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(54) FRAC PLUG WITH RETENTION MECHANISM

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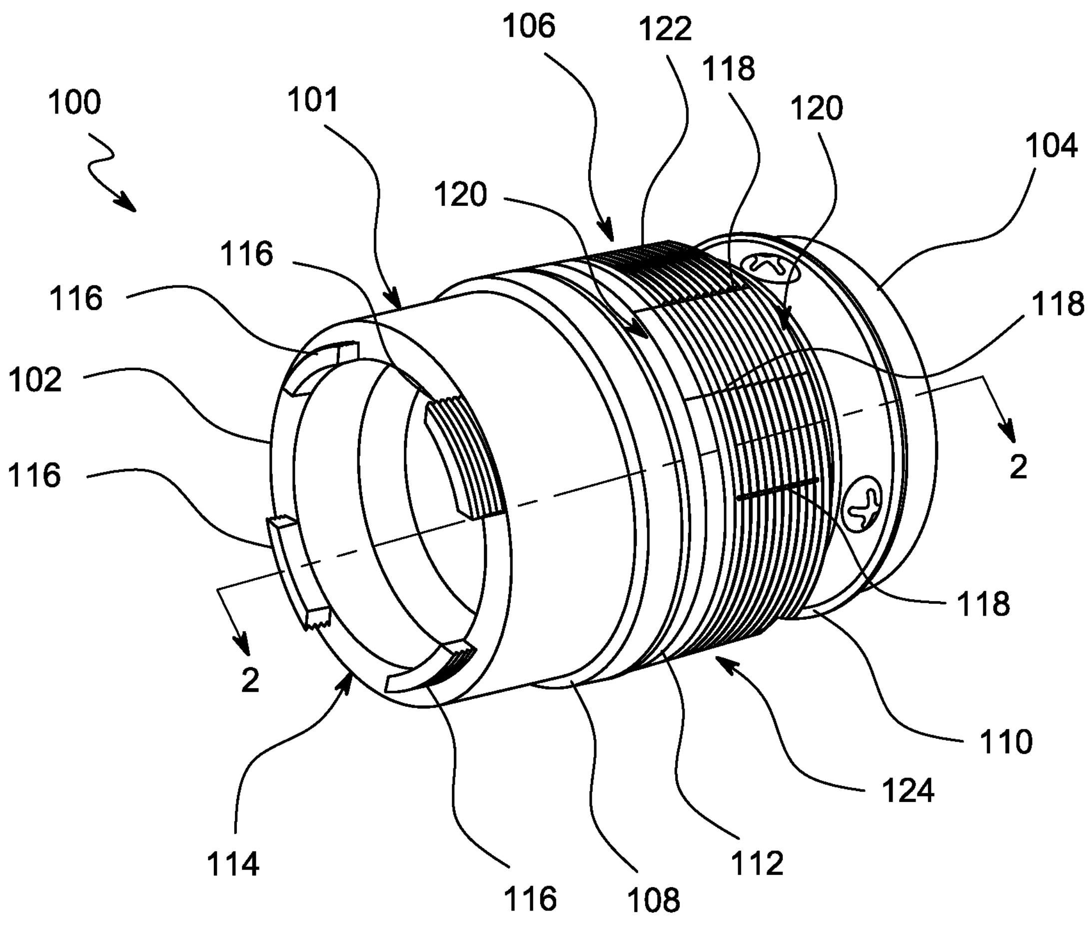
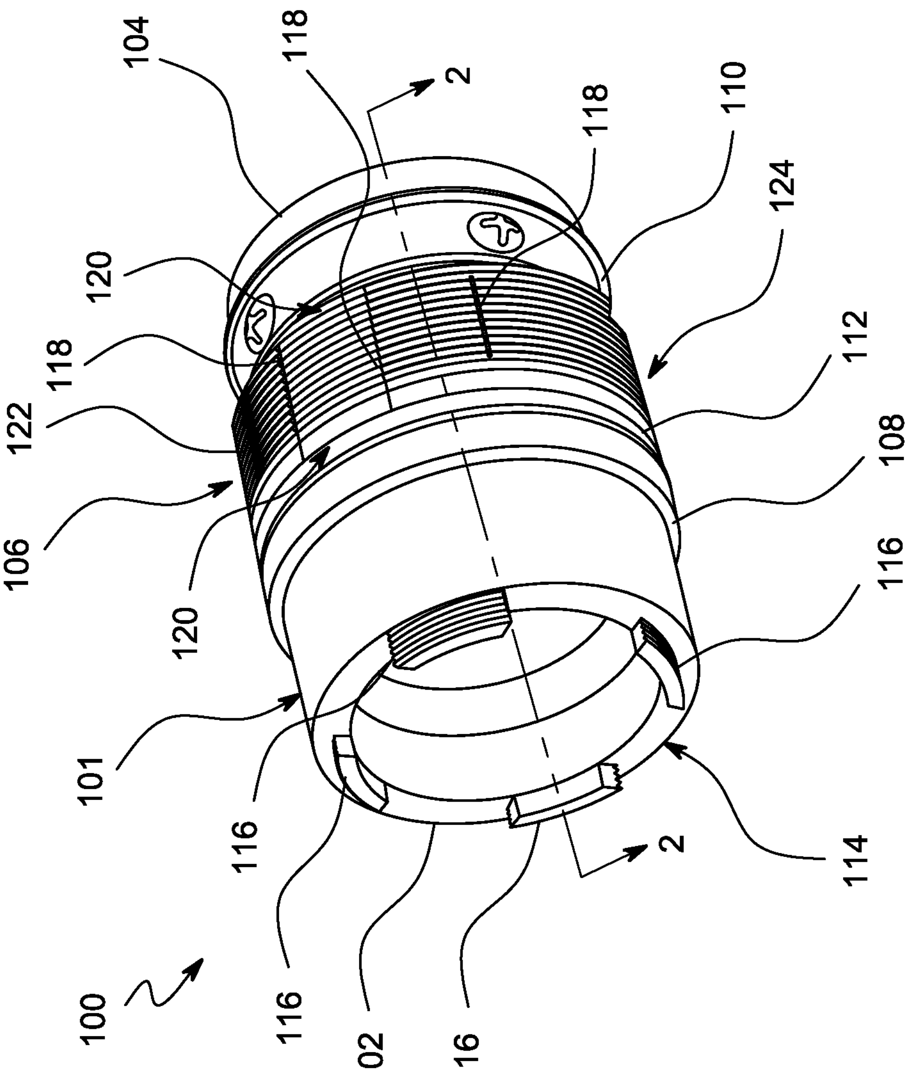
(57) ABSTRACT

A slip for a downhole tool is provided. The slip may include an annular body having a first axial end, a second axial end, an inner surface, an outer surface, and an axial length. The annular embody further includes a taper on the inner surface that extends along the axial length of the annular body, and a left-hand thread pattern defined by the outer surface and extending from the first axial end along a portion of the axial length, each thread of the left-hand thread pattern having a crest that is angled toward the first axial end.




104
118
2
118
110
124
120
118
122
106
120
112
108
116
101
116
116
102
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2
114
100

