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Systems and methods for sealing a wellbore

Abstract

A plug for sealing a wellbore includes a mandrel extending between an uphole end defining an uphole end of the plug, and a downhole end opposite the uphole end of the mandrel, a slip assembly extending around the mandrel and including a plurality of arcuate slip segments, a nose coupled to the downhole end of the mandrel and defining a downhole end of the plug, wherein the nose includes an uphole end coupled to the downhole end of the mandrel and a downhole end opposite the uphole end of the nose and defining a downhole end of the plug, and a packer extending around the mandrel and including a first configuration configured to permit fluid flow across the plug when the plug is received in the wellbore, and a second configuration configured to seal the wellbore when the plug is positioned in the wellbore.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) The present application is a continuation of U.S. non-provisional patent application Ser. No. 17/484,260 filed Sep. 24, 2021, entitled “Systems and Methods for Sealing a Wellbore”, which is a continuation of U.S. non-provisional patent application Ser. No. 16/152,184 filed Oct. 4, 2018, entitled “Systems and Methods for Sealing a Wellbore”, now U.S. Pat. No. 11,131,163 issued Sep. 28, 2021, which claims benefit of U.S. provisional patent application No. 62/569,447 filed Oct. 6, 2017, entitled “Downhole Plug,” and U.S. provisional patent application No. 62/734,803 filed Sep. 21, 2018, entitled “Downhole Plug,” all of which are hereby incorporated herein by reference in their entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT (1) Not applicable.
BACKGROUND
(2) After a wellbore has been drilled through a subterranean formation, the wellbore may be cased by inserting lengths of pipe (“casing sections”) connected end-to-end into the wellbore. Threaded exterior connectors known as casing collars may be used to connect adjacent ends of the casing sections at casing joints, providing a casing string including casing sections and connecting casing collars that extends from the surface towards the bottom of the wellbore. The casing string may

then be cemented into place to secure the casing string within the wellbore.
(3) In some applications, following the casing of the wellbore, a wireline tool string may be run into the wellbore as part of a “plug-n-pert” hydraulic fracturing operation. The wireline tool string may include a perforating gun for perforating the casing string at a desired location in the wellbore, a downhole plug that may be set to couple with the casing string at a desired location in the wellbore, and a setting tool for setting the downhole plug. In certain applications, once the casing string has been perforated by the perforating gun and the downhole plug has been set, a ball or dart may be pumped into the wellbore for landing against the set downhole plug, thereby isolating the portion of the wellbore extending uphole from the set downhole plug. With this uphole portion of the wellbore isolated, the formation extending about the perforated section of the casing string may be hydraulically fractured by fracturing fluid pumped into the wellbore.

