.01); E21B 33/12(2006.01); E21B 43/10(2006.01);
F16J 15/08(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: metal-to-metal seal, inner seal portion, outer seal portion, central seal portion, outer ridge, concave central seal surface, plunger

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4751965 A (CASSITY, THOMAS G.) 21 June 1988 (1988-06-21) column 2, line 55 - column 3, line 59, claim 1 and figures 2-3	1-8,11-15
Y		9-10
Y	US 2003-0155721 A1 (ZHENG, QIU SHI) 21 August 2003 (2003-08-21) paragraph [0040] and figure 8	9-10
X	US 2012-0012336 A1 (GALLE et al.) 19 January 2012 (2012-01-19) paragraphs [0006], [0014], claims 14-18 and figures 2-4	16-20
A	WO 2021-150454 A1 (BAKER HUGHES OILFIELD OPERATIONS LLC) 29 July 2021 (2021-07-29) paragraphs [0026]-[0054] and figures 1-12	1-20
A	EP 0622520 A1 (COOPER CAMERON CORPORATION) 02 November 1994 (1994-11-02) claims 1-15 and figures 1-12	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

05 January 2024

Date of mailing of the international search report

05 January 2024

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon
35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

PARK, Tae Wook

Telephone No. +82-42-481-3405

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2023/073851

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	US 2023-0243227 A1 (BAKER HUGHES OILFIELD OPERATIONS LLC) 03 August 2023 (2023-08-03) claims 1-20 *The above document is a publication of the earlier application whose priority has been claimed in this international application.	1-20

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2023/073851

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

I. Claims 1-15 directed to a metal-to-metal seal for sealing between a pair of annular surfaces or a method of sealing an annular space of a well.

II. Claims 16-20 directed to a method of resealing an annular space.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2023/073851

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	4751965	A	21 June 1988	EP	0289107	A2	02 November 1988
				EP	0289107	B1	19 August 1992
				JP	63-272897	A	10 November 1988
US	2003-0155721	A1	21 August 2003	AU	2003-213012	A1	09 September 2003
				WO	03-071170	A1	28 August 2003
US	2012-0012336	A1	19 January 2012	AU	2011-203529	A1	02 February 2012
				BR	PI1103637	A2	04 December 2012
				GB	2482059	A	18 January 2012
				GB	2482059	B	12 October 2016
				MY	155075	A	28 August 2015
				NO	20111010	A1	17 January 2012
				SG	177838	A1	28 February 2012
				US	8517089	B2	27 August 2013
WO	2021-150454	A1	29 July 2021	BR	112022014128	A2	04 October 2022
				GB	2606495	A	09 November 2022
				NO	20220862	A1	09 August 2022
				US	11713639	B2	01 August 2023
				US	2021-0222508	A1	22 July 2021
EP	0622520	A1	02 November 1994	AU	5904394	A	27 October 1994
				AU	671711	B2	05 September 1996
				CA	2119196	A1	27 October 1994
				DE	69412166	T2	10 December 1998
				EP	0622520	B1	05 August 1998
				SG	52423	A1	28 September 1998
				US	5997003	A	07 December 1999
US	2023-0243227	A1	03 August 2023	US	2023-0243232	A1	03 August 2023