FIG. 1

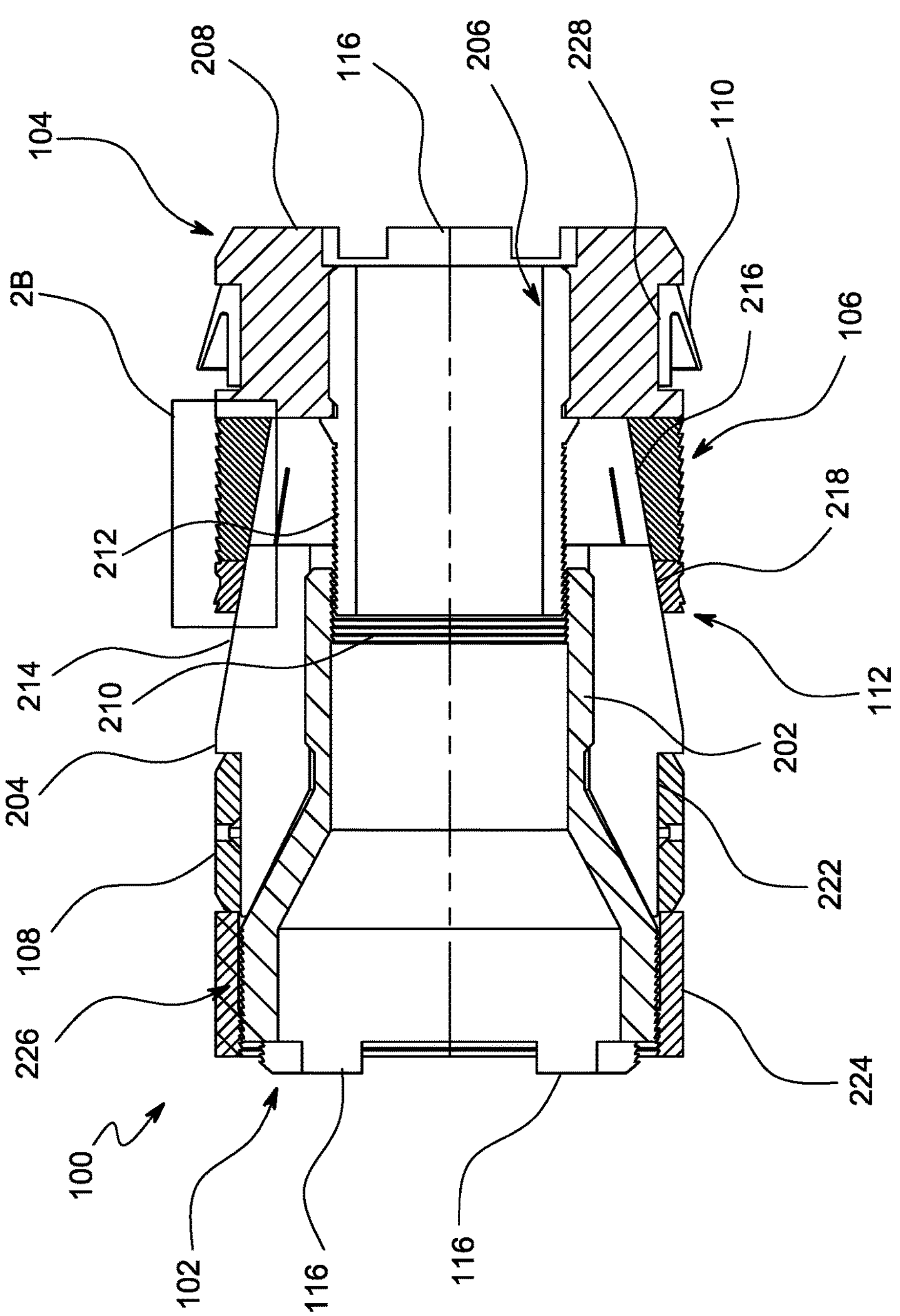
104
208
116
206
228
110
2B
216
106
218
212
214
210
112
202
204
222
108
226
224
100
102
116
116