SUMMARY OF THE DISCLOSURE

(4) An embodiment of a plug for sealing a wellbore comprises a mandrel extending between an uphole end defining an uphole end of the plug, and a downhole end opposite the uphole end of the mandrel, a slip assembly extending around the mandrel and comprising a plurality of arcuate slip segments, a nose coupled to the downhole end of the mandrel and defining a downhole end of the plug, wherein the nose comprises an uphole end coupled to the downhole end of the mandrel and a downhole end opposite the uphole end of the nose and defining a downhole end of the plug, and a packer extending around the mandrel and comprising a first configuration configured to permit fluid flow across the plug when the plug is received in the wellbore, and a second configuration configured to seal the wellbore when the plug is positioned in the wellbore, wherein one of the downhole end of the nose and the uphole end of the mandrel comprises a plurality of axially extending protrusions circumferentially spaced about a central axis of the plug, wherein the other of the downhole end of the nose and the uphole end of the mandrel comprises which does not comprise the plurality of protrusions comprises a plurality of axially extending recesses circumferentially spaced about the central axis of the plug. In some embodiments, the plurality of protrusions are each arcuate in shape, and wherein the plurality of recesses are each arcuate in shape. In some embodiments, the plurality of protrusions and the plurality of recesses are positioned along a common diameter extending around the central axis of the plug. In certain embodiments, one of the uphole end of the nose and a downhole end of the slip assembly comprises a plurality of notches circumferentially spaced about the central axis of the plug while the other of the uphole end of the nose and the downhole end of the slip assembly comprises a plurality of pockets circumferentially spaced about the central axis of the plug and configured to interlockingly receive the plurality of notches to restrict relative rotation between the nose and the slip assembly. In certain embodiments, relative rotation about the central axis of the plug is restricted between the nose and the packer.
(5) An embodiment of a system for completing a wellbore comprises a first plug, comprising a first mandrel extending between an uphole end defining an uphole end of the first plug, and a downhole end opposite the uphole end of the first mandrel, a first slip assembly extending around the first mandrel and comprising a plurality of arcuate first slip segments, a first nose coupled to the downhole end of the first mandrel and defining a downhole end of the first plug, wherein the first nose comprises an uphole end coupled to the downhole end of the first mandrel and a downhole end opposite the uphole end of the first nose and defining a downhole end of the first plug, and a first packer extending around the first mandrel and comprising a first configuration configured to permit fluid flow across the first plug when the first plug is received in the wellbore, and a second configuration configured to seal the wellbore when the first plug is positioned in the wellbore. In addition, the system comprises a second plug, comprising a second mandrel extending between an uphole end defining an uphole end of the second plug, and a downhole end opposite the uphole end of the second mandrel, a second slip assembly extending around the second mandrel and comprising a plurality of arcuate second slip segments, a second nose coupled to the downhole end

of the second mandrel and defining a downhole end of the second plug, wherein the second nose comprises an uphole end coupled to the downhole end of the second mandrel and a downhole end opposite the uphole end of the second nose and defining a downhole end of the second plug, and a second packer extending around the second mandrel and comprising a first configuration configured to permit fluid flow across the second plug when the second plug is received in the wellbore, and a second configuration configured to seal the wellbore when the second plug is positioned in the wellbore, wherein one of the downhole end of the second nose and the uphole end of the first mandrel comprises a plurality of axially extending notches circumferentially spaced about a central axis of the plug, and wherein the other of the downhole end of the second nose and the uphole end of the first mandrel comprises which does not comprise the plurality of notches comprises a plurality of axially extending recesses circumferentially spaced about the central axis of the plug configured to interlockingly receive the plurality of notches to restrict relative rotation between the second nose and the first mandrel. In some embodiments, the plurality of notches are each arcuate in shape, and wherein the plurality of recesses are each arcuate in shape. In some embodiments, the plurality of notches and the plurality of recesses are positioned along a common diameter extending around the central axis of the plug. In certain embodiments, one of the uphole end of the first nose and a downhole end of the first slip assembly comprises a plurality of notches circumferentially spaced about the central axis of the first plug while the other of the uphole end of the first nose and the downhole end of the first slip assembly comprises a plurality of pockets circumferentially spaced about the central axis of the first plug and configured to interlockingly receive the plurality of notches to restrict relative rotation between the first nose and the first slip assembly. In certain embodiments, relative rotation about the central axis of the first plug is restricted between the first nose and the first packer.