FIG. 2A

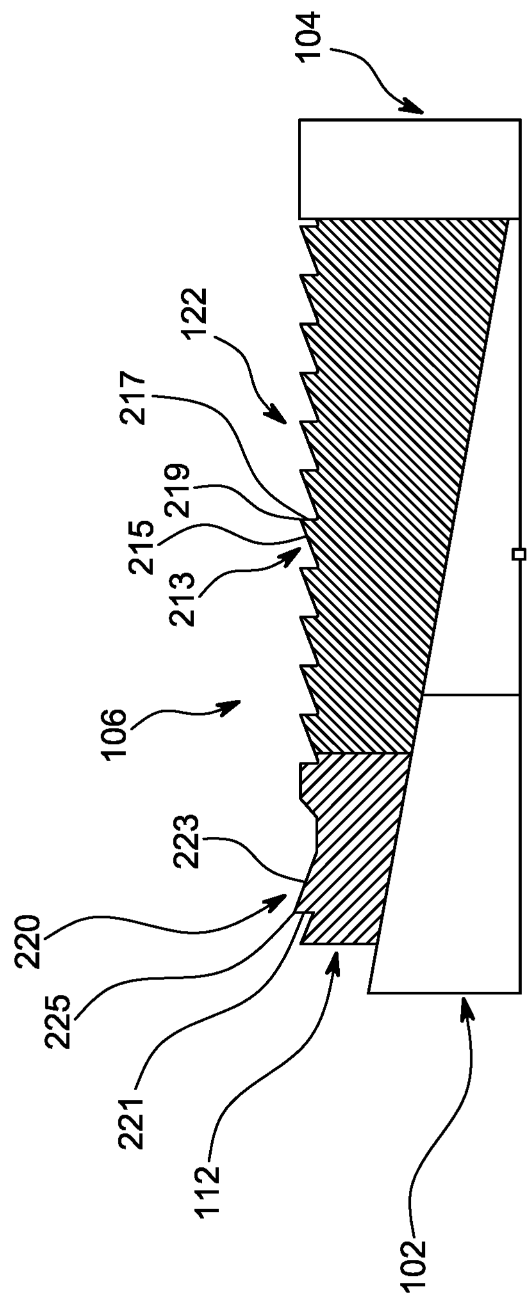

FIG. 2B

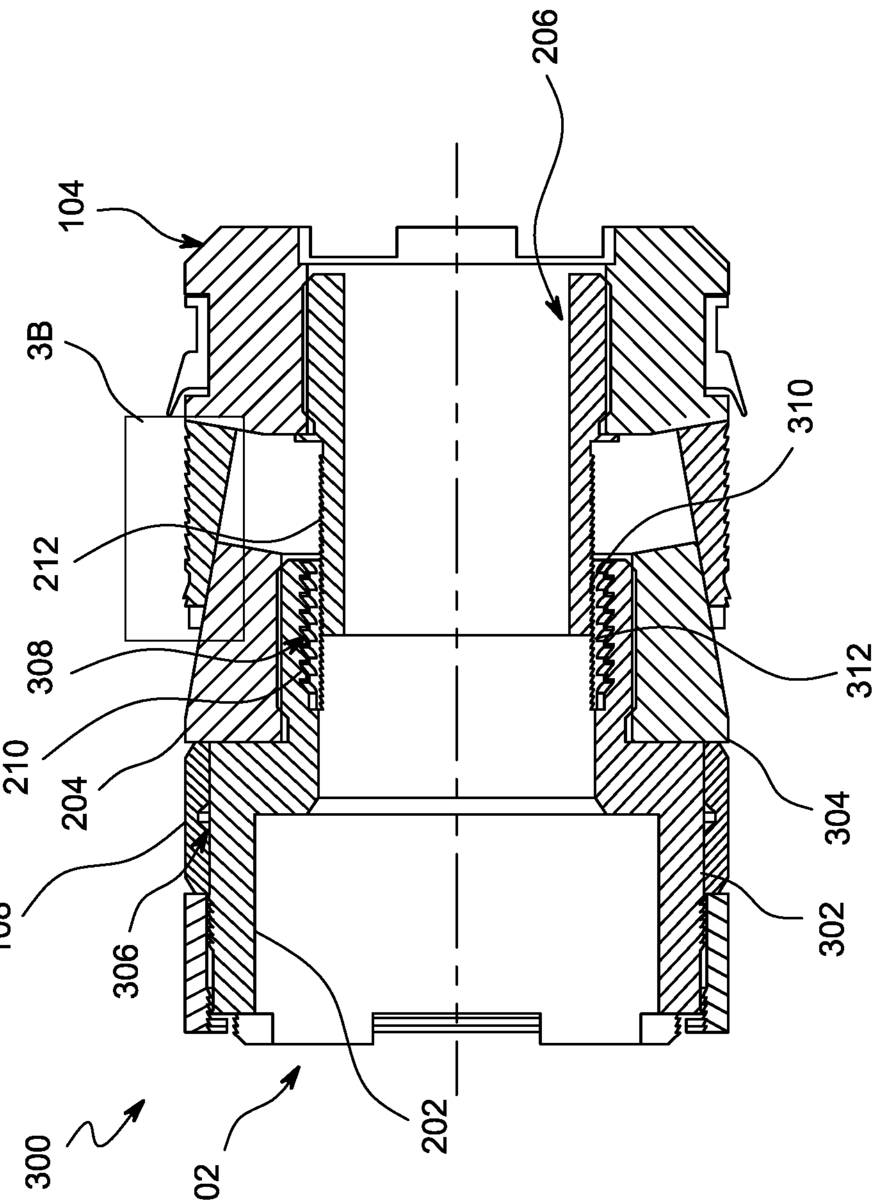

FIG. 3A

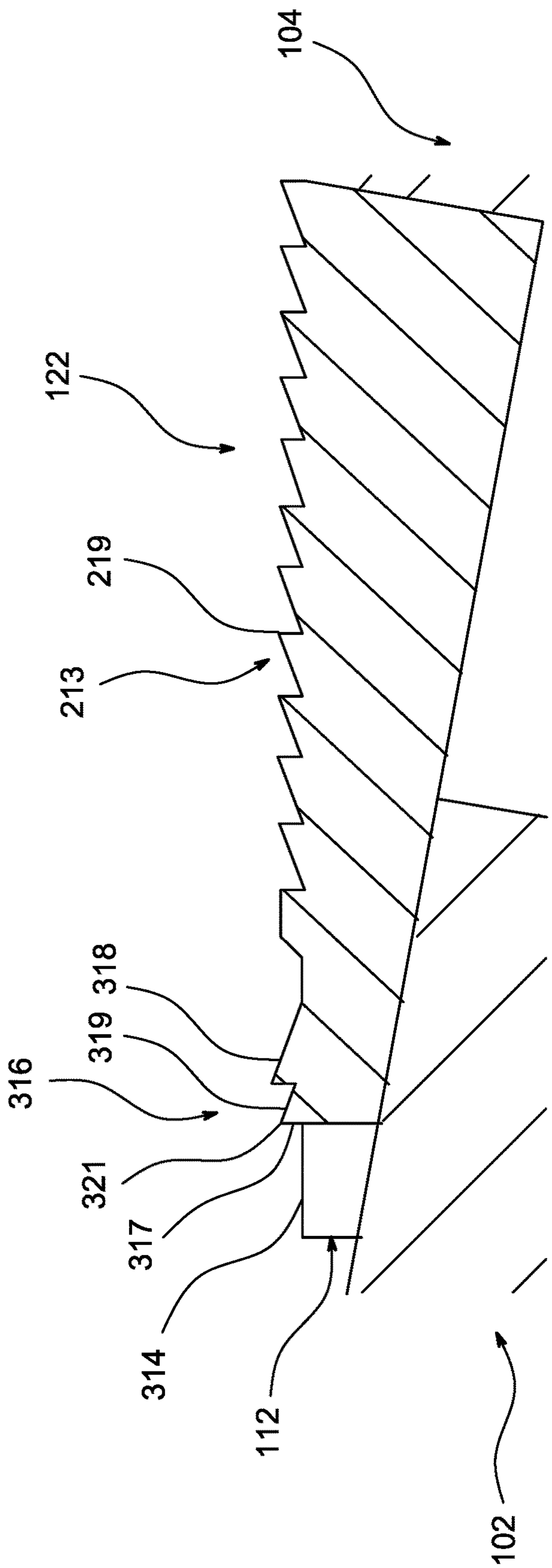

FIG. 3B

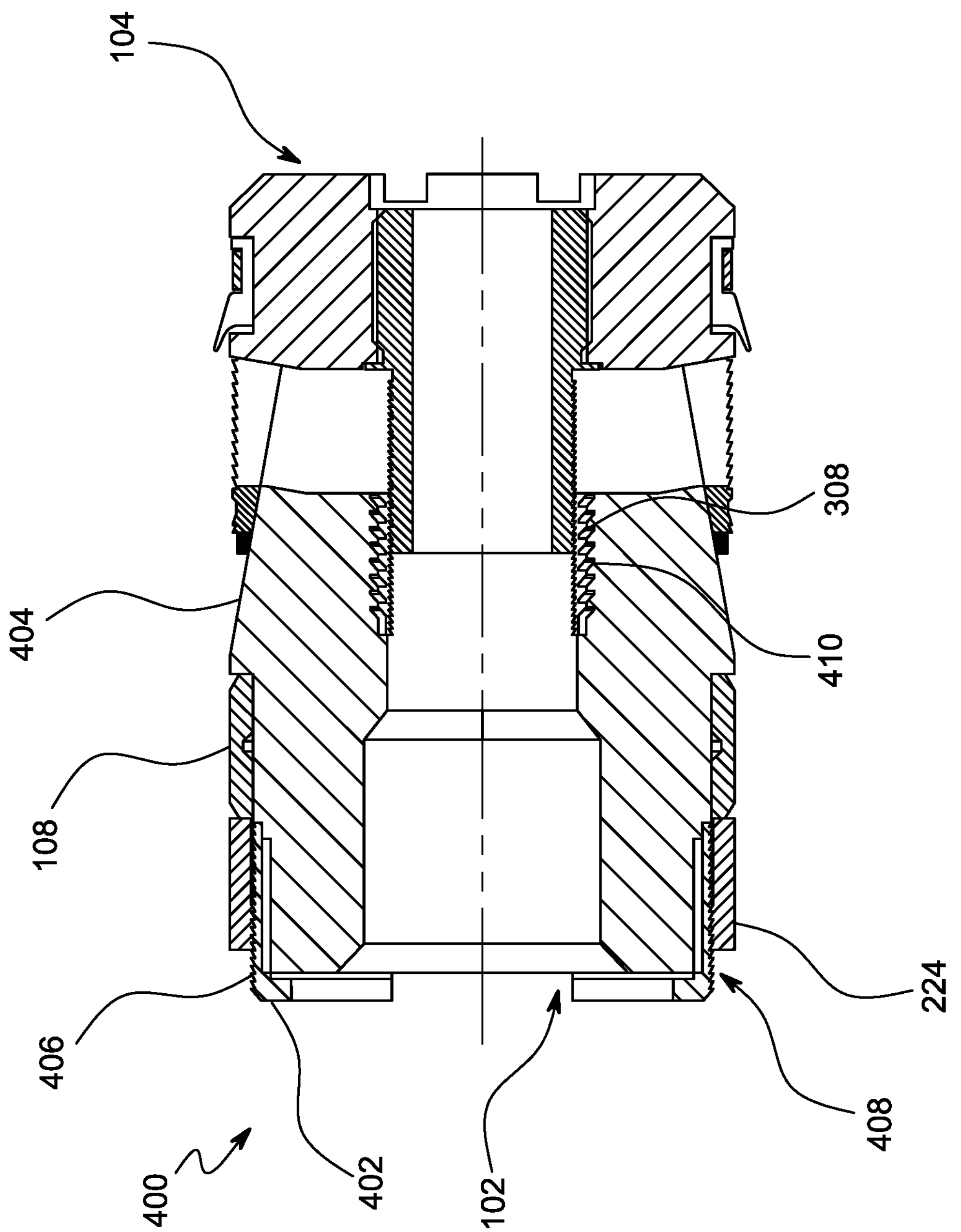

FIG. 4

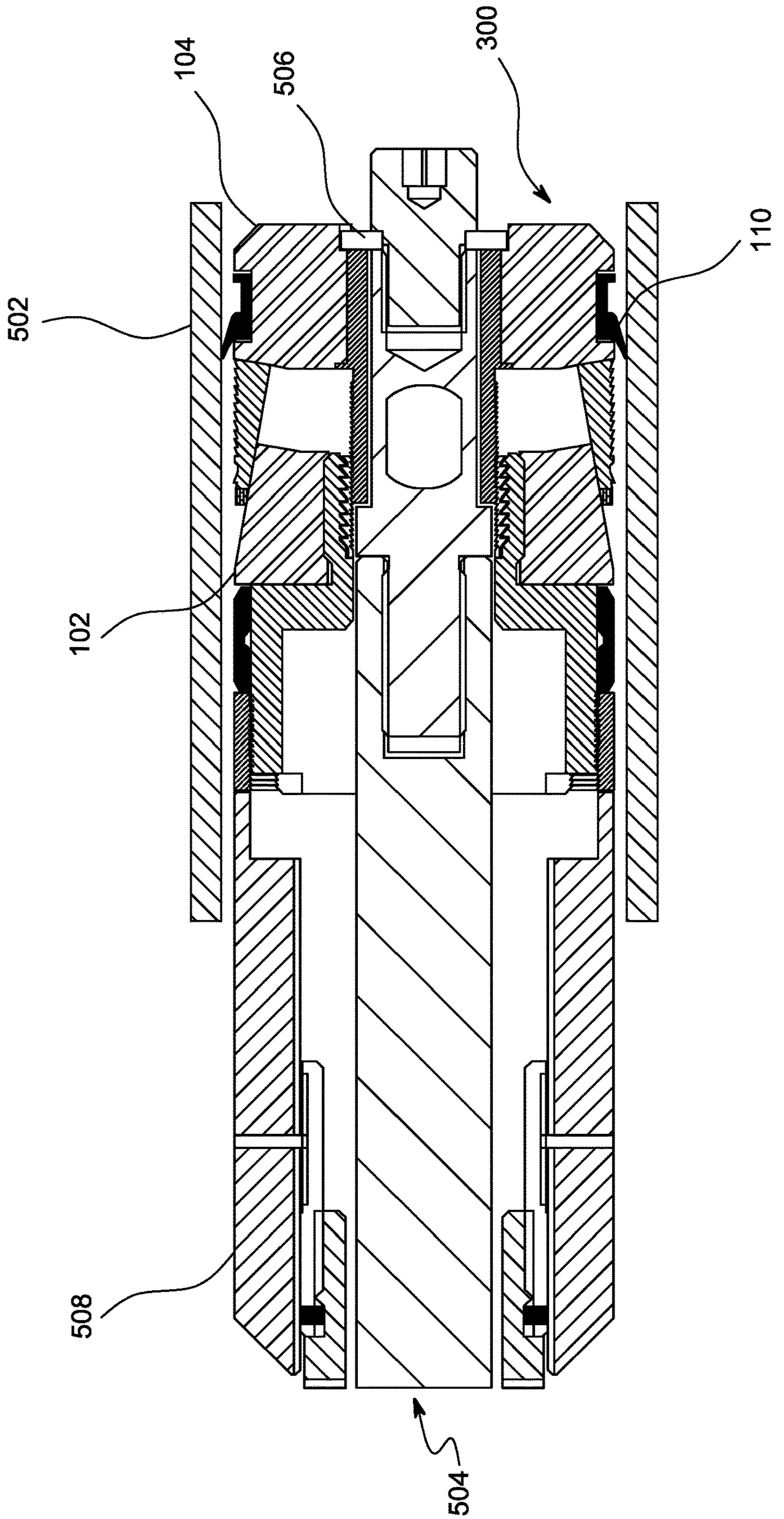

FIG. 5

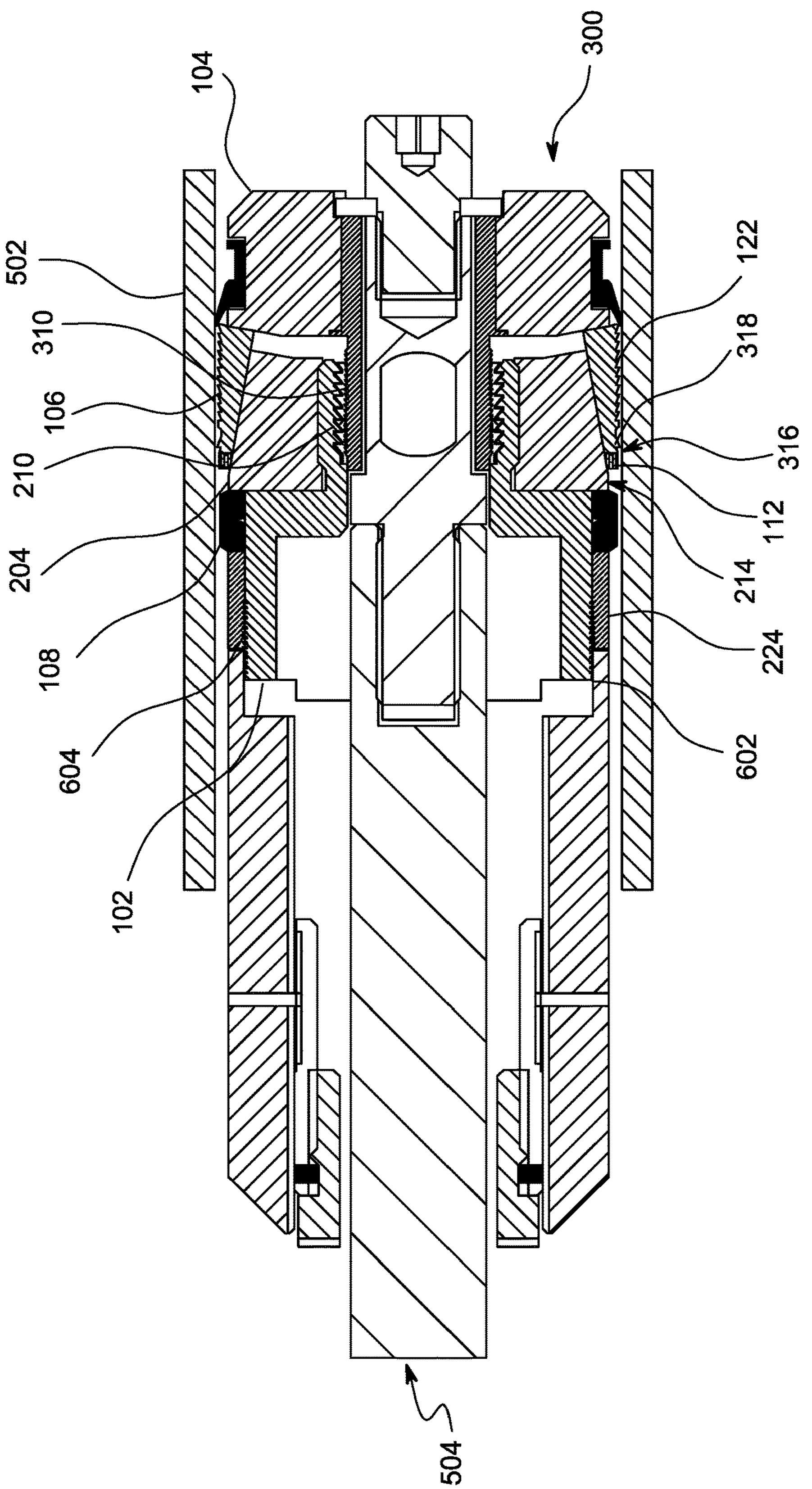
300
104
502
310
106
210
204
108
604
102
122
318
316
112
214
224
602
504