(6) An embodiment of a method for completing a wellbore comprises (a) positioning a first plug at a first location within the wellbore, (b) setting the first plug to lock the first plug at the first location to a casing string extending through wellbore and to seal the wellbore at the first location, (c) positioning a second plug at a second location within the wellbore that is uphole from the first location, (d) setting the second plug to lock the second plug at the second location to the casing string and to seal the wellbore at the second location, (e) releasing a nose of the second plug from the casing string permitting the nose of the second plug to travel through the wellbore, wherein a downhole end of the nose defines a downhole end of the second plug, and (f) interlocking the downhole end of nose of the second plug with an uphole end of a mandrel of the first plug to restrict relative rotation between the nose of the second plug and the mandrel of the first plug. In some embodiments, (e) comprises drilling into an uphole end of the second plug with a drill positioned in the wellbore to release the nose of the second plug from a slip assembly of the second plug. In some embodiments, (f) comprises interlockingly receiving a plurality of circumferentially spaced protrusions of one of the nose of the second plug and the mandrel of the first plug in a plurality of circumferentially spaced recesses of the other of the nose of the second plug and the mandrel of the first plug. In certain embodiments, the plurality of protrusions are each arcuate in shape, and wherein the plurality of recesses are each arcuate in shape. In certain embodiments, the plurality of protrusions and the plurality of recesses are positioned along a common diameter extending around a central axis of the plug. In some embodiments, the method further comprises (g) pumping the nose of the second plug through the wellbore following (e) whereby the downhole end of the nose lands against the uphole end of the mandrel of the first plug. In some embodiments, the method further comprises (g) pumping a fracturing fluid through the wellbore following (d) to form one or more fractures in an earthen subterranean formation through which the wellbore extends at one or more locations located along the wellbore uphole from the second location. In certain embodiments, the method further comprises (g) pumping a fracturing fluid through the wellbore following (b) to form one or more fractures in an earthen subterranean formation through which the wellbore extends at one or more locations located along the wellbore between the first

location and the second location. In certain embodiments, the method further comprises (g) drilling into an uphole end of the nose of the second plug following (f) with a drill positioned in the wellbore while the nose is interlocked with the mandrel of the first plug. In some embodiments, the method further comprises (h) releasing a nose of the first plug from the casing string following (g) to permit the nose of the first plug to travel through the wellbore.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) For a detailed description of exemplary embodiments of the disclosure, reference will now be made to the accompanying drawings in which:
(2) FIG. **1** is a schematic, partial cross-sectional view of a system for completing a subterranean well including an embodiment of a downhole plug in accordance with the principles disclosed herein;
(3) FIG. **2** is a side view of the downhole plug of FIG. **1**;
(4) FIG. **3** is a front view of the downhole plug of FIG. **1**;
(5) FIG. **4** is a rear view of the downhole plug of FIG. **1**;
(6) FIG. **5** is an exploded side view of the downhole plug of FIG. **1**;
(7) FIGS. **6** and **7** are exploded perspective views of the downhole plug of FIG. **1**;
(8) FIG. **8** is side cross-sectional view of the downhole plug of FIG. **1** in a run-in position in accordance with principles disclosed herein;
(9) FIG. **9** is a rear view of an embodiment of an engagement disk of the downhole plug of FIG. **1** in accordance with principles disclosed herein;
(10) FIG. **10** is a front view of an embodiment of a clamping member of the downhole plug of FIG. **1** in accordance with principles disclosed herein;
(11) FIG. **11** is a rear view of an embodiment of a slip assembly of the downhole plug of FIG. **1** in accordance with principles disclosed herein;
(12) FIG. **12** is a perspective view of an embodiment of a nose cone of the downhole plug of FIG. **1** in accordance with principles disclosed herein;
(13) FIG. **13** is side cross-sectional view of the downhole plug of FIG. **1** in a set position in accordance with principles disclosed herein;
(14) FIG. **14** is a perspective view of another embodiment of a downhole plug in accordance with the principles disclosed herein;
(15) FIG. **15** is a perspective view of an embodiment of a mandrel of the downhole plug **14** in accordance with the principles disclosed herein;
(16) FIG. **16** is an exploded perspective view of the mandrel of FIG. **15**; and
(17) FIG. **17** is a side cross-sectional view of the mandrel of FIG. **15**.
DETAILED DESCRIPTION
(18) The following discussion is directed to various exemplary embodiments. However, one skilled in the art will understand that the examples disclosed herein have broad application, and that the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to suggest that the scope of the disclosure, including the claims, is limited to that embodiment. Certain terms are used throughout the following description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but not function. The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