FIG. 6

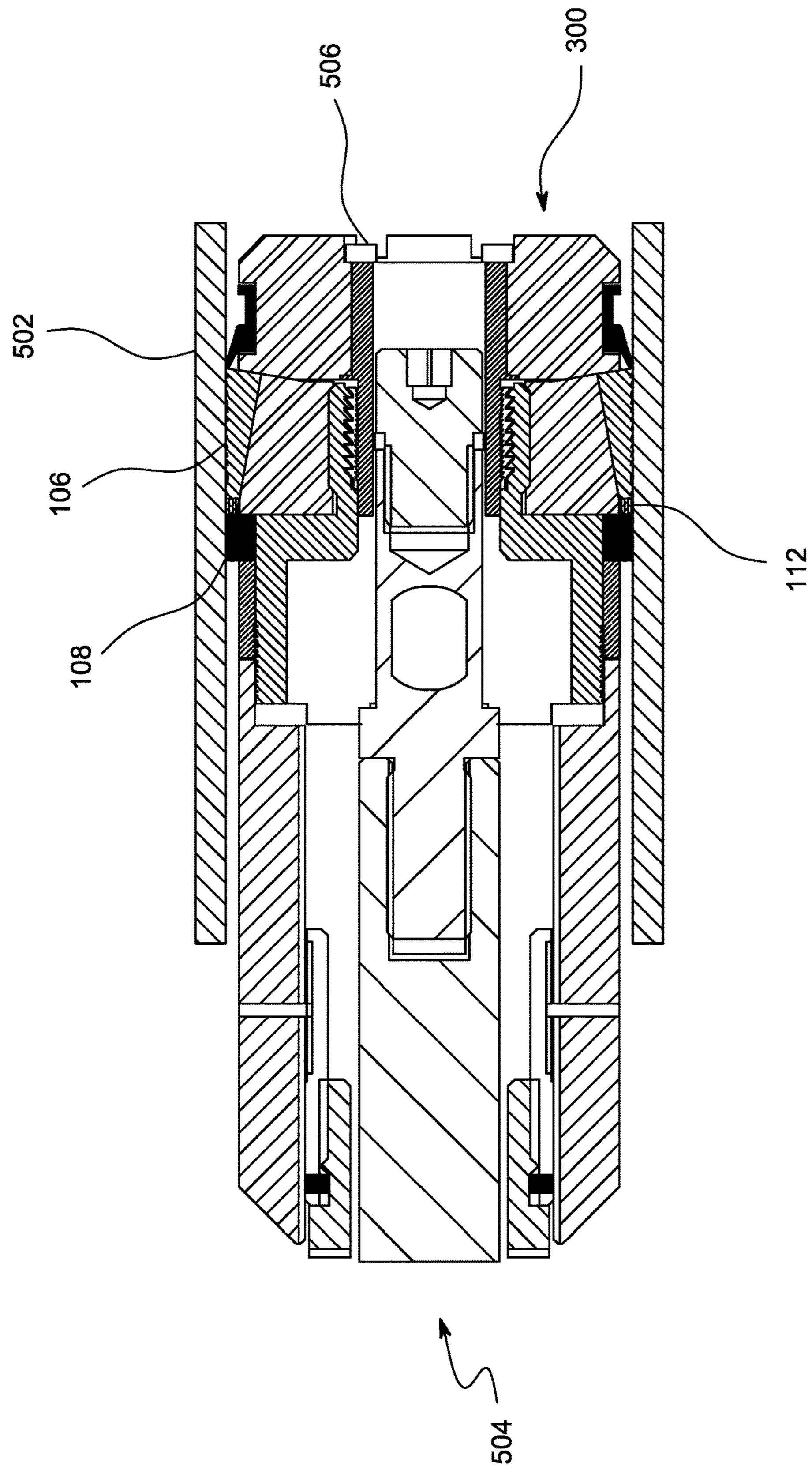

FIG. 7

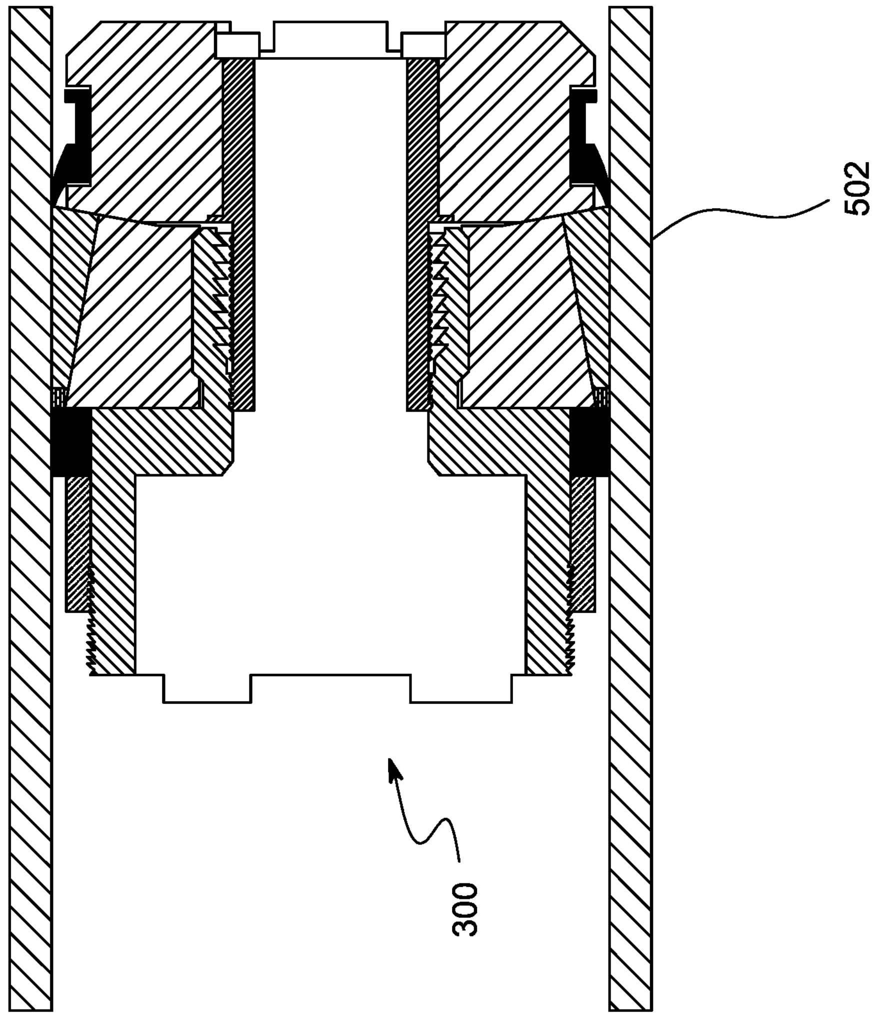

FIG. 8

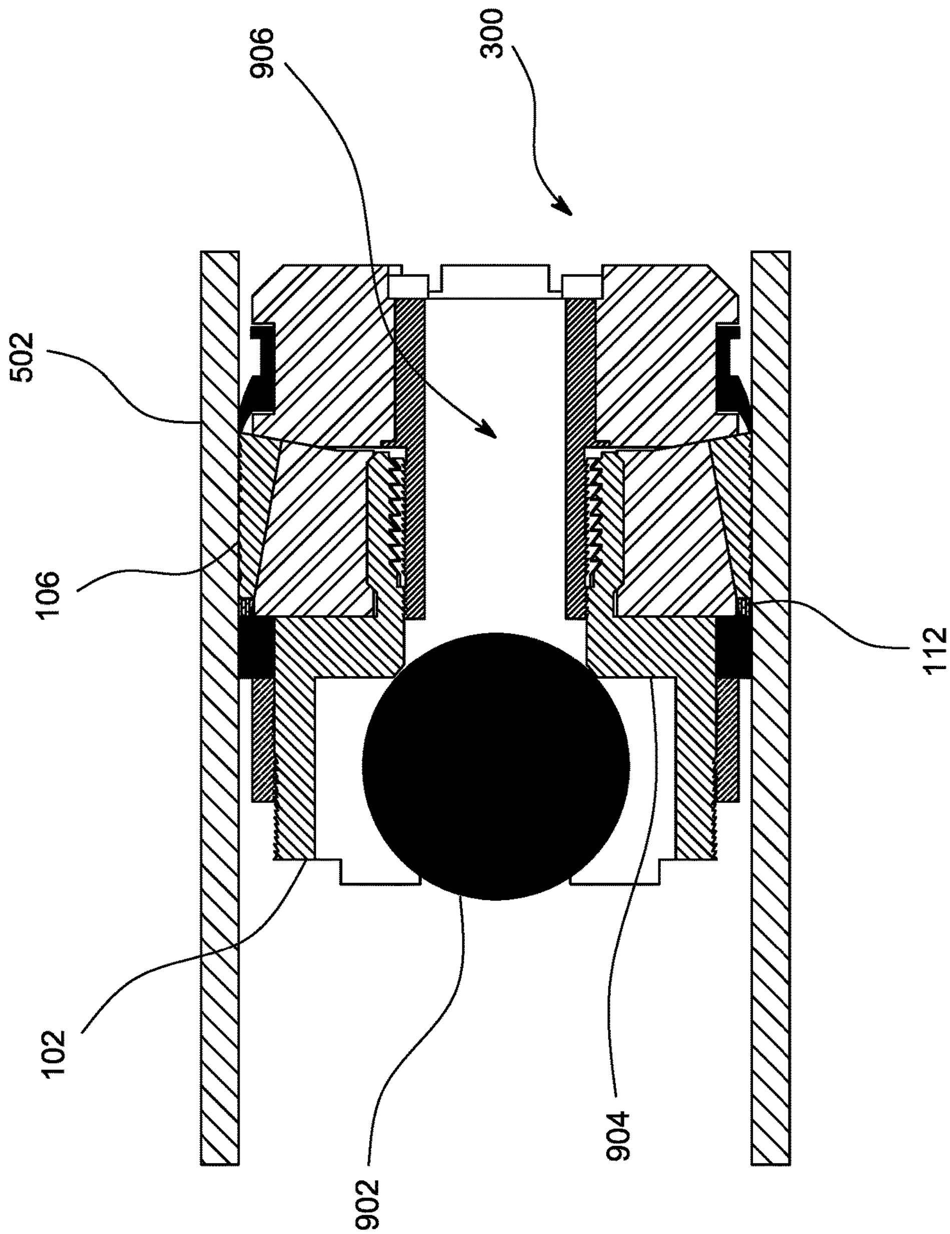

FIG. 9

FRAC PLUG WITH RETENTION MECHANISM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application having Ser. No. 62/350,231 filed on Jun. 15, 2016, U.S. Provisional Patent Application having Ser. No. 62/382,464 filed on Sep. 1, 2016, and U.S. Provisional Patent Application having Ser. No. 62/466,482 filed on Mar. 3, 2017. These priority applications are hereby incorporated by reference in their entirety into the present application.

BACKGROUND

[0002] In oil and gas production, it is sometimes beneficial to stimulate a reservoir by pumping in high pressure fluids and particulates, such as sand. In order to do this, one or more tubular sections of a tubular installed in the well may need to be isolated for a period of time and re-opened so the well can be produced. Some current methods of isolation use a frac plug and a sealing ball. A frac plug is a hollow, cylindrical plug that can be installed in the tubular section(s) selected for isolation within the well. The sealing ball then seats in the frac plug to stop fluid flow through the frac plug location and isolate the selected tubular section(s).

[0003] Currently, frac plugs are built around a central mandrel. Typically, the central mandrel is then held in place within a tubular section using upper and lower slips. However, such designs may shift within the tubular section when a sealing ball is installed. Additionally, the sealing element is positioned between the slips. This arrangement may prevent the sealing element from fully compressing if the slips become fully engaged prior to full compression of the sealing element. Further, current frac plugs may allow extrusion of the seal during stimulation of the reservoir, or move as the plug is milled or ground to allow production.

[0004] What is needed, therefore, is a frac plug that can maintain the desired position within the tubular section, ensure full compression of the sealing element, and remain in place during milling or grinding operations.

SUMMARY

[0005] Embodiments of the disclosure may provide a slip for a downhole tool. The slip may include an annular body having a first axial end, a second axial end, an inner surface, outer surface, and an axial length. The annular body may include a taper on the inner surface that extends along the axial length of the annular body. The annular body may further include a left-hand thread pattern defined by the outer surface that extends from the first axial end along a portion of the axial length, and each thread of the left-hand thread pattern may have a crest that is angled toward the first axial end.

[0006] Embodiments of the disclosure may further provide a frac plug. The frac plug may include a plug body, a sealing element, and a slip. The sealing element may be circumferentially disposed about the plug body and seal an annulus between the frac plug and a tubular section when actuated. The slip may be circumferentially disposed about the plug body and engage the tubular section when actuated. The slip may include an annular body having a first axial end, a second axial end, an inner surface, an outer surface, and an axial length. The annular body may include a taper on the inner surface that extends along the axial length of the annular body. The annular body may further include a left-hand thread pattern defined by the outer surface that extends from the first axial end along a portion of the axial length, and each thread the left-hand thread pattern may have a crest that is angled toward the first axial end.

[0007] Embodiments of the disclosure may further provide a method for setting and removing a frac plug from a tubular section. The method may include disposing the frac plug on a running tool. The frac plug may define a left-hand thread pattern in an outer surface of a slip of the frac plug. The method may also include positioning the frac plug within the tubular section using the running tool. The method may further include compressing the frac plug with the running tool such that the left-hand thread pattern engages with the tubular section. The method may also include milling the frac plug in a clockwise direction such that the left-hand thread pattern defined in the outer surface of the slip further engages with the tubular section and prevents movement of the frac plug away from a milling tool as the frac plug is milled.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present disclosure is best understood from the following detailed description when read with the accompanying Figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0009] FIG. **1** illustrates an exemplary frac plug, according to one or more embodiments disclosed.

[0010] FIG. **2**A illustrates a cross-sectional view of the frac plug of FIG. **1** along line **2**-**2**.

[0011] FIG. **2**B illustrates an enlarged view of the portion of the frac plug indicated by the detail labeled **2**B of FIG. **2**A.

[0012] FIG. **3**A illustrates a cross-sectional view of an exemplary frac plug, according to one or more embodiments disclosed.

[0013] FIG. **3**B illustrates an enlarged view of the portion of the frac plug indicated by the detail labeled **3**B of FIG. **3**A.

[0014] FIG. **4** illustrates a cross-sectional view of an exemplary frac plug, according to one or more embodiments disclosed.

[0015] FIG. **5** illustrates the frac plug of FIG. **3**A being run into the wellbore.

[0016] FIG. **6** illustrates the frac plug of FIG. **3**A as the frac plug is being set in position within a tubular section by a running tool after being run in as shown in FIG. **5**.

[0017] FIG. **7** illustrates the running tool being retracted from the frac plug of FIG. **3**A after the frac plug is set as shown in FIG. **6**.

[0018] FIG. **8** illustrates the frac plug of FIG. **3**A in the set position within a tubular section with the running tool fully retracted.

[0019] FIG. **9** illustrates the frac plug of FIG. **3**A once set and sealed.

DETAILED DESCRIPTION

[0020] It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure; however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the various Figures. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Finally, the exemplary embodiments presented below may be combined in any combination of ways, i.e., any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0021] Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities may refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function. Additionally, in the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to." All numerical values in this disclosure may be exact or approximate values unless otherwise specifically stated. Accordingly, various embodiments of the disclosure may deviate from the numbers, values, and ranges disclosed herein without departing from the intended scope. Furthermore, as it is used in the claims or specification, the term "or" is intended to encompass both exclusive and inclusive cases, i.e., "A or B" is intended to be synonymous with "at least one of A and B," unless otherwise expressly specified herein.

[0022] FIG. **1** illustrates an exemplary frac plug **100**, according to one or more embodiments disclosed. The frac plug **100** may include a plug body **101** that includes a first sub **102** and a second sub **104**. Alternative embodiments of the frac plug **100** may instead include a plug body **101** having a single sub. The frac plug **100** may further include a slip **106**, a sealing element **108**, a pump down ring **110**, and a back-up ring **112**. In at least one embodiment, the external axial ends (one shown **114**) of the frac plug **100** may include circumferentially spaced, axial protrusions (four shown **116**), or "castellations", extending from the frac plug **100**. Other embodiments of the frac plug may have two, three, five, or more castellations **116** extending from each external axial end **114**, or the castellations **116** may be omitted from one or both of the external axial ends **114** of the frac plug **100**. The castellated axial ends **114** are used in stacking multiple frac plugs **100** in a manner known to the art in some embodiments.

[0023] In the exemplary embodiment, the slip **106** includes a plurality of longitudinal, only three of which are shown. The longitudinal grooves **118** extend through a portion of the axial length of the slip **106**. In the exemplary embodiment, adjacent longitudinal grooves **118** extend from opposing axial ends **120** of the slip **106**. In another embodiment, the longitudinal grooves may extend from only one axial end **120** of the slip **106**. Other embodiments of the slip **106** may include two or more adjacent longitudinal grooves **118** that extend from the same axial end **120** of the slip **106**, include longitudinal grooves **118** that extend axially through the slip **106** without interfacing with either axial end **120**, or omit the longitudinal grooves **118**. In the exemplary embodiment, the slip **106** also includes a left-hand thread profile **122** that is defined in an outer surface **124** of the slip **106**.

[0024] FIG. **2A** illustrates a cross-sectional view of the frac plug **100** of FIG. **1** along line **2-2**. In the exemplary embodiment, the first sub **102** includes a cast or powdered metal core **202** bonded to an outer sleeve **204** formed from a resin and fiber composite material. Other embodiments of the first sub **102** may include a core **202** and outer sleeve **204** that are coupled using adhesives, a threaded connection, or both. Still other mechanisms for coupling the core **202** and sleeve **204**, such as brazing, welding, and mechanical fasteners, may be used in alternative embodiments. Although the composite material in the exemplary embodiment of the outer sleeve **204** is a resin and fiber composite, other suitable composites known in the art may be used. Additionally, other embodiments of the first sub **102** may be cast or formed from powdered metal, and omit the fiber and resin composite. In another embodiment, the first sub **102** may be formed entirely from a composite material.

[0025] The second sub **104** may include a cast or powdered metal core **206** and composite outer sleeve **208**, as shown in the exemplary embodiment. The core **206** may be bonded, threadably engaged, or coupled to the outer sleeve **208** using the methods described above. As with the first sub **102**, the second sub **104** may be a single component that is cast, formed from powdered metal, or formed from a composite material. When assembled, the core **206** of the second sub **104** is partially disposed within the core **202** of the first sub **102**. As shown FIG. **2A**, the first core **202** may define an inner thread **210** that mates with an outer thread **212** of the second core **206** to couple the first sub **102** to the second sub **104**.

[0026] Other embodiments of the frac plug **100** may include a first sub **102**, a second sub **104**, or both a first sub **102** and a second sub **104** that are predominately composite (i.e., over about 50% composite). In this context, "about" indicates that the measure need not be precisely 50%, but may be more or less depending on a number of factors. For example, variations in manufacturing processes and tools might result in embodiments whose content might deviate from the 50% mark. Similarly, some implementation specific constraints might mitigate for some deviation more or less from a precise 50% composition.

[0027] Another embodiment (not shown) of the frac plug **100** may include first and second subs **102**, **104** that are completely composite. As will be appreciated by those skilled in the art, construction of completely composite first and second subs **102**, **104** might possibly mitigate for a reduction of the inner bore of the frac plug **100** to prevent excessive stress in the composite material. Additional embodiments of the frac plug **100** may include first and second subs **102**, **104** that are different materials, such as a cast first sub **102** and a composite second sub **104**. Further embodiments (also not shown) of the frac plug **100** may include a single plug body **101** that includes a metal core (not shown) bonded, threadably engaged, or coupled to an outer sleeve (not shown) using the methods described above.

[0028] In the illustrated embodiment, the slip **106** and back-up ring **112** are positioned between the first and second subs **102**, **104** of the frac plug **100**, with the back-up ring **112** positioned adjacent the outer sleeve **204** and the slip **106**. As shown in FIG. **2**A, a portion of the outer surface **214** of the outer sleeve **204** is tapered. The slip **106**, the back-up ring **112**, or both may include a tapered inner surface **216**, **218** that contacts the tapered outer surface **214** of the first sub **102**.

[0029] In the exemplary embodiment, the slip **106** is made of a powdered metal and the back-up ring **112** is made of brass. Other embodiments of the slip **106** may be a composite material, cast iron, or any other material known in the art that is suitable for a slip. Additionally, other embodiments of the back-up ring **112** may be made of titanium or another ductile metal that will allow the back-up ring **112** to expand without fracturing.