(19) 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 . . . .” Also, the term “couple” or “couples” is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection via other devices, components, and connections. In addition, as used herein, the terms “axial” and “axially” generally mean along or parallel to a central axis (e.g., central axis of a body or a port), while the terms “radial” and “radially” generally mean perpendicular to the central axis. For instance, an axial distance refers to a distance measured along or parallel to the central axis, and a radial distance means a distance measured perpendicular to the central axis. Any reference to up or down in the description and the claims is made for purposes of clarity, with “up”, “upper”, “upwardly”, “uphole”, or “upstream” meaning toward the surface of the borehole and with “down”, “lower”, “downwardly”, “downhole”, or “downstream” meaning toward the terminal end of the borehole, regardless of the borehole orientation. Further, the term “fluid,” as used herein, is intended to encompass both fluids and gasses.
(20) Referring now to FIG. **1**, a system **10** for completing a wellbore **4** extending into a subterranean formation **6** is shown. In the embodiment of FIG. **1**, wellbore **4** is a cased wellbore including a casing string **12** secured to an inner surface **8** of the wellbore **4** using cement (not shown). In some embodiments, casing string **12** generally includes a plurality of tubular segments coupled together via a plurality of casing collars. In this embodiment, completion system **10** includes a tool string **20** disposed within wellbore **4** and suspended from a wireline **22** that extends to the surface of wellbore **4**. Wireline **22** comprises an armored cable and includes at least one electrical conductor for transmitting power and electrical signals between tool string **20** and the surface. System **10** may further include suitable surface equipment for drilling, completing, and/or operating completion system **10** and may include, in some embodiments, derricks, structures, pumps, electrical/mechanical well control components, etc. Tool string **20** is generally configured to perforate casing string **12** to provide for fluid communication between formation **6** and wellbore **4** at predetermined locations to allow for the subsequent hydraulic fracturing of formation **6** at the predetermined locations.
(21) In this embodiment, tool string **20** generally includes a cable head **24**, a casing collar locator (CCL) **26**, a direct connect sub **28**, a plurality of perforating guns **30**, a switch sub **32**, a plug-shoot firing head **34**, a setting tool **36**, and a downhole or frac plug **100** (shown schematically in FIG. **1**). Cable head **24** is the uppermost component of tool string **20** and includes an electrical connector for providing electrical signal and power communication between the wireline **22** and the other components (CCL **26**, perforating guns **30**, setting tool **36**, etc.) of tool string **20**. CCL **26** is coupled to a lower end of the cable head **24** and is generally configured to transmit an electrical signal to the surface via wireline **22** when CCL **26** passes through a casing collar, where the transmitted signal may be recorded at the surface as a collar kick to determine the position of tool string **20** within wellbore **4** by correlating the recorded collar kick with an open hole log. The direct connect sub **28** is coupled to a lower end of CCL **26** and is generally configured to provide a connection between the CCL **26** and the portion of tool string **20** including the perforating guns **30** and associated tools, such as the setting tool **36** and downhole plug **100**.
(22) Perforating guns **30** of tool string **20** are coupled to direct connect sub **28** and are generally configured to perforate casing string **12** and provide for fluid communication between formation **6** and wellbore **4**. Particularly, perforating guns **30** include a plurality of shaped charges that may be detonated by a signal conveyed by the wireline **22** to produce an explosive jet directed against casing string **12**. Perforating guns **30** may be any suitable perforation gun known in the art while still complying with the principles disclosed herein. For example, in some embodiments, perforating guns **30** may comprise a hollow steel carrier (HSC) type perforating gun, a scalloped perforating gun, or a retrievable tubing gun (RTG) type perforating gun. In addition, gun **30** may comprise a wide variety of sizes such as, for example, 2¾″, 3⅛″, or 3⅜″, wherein the above listed

size designations correspond to an outer diameter of perforating guns **30**.

(23) Switch sub **32** of tool string **20** is coupled between the pair of perforating guns **30** and includes an electrical conductor and switch generally configured to allow for the passage of an electrical signal to the lowermost perforating gun **30** of tool string **20**. Tool string **20** further includes plug-shoot firing head **34** coupled to a lower end of the lowermost perforating gun **30**. Plug-shoot firing head **34** couples the perforating guns of the tool string **20** to the setting tool **36** and downhole plug **100**, and is generally configured to pass a signal from the wireline **22** to the setting tool **36** of tool string **20**. Plug-shoot firing head **34** may also include mechanical and/or electrical components to fire the setting tool **36**.

(24) In this embodiment, tool string **20** further includes setting tool **36** and downhole plug **100**, where setting tool **36** is coupled to a lower end of plug-shoot firing head **34** and is generally configured to set or install downhole plug **100** within casing string **12** to isolate desired segments of the wellbore **4**. As will be discussed further herein, once downhole plug **100** has been set by setting tool **36**, an outer surface of downhole plug **100** seals against an inner surface of casing string **12** to restrict fluid communication through wellbore **4** across downhole plug **100**. Setting tool **36** of tool string **20** may be any suitable setting tool known in the art while still complying with the principles disclosed herein. For example, in some embodiments, tool **34** may comprise a #10 or #20 Baker style setting tool. In addition, setting tool **36** may comprise a wide variety of sizes such as, for example, 1.68 in., 2.125 in., 2.75 in., 3.5 in., 3.625 in., or 4 in., wherein the above listed sizes correspond to the overall outer diameter of the tool. Additionally, although downhole plug **100** is shown in FIG. **1** as incorporated in tool string **20**, downhole plug **100** may be used in other tool strings comprising components differing from the components comprising tool string **20**.

(25) Referring to FIGS. **1-13**, an embodiment of the downhole plug **100** of the tool string **20** of FIG. **1** is shown in FIGS. **2-13**. In the embodiment of FIGS. **2-13**, downhole plug **100** has a central or longitudinal axis **105** and generally includes a mandrel **102**, an engagement disk **130**, a body lock ring assembly **140**, a first clamping member **160**, an elastomeric member or packer **170**, a second clamping member **180**, a slip assembly **200**, and a nose cone **220**.

(26) In this embodiment, mandrel **102** of downhole plug **100** has a first end **102**A, a second end **102**B, a central bore or passage **104** defined by a generally cylindrical inner surface **106** extending between ends **102**A, **102**B, and a generally cylindrical outer surface **108** extending between ends **102**A, **102**B. The inner surface **106** of mandrel **102** includes a frustoconical seat **110** proximal first end **102**A. As will be discussed further herein, following the setting of downhole plug **100**, a ball or dart **300** may be pumped into wellbore **4** for seating against seat **110** such that fluid flow through central bore **104** of mandrel **102** is restricted. In this embodiment, the first end **102**A of mandrel **102** includes a pair of circumferentially spaced arcuate slots or recesses **112**. Additionally, in this embodiment, the outer surface **108** of mandrel **102** includes an expanded diameter portion **114** at first end **102**A that forms an annular shoulder **116**. Expanded diameter portion **114** of outer surface **108** includes a plurality of circumferentially spaced apertures **118** configured to receive a plurality of connecting members for coupling mandrel **102** with setting tool **36**. Mandrel **102** includes a plurality of ratchet teeth **120** that extend along a portion of outer surface **108** proximal shoulder **116**. Further, in this embodiment, the outer surface **108** of mandrel **102** includes a connector **122** located proximal to second end **102**B.

(27) Engagement disk **130** of downhole plug **100** is disposed about mandrel **102** and has a first end **130**A and a second end **130**B. In this embodiment, first end **130**A of engagement disk **130** comprises an annular engagement surface **130**A configured to engage a corresponding annular engagement surface of setting tool **36** for actuating downhole plug **100** from a first or run-in position shown in FIG. **8** to a second or set position shown in FIG. **13**, as will be discussed further herein. In the run-in position of downhole plug **100**, engagement surface **130**A of engagement disk **130** is disposed directly adjacent or contacts shoulder **116** of mandrel **102**. In this embodiment, the second end **130**B of engagement disk **130** includes an anti-rotation hexagonal shoulder or

protrusion **132** extending axially therefrom.