[0030] FIG. **2**B illustrates an enlarged view of the portion of the frac plug **100** indicated by the detail labeled **2**B of FIG. **2**A. As shown in FIG. **2**B, each thread **213** (only one indicated) of the left-hand thread profile **122** may include a first flank **215** (only one indicated) that is longer than a second flank **217** (only one indicated), angling the crest **219** (only one indicated) of each thread **213** towards the second sub **104**. Other embodiments may include threads **213** having a first flank **215** and a second flank **217** that are similar in size, and the crest **219** may be perpendicular to the slip **106**.

[0031] The back-up ring **112** may include one or more threads **220** radially extending from the back-up ring **112**. As shown in FIG. **2**B, each thread **220** includes a first flank **221** that may be shorter than a second flank **223**, angling the crest **225** of each thread **220** towards the first sub **102**. In another embodiment, the threads **220** may be replaced by radial protrusions (not shown), or "teeth", having points (not shown) that angle towards the first sub **102**. Other embodiments of the back-up ring **112** may include threads **220** having crests **225** or teeth having points that are generally perpendicular back-up ring **112**. Further embodiments of the back-up ring **112** may omit the threads **220** and have a smooth outer surface.

[0032] Referring back to FIG. **2**A, the sealing element **108** may be positioned within an annular recess **222** in the outer surface **214** of the outer sleeve **204**. As shown in FIG. **2**A, the sealing element **108** is independent of the slip **106**. This arrangement allows the sealing element **108** and the slip **106** to be compressed independently. A compression ring **224** may be coupled to the first core **202** using a threaded connection **226**, retaining the sealing element **108** in place. Additionally, the pump down ring **110** may be positioned within an annular recess **228** defined by the outer sleeve **208** of the second sub **104**, as shown in FIG. **2**A. Other embodiments of the frac plug **100** may omit the pump down ring **110**, the annular recess **228**, or both.

[0033] FIG. **3**A illustrates a cross-sectional view of an exemplary frac plug **300**, according to one or more embodiments. The frac plug **300** illustrated in FIG. **3**A is an alternative embodiment that may be used in place of the frac plug **100** illustrated in FIGS. **1** and **2**A. The frac plug **300** may be substantially similar in several respects to the frac plug **100** described above with reference to FIGS. **1** and **2**A. Accordingly, the frac plug **300** may be best understood with reference to the frac plug **100**, where like numerals indicate like elements and therefore will not be described again in detail.

[0034] The first core **202** of the frac plug **300** may have an outer diameter **302** that is smaller than an outer diameter **304** of the outer sleeve **204**, as shown in the exemplary embodiment. This may create a recessed portion **306** of the first sub **102** that allows the sealing element **108** to be circumferentially disposed about the first core **202** and adjacent the outer sleeve **204**. The frac plug **300** may also include a lock ring **308** positioned between the first core **202** and the second core **206**. In the exemplary embodiment, the lock ring **308** is a C-ring type lock ring that includes a gap. Other embodiments of the lock ring **308** may be continuous. The lock ring **308** may define both inner threads **310** and outer threads **312**.

[0035] In the exemplary embodiment, the outer threads **312** of the lock ring **308** mate with the inner threads **210** of the first core **202**, and the inner threads **310** of the lock ring **308** may mate with the outer threads **212** of the second core **206**. The outer threads **312** of the lock ring **308** and the inner threads **210** of the first core **202** may have a larger pitch than the inner threads **310** of the lock ring **308** and the outer threads **212** of the second core **206**, as shown in FIG. **3**A. In other embodiments, the pitch of the two sets of threads **312**, **210**, **310**, **212** may be the same size, or the outer threads **312** of the lock ring **308** and the inner threads **210** of the first core **202** may have a smaller pitch than the inner threads **310** of the lock ring **308** and the outer threads **212** of the second core **206**.

[0036] FIG. **3**B illustrates an enlarged view of the portion of the frac plug **300** indicated by the detail labeled **3**B of FIG. **3**A. As shown in FIG. **3**B, the back-up ring **112** of the frac plug **300** may be trapezoidal and have a relatively smooth outer surface **314**. In the exemplary embodiment, the slip **106** includes a left-hand thread profile **122** where the crest **219** (only one indicated) of each thread **213** (only one indicated) is angled towards the second sub **104**, as described above. Additionally, a portion of the slip **106** adjacent the back-up ring **112** may define one or more threads **316**. Each thread **316** includes a first flank **317** that is shorter than a second flank **319**, angling the crest **321** of each thread **316** towards the first sub **102**. In one embodiment, the slip **106** may include a second thread **318** has a larger pitch, a larger pitch diameter, or both a larger pitch and a larger pitch diameter than the other threads **316** that have crests **321** angled towards the first sub **102**.

[0037] Other embodiments of the slip **106** may include threads **316** that have a pitch, a pitch diameter, or both a pitch and a pitch diameter that are the same size, or a different thread may have a larger pitch, a larger pitch diameter, or both a larger pitch and a larger pitch diameter than the other threads **316**. In another embodiment, the threads **316** may be replaced by teeth (not shown) having points (not shown) that angle towards the first sub **102**. Further embodiments of the slip **106** may include a left-hand thread profile **122**, threads **316**, or both a left-hand thread profile **122** and threads **316** that have crests **219**, **321** that are generally perpendicular to the outer surface **124** of the slip **106**.

[0038] It should be appreciated that while the slip **106** is particularly well suited to the frac plug **100**, the present disclosure is not thereby limited. The slip **106** may be used on other frac plugs having a single body, a central mandrel, or more than one slip. Similarly, the slip **106** disclosed herein includes features that may readily be applied to slips currently used on other downhole tools.

[0039] FIG. **4** illustrates a cross-sectional view of an exemplary frac plug **400**, according to one or more embodiments. Although the frac plug **400** in FIG. **4** is alternative to the frac plugs **100** and **300** in FIGS. **1**, **2**A, and **3**A, it is substantially similar in several respects. Accordingly, like numerals indicate like elements and therefore will not be described again in detail except where material to the present embodiment.

[0040] The first sub **102** of the frac plug **400** may include a cast metallic cap **402** coupled to a resin and fiber composite main body **404**, as shown in FIG. **4**. The cap **402** may be coupled to the main body **404** using adhesives, a threaded connection, or both. Still other mechanisms for coupling the cap **402** and the main body **404**, such as bonding and mechanical fasteners, may be used in alternative embodiments. Although the composite material in the exemplary embodiment of the main body **404** is a resin and fiber composite, other suitable composites known in the art may be used. Additionally, other embodiments of the cap **402** may be machined or formed from powdered metal.

[0041] As illustrated in this particular embodiment, the cap **402** may include threads **406** defined in an outer surface **408** of the cap **402**. The threads **406** may engage with the compression ring **224** to retain the sealing element **108**. Additionally, the lock ring **308** may engage with inner threads **410** defined by the main body **404** to couple the first sub **102** and the second sub **104**, as shown in FIG. **4**.

[0042] FIGS. **5-9** illustrate the installation of the frac plug **300** of FIG. **3**A. Initially, the frac plug **300** is positioned within a tubular section **502** using a running tool **504** that extends through the frac plug **300**, as shown in FIG. **5**. The frac plug **300** is retained on the running tool **504** by a shear ring **506** configured to break at a predetermined load and a cylindrical retainer **508**. The shear ring **506** may be positioned adjacent the second sub **104** and the cylindrical retainer **508** may be positioned adjacent the first sub **102**. The process of positioning the frac plug **300** within the tubular section **502** may be aided by the pump down ring **110**, which helps move the frac plug **300** into position within the tubular section **502**. Once the frac plug **300** reaches the desired location, the running tool **504** begins to compress the frac plug **300** by pulling the shear ring **506** towards the cylindrical retainer **508** and pushing the cylindrical retainer **508** towards the shear ring **506**.

[0043] As shown in FIG. **6**, the tapered surface **214** of the outer sleeve **204** may radially expand the slip **106** and back-up ring **112** as the frac plug **300** is compressed. In some embodiments, this expansion may cause the slip **106** to fracture along the longitudinal grooves **118**, creating a plurality of slip segments (not shown). In other embodiments, the longitudinal grooves **118** in the slip **106** may allow the slip **106** to expand without fracturing. As the back-up ring **112** is made of a ductile material, the back-up ring **112** expands without fracturing as it moves along the tapered surface **214**.

[0044] As the frac plug **300** is compressed, the threads **316** on the slip **106** that are facing the first sub **102** contact the tubular section **502**. The threads **316**, and, in particular, the larger thread **318**, may engage or "bite" into the inner diameter of tubular section **502**, preventing further movement of the second sub **104** towards the first sub **102**. Since the frac plug **300** is being compressed by the running tool **504**, the cylindrical retainer **508** will continue to push the first sub **102** towards the second sub **104**. This movement allows the slip **106** and back-up ring **112** to continue to move along the tapered surface **214** of the outer sleeve **204**. The continued expansion of the slip **106** allows the left-hand threads **122** of the slip **106** to engage with the tubular section **502**, preventing movement of the slip **106** away from the first sub **102** and further retaining the frac plug **300** in position.