(28) In this embodiment, the body lock ring assembly **140** of downhole plug **100** comprises a plurality of circumferentially spaced arcuate lock ring segments **142** disposed about mandrel **102**, and an annular lock ring retainer **150** disposed about lock ring segments **142**. Each lock ring segment **142** includes a first end **142**A, a second end **142**B, and an arcuate inner surface extending between ends **142**A, **142**B that comprises a plurality of ratchet teeth **144**. Ratchet teeth **144** matingly engage the ratchet teeth **120** of mandrel **102** to restrict relative axial movement between lock ring segments **142** and mandrel **102**. Particularly, the mating engagement between ratchet teeth **144** of lock ring segments **142** and ratchet teeth **120** of mandrel **102** prevent lock ring segments **142** from travelling axially towards the first end **102**A of mandrel **102**, but permits lock ring segments **142** to travel axially towards the second end **102**B of mandrel **102**. Additionally, each lock ring segment **142** includes an outer surface extending between ends **142**A, **142**B, that comprises an arcuate groove **146** disposed proximate first end **142**A and a generally frustoconical surface **148** extending from second end **142**B. Lock ring retainer **150** retains lock ring segments **142** in position about mandrel **102** such that segments **142** do not move axially relative to each other.

(29) First clamping member **160** of downhole plug **100** is generally annular and is disposed about mandrel **102** between engagement disk **130** and packer **170**. In this embodiment, first clamping member **160** has a first end **160**A, a second end **160**B, and a generally cylindrical inner surface extending between ends **160**A, **160**B that includes a first frustoconical surface **162** located proximal first end **160**A and a second frustoconical surface **164** extending from second end **160**B. Additionally, in this embodiment, first clamping member **160** includes a hexagonal recess **166** that extends axially into the first end **160**A of first clamping member **160**. Hexagonal recess **166** of first clamping member **160** is configured to matingly receive the hexagonal shoulder **132** of engagement disk **130** to thereby restrict relative rotation between first clamping member **160** and engagement disk **130**. Although in this embodiment hexagonal shoulder **132** of engagement disk **130** and hexagonal recess **166** of first clamping member **160** are each six-sided in shape, in other embodiments, shoulder **132** and recess **166** may comprise varying number of sides. Additionally, as will be described further herein, the first frustoconical surface **162** of first clamping member **160** is configured to matingly engage the frustoconical surface **148** of each lock ring segment **142** when downhole plug **100** is set in wellbore **4**. Although in this embodiment engagement disk **130** comprises shoulder **132** and first clamping member **160** comprises recess **166**, in other embodiments, first clamping member **160** may comprise a hexagonal shoulder or protrusion while engagement disk **130** comprises a corresponding hexagonal recess configured to receive the shoulder of the first clamping member **160** to restrict relative rotation between engagement disk **130** and first clamping member **160**.

(30) Packer **170** of downhole plug **100** is generally annular and disposed about mandrel **102** between first clamping member **160** and second clamping member **180**. Packer **170** comprises an elastomeric material and is configured to sealingly engage an inner surface **14** of casing string **12** when downhole plug **100** is set, as shown particularly in FIG. **13**. In this embodiment, packer **170** comprises a generally cylindrical outer surface **172** extending between first and second ends of packer **170**. Outer surface **172** of packer **170** includes a pair of frustoconical surfaces **174** extending from each end of packer **170**.

(31) Second clamping member **180** of downhole plug **100** is generally annular and is disposed about mandrel **102** between packer **170** and slip assembly **200**. In this embodiment, second clamping member **180** has a first end **180**A, a second end **180**B, and a generally cylindrical inner surface extending between ends **180**A, **180**B that includes an inner frustoconical surface **182** extending from first end **180**A. Additionally, second clamping member **180** includes a generally cylindrical outer surface extending between ends **180**A, **180**B that includes a plurality of circumferentially spaced planar (e.g., flat) surfaces **184** extending from second end **180**B. Each

planar surface **184** extends at an angle relative to the central axis **105** of downhole plug **100**. In some embodiments, friction resulting from contact between the elastomeric material comprising packer **170** and frustoconical surfaces **164** and **182** of clamping members **160**, **180**, respectively, assists in preventing relative rotation between packer **170** and clamping members **160**, **180**.

(32) Slip assembly **200** is generally configured to engage or "bite into" the inner surface **14** of casing string **12** when downhole plug **100** is actuated into the set position to couple or affix downhole plug **100** to casing string **12**, thereby restricting relative axial movement between downhole plug **100** and casing string **12**. In this embodiment, slip assembly **200** comprises a plurality of circumferentially spaced arcuate slip segments **202** disposed about mandrel **102**, and a pair of axially spaced annular retainers **215** each disposed about the slip segments **202**. In this embodiment, each slip segment **202** includes a first end **202**A, a second end **202**B, and an arcuate inner surface extending between ends **202**A, **202**B that includes a planar (e.g., flat) surface **204** extending from first end **202**A. The planar surface **204** of each slip segment **202** extends at an angle relative to central axis **105** of downhole plug **105** and is configured to matingly engage one of the planar surfaces **184** of second clamping member **180**.

(33) The planar (e.g., flat) interface formed between each corresponding planar surface **184** of clamping member **180** and each planar surface **204** of slip segments **202** restricts relative rotation between second clamping member **180** and slip segments **202**. Additionally, as will be described further herein, relative axial movement between second clamping member **180** and slip assembly **200** is configured to force slip segments **202** radially outwards, snapping retainers **215**, via the angled or cammed sliding contact between planar surfaces **184** of second clamping member **180** and the planar surfaces **204** of slip segments **202**. In this embodiment, retainers **215** each comprise a filament wound band; however, in other embodiments, retainers **215** may comprise various materials and may be formed in varying ways.

(34) In this embodiment, each retainer ring **202** includes a generally arcuate outer surface extending between ends **202**A, **202**B that includes a plurality of engagement members **206**. Engagement members **206** are configured to engage or bite into the inner surface **14** of casing string **12** when downhole plug **100** is actuated into the set position to thereby affix downhole plug **100** to casing string **12** at a desired or predetermined location. Thus, engagement members **206** comprise a suitable material for engaging with inner surface **14** of casing string **12** during operations. For example, engagement members **206** may comprise 8620 Chrome-Nickel-Molybdenum alloy, carbon steel, tungsten carbide, cast iron, and/or tool steel. In some embodiments, engagement members **206** may comprise a composite material. Additionally, in this embodiment, each slip segment **202** of slip assembly **200** includes a pocket or receptacle **208** located at the second end **202**B which extends into the inner surface of the slip segment **202**.

(35) Nose cone **2202** of downhole plug **100** is generally annular and is disposed about the second end **102**B of mandrel **102**. Nose cone **220** has a first end **220**A, a second end **220**B, a central bore or passage **222** defined by a generally cylindrical inner surface **224** extending between ends **220**A, **220**B, and a generally cylindrical outer surface **226** extending between ends **220**A, **220**B. In this embodiment, the inner surface **224** of nose cone **200** includes a connector **228** that releasably or threadably couples with the connector **122** of mandrel **102** to restrict relative axial movement between mandrel **102** and nose cone **220**. Additionally, in this embodiment, nose cone **220** includes a plurality of circumferentially spaced protrusions or notches **230** extending from inner surface **224**. As will be discussed further herein, protrusions **230** prevent ball **300** from seating and sealing against inner surface **224**. Thus, in the event that ball **300** lands against inner surface **224** of nose cone **220**, protrusions **230** will contact ball **300** to maintain fluid communication between passage **222** of nose cone **220** and passage **104** of mandrel **102**.

(36) In this embodiment, the outer surface **226** of nose cone **220** includes a plurality of axially spaced annular fins **232**. Fins **232** increase the surface area of outer surface **226** to facilitate the creation of turbulent fluid flow around fins **232** when downhole plug **100** is pumped through

wellbore **4** along with the other components of tool string **20**. The turbulent fluid flow created by fins **232** increases the pressure differential in wellbore **4** between the uphole and downhole ends of downhole plug **100**, thereby reducing the amount of fluid in wellbore **4** that flows around downhole plug **100** as downhole plug **100** is pumped through wellbore **4**. The reduction in fluid that flows around downhole plug **100** reduces the total volume of fluid required to pump tool string into the desired or predetermined position in wellbore **4**, thereby reducing the cost of completing wellbore **4**.