[0045] Additionally, the compression ring **224** shifts along the external threads **602** of the first core **202** as the frac plug is compressed, compressing the sealing element **108** and creating a seal between the frac plug **300** and the tubular section **502**. The interface between the compression ring **224** and the first core **202** may also have a ratcheting effect, where the threads **604** of the compression ring **224** slide over the external threads **602** of the first core in one direction, but are restricted from moving in the opposite direction by the external threads **602**. Accordingly, the ratcheting effect may prevent movement of the compression ring **224** away from the sealing element **108** and the outer sleeve **204**. Similarly, the lock ring **308** may ratchet along the inner threads **210** of the first core **202**, and the second core **206** may ratchet along the inner threads **310** the lock ring **308**, preventing decompression of the frac plug **300**.

[0046] As shown in FIG. **6**, the compression ring **224** and sealing element **108** are both circumferentially disposed about the first sub **102** and separated from the slip **106** by the outer sleeve **204**. This allows the compressive force applied by the running tool **504** to independently act on the ratcheting interface between the compression ring **224** and the first sub **102**, and the ratcheting interface between the first sub **102**, lock ring **308**, and the second sub **104**. This arrangement allows the frac plug **300** to continue to compress even if one of the interfaces reaches full compression before the other interface, ensuring the frac plug **300** is fully set within the tubular section.

[0047] As shown in FIG. **7**, the slip **106** may engage with the inner diameter of the tubular section **502** when the frac plug **300** is set, securing the frac plug **300** in place. Additionally, the back-up ring **112**, having expanded into the position shown in FIG. **7**, contacts the tubular section **502** and may prevent extrusion of the sealing element **108**. Once the frac plug **300** is set in position, the shear ring **506** breaks when the predetermined load is reached. The running tool **504** is then tripped out of the tubular section.

[0048] Once the running tool **504** is removed from the frac plug **300** and tubular section **502**, as shown in FIG. **8**, a sealing ball **902** is dropped down the tubular section **502**. The sealing ball **902** seats against the inner surface **904** of the first sub **102**, as shown in FIG. **9**, sealing the bore **906** of the frac plug **300**. The force of the sealing ball **902** against the first sub **102** of the frac plug **300** may further secure the frac plug **300** in place by shifting the back-up ring **112** and slip **106** further along the tapered surface **214** of the first sub **102**.

[0049] Although not illustrated, it should be understood that the processes of running and setting frac plugs **100** and **400** are substantially similar to the process of running and setting frac plug **300**. However, the second sub **104** of frac plug **100** ratchets within the first sub **102** to retain the frac plug **100** in the compressed position, omitting the lock ring **308**.

[0050] Once the fracturing operations are complete, the frac plugs **100**, **300**, and **400** may be removed through milling. In embodiments employing a slip **106** with a left-hand thread **122**, the left-hand thread **122** of the slip **106** may prevent the frac plug **300** from rotating as the frac plug **100**, **300** is being milled, since milling tools typically rotate clockwise. Additionally, the castellations **116** in the first and second subs **102**, **104** of the frac plug **100**, **300** may allow the frac plug **300** to interface with a second, downstream frac plug **100**, **300** as it is milled, reducing or eliminating rotational movement of the frac plug **100**, **300** being milled.

[0051] In addition to the embodiments described above, U.S. Provisional Patent Application Ser. Nos. 62/350,231, 62/382,464, and 62/466,482 incorporated by reference above disclose additional embodiments differing from embodiments described herein in various ways. Although not expressly disclosed herein, these embodiments disclosed in the aforementioned provisional applications are, as previously stated, incorporated by reference into the present application. It is to be understood that the lack of an express disclosure herein does not disclaim such embodiments. Those incorporated embodiments are, through their incorporation, a part of this disclosure as if expressly set forth herein. They therefore are within the scope of the subject matter claimed below.

[0052] As previously noted, the embodiments disclosed in the above provisional applications differ from the embodiments disclosed herein. For example, the embodiment disclosed in Provisional Application 62/350,231 includes a sealing element **108** with an integrated steel back-up ring and pump down ring **110**. The embodiment of Provisional Application 62/350,231 also includes a tapered second sub **104**. The embodiment of Provisional Application 62/350,231 further includes a back-up ring **112** that is circumferentially disposed about the taper of the second sub and pushes the sealing element **108** up the tapered surface **214** of the first sub **102** to expand the sealing element **108**, instead of compressing the sealing element with a compression ring **224**.

[0053] Additional embodiments, disclosed in Provisional Application 62/382,464, include many of the features disclosed in Provisional Application 62/350,231. However, one embodiment disclosed in Provisional Application 62/382,464 includes a back-up ring **112** that is integral with the slip **106**, instead of the sealing element **108**. Another embodiment disclosed in Provisional Application 62/382,464 includes a slip **106** having a right-hand thread profile defined in the outer surface **124** instead of a left-hand thread profile **122** to accommodate milling tools that rotate counter-clockwise.

[0054] The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A slip for a downhole tool, comprising:

an annular body having a first axial end, a second axial end, an inner surface, an outer surface, and an axial length, the annular body comprising:

a taper on the inner surface that extends along the axial length of the annular body, and

a left-hand thread pattern defined by the outer surface and extending from the first axial end along a portion of the axial length, each thread of the left-hand thread pattern having a crest that is angled toward the first axial end.

2. The slip of claim **1**, wherein the annular body further comprises at least one thread defined by the outer surface and adjacent the second axial end, the at least one thread having a crest that is angled away from the left-hand thread pattern.

3. The slip of claim **1**, wherein the annular body defines a plurality of grooves circumferentially spaced along the diameter of the annular body and extending along a portion of the axial length.

4. The slip of claim **3**, wherein adjacent grooves of the plurality of grooves alternately extend from the first axial end and the second axial end.

5. The slip of claim **3**, wherein at least two adjacent grooves of the plurality of grooves extend from the same axial end of the slip.

6. The slip of claim **1**, wherein the slip comprises a cast metal.

7. The slip of claim **1**, wherein the slip comprises a powdered metal.

8. The slip of claim **1**, wherein the slip comprises a composite material.

9. A frac plug, comprising:

a plug body;

a sealing element circumferentially disposed about the plug body that, when actuated, seals an annulus between the frac plug and a tubular section; and

a slip circumferentially disposed about the plug body that, when actuated, engages the tubular section, the slip comprising:

an annular body having a first axial end, a second axial end, an inner surface, an outer surface, and an axial length, the annular body comprising:

a taper on the inner surface that extends along the axial length of the annular body, and

a left-hand thread pattern defined by the outer surface and extending from the first axial end along a portion of the axial length, each thread of the left-hand thread pattern having a crest that is angled toward the first axial end.

10. The frac plug of claim **9**, wherein the plug body comprises a first sub and a second sub.

11. The frac plug of claim **10**, wherein the first sub and the second sub each comprise a composite material outer sleeve and a metal inner core engaged with and structurally supporting the composite material outer sleeve.

12. The frac plug of claim **9**, further comprising a back-up ring positioned adjacent to the slip.

13. The slip of claim **9**, wherein the annular body of the slip defines a plurality of grooves circumferentially spaced along the diameter of the annular body and extending along a portion of the axial length.

14. The frac plug of claim **13**, wherein adjacent grooves of the plurality of grooves alternately extend from the first axial end of the slip and the second axial end of the slip.

15. The frac plug of claim **13**, wherein at least two adjacent grooves of the plurality of grooves extend from the same axial end of the slip.

16. The frac plug of claim **9**, wherein the annular body of the slip further comprises at least one thread defined by the outer surface and adjacent the second axial end, the at least one thread having a crest that is angled away from the left-hand thread pattern.

17. The frac plug of claim **9**, wherein the slip comprises a cast metal.

18. The frac plug of claim **9**, wherein the slip comprises a powdered metal.

19. The frac plug of claim **9**, wherein the slip comprises a composite material.

20. A method for setting and removing a frac plug from a tubular section, the method comprising:

disposing the frac plug on a running tool, the frac plug defining a left-hand thread pattern in an outer surface of a slip of the frac plug;

positioning the frac plug within the tubular section using the running tool;

compressing the frac plug with the running tool such that the left-hand thread pattern engages with the tubular section; and

milling the frac plug in a clockwise direction such that the left-hand thread pattern defined in the outer surface of the slip further engages with the tubular section and prevents movement of the frac plug away from a milling tool as the frac plug is milled.

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