(37) In this embodiment, nose cone **220** includes a plurality of circumferentially spaced protrusions or notches **234** extending axially from first end **220**A of nose cone **220**. Protrusions **234** of nose cone **220** are matingly received in pockets **208** of slip segments **202** to form an interlocking engagement between nose cone **220** and the slip segments **202** of slip assembly **200**. The interlocking engagement formed between protrusions **234** of nose cone **220** and pockets **208** of slip segments **202** restrict relative rotation between slip segments **202** and nose cone **220**. Additionally, the interlocking engagement between protrusions **234** and pockets **208** spaces slip segments equidistantly relative to each other about central axis **105** of downhole plug **100**. Equidistant circumferential spacing of slip segments **202** ensures generally uniform contact and coupling between slip assembly **200** and the inner surface **14** of casing string **12** about the entire circumference of downhole plug **100**. Further, in this embodiment, nose cone **220** includes a pair of circumferentially spaced arcuate clutching members or protrusions **236** that extend axially from second end **220**B of nose cone **220**. As will be discussed further herein, protrusions **236** of the nose cone **220** of downhole plug **100** are configured to be matingly received in the slots **112** of an adjacent downhole plug **100** disposed farther downhole in wellbore **4** to prevent relative rotation between the two downhole plugs **100** (FIGS. **5-7** illustrate an adjacently disposed nose cone **220** for clarity).

(38) Downhole plug **100** includes multiple components comprising nonmetallic materials. Particularly, in this embodiment, engagement disk **130**, first clamping member **170**, and nose cone **220** are each molded from nonmetallic materials. In some embodiments, engagement disk **130**, first clamping member **170**, and nose cone **220** are injection or compression molded from various high performance resins. By forming engagement disk **130**, first clamping member **170**, and nose cone **220** using nonmetallic materials, components **130**, **170**, and **220** may include features including complex or irregular geometries that are easily and conveniently formed using a molding process. For instance, protrusions **230** and fins **232** of nose cone **220** are conveniently formed using a molding process whereas such features may be relatively difficult to form using a machining process.

(39) As described above, downhole plug **100** is pumped downhole though wellbore **4** along with the other components of tool string **20**. As tool string **20** is pumped through wellbore **4**, the position of tool string **20** in wellbore **4** is monitored at the surface via signals generated from CCL **26** and transmitted to the surface using wireline **22**. Once tool string **20** is disposed in a desired location in wellbore **4**, one or more of perforating guns **30** may be fired to perforate casing **12** at the desired location and setting tool **36** may be fired or actuated to actuate downhole plug **100** from the run-in position shown in FIG. **8** to the set position shown in FIG. **13**.

(40) Particularly, setting tool **36** includes an inner member or mandrel (not shown) that moves axially relative to an outer member or housing of setting tool **36** upon the actuation of tool **36**. The mandrel of setting tool **36** is coupled to mandrel **102** of downhole plug **100** such that the movement of the mandrel of setting tool **36** pulls mandrel **102** uphole (e.g., towards setting tool **36**). Additionally, the outer member of setting tool **36** contacts engagement surface **130**A of engagement disk **130** to prevent disk **130**, clamping members **160**, **180**, packer **170**, and slip assembly **200** from travelling in concert with mandrel **102**, thereby providing relative axial movement between mandrel **102** and disk **130**, clamping members **160**, **180**, packer **170**, and slip assembly **200**.

(41) As mandrel **102** travels uphole towards setting tool **36**, the first end **220**A of nose cone **220**

and the second end **130**B of engagement disk **130** apply an axially compressive force against clamping members **160**, **180**, packer **170**, and slip assembly **200**. In response to the application of the compressive force, slip segments **202** are forced radially outward towards casing string **12** as planar surfaces **184** of second clamping member **180** slide along the planar surfaces **204** of slip segments **202**, snapping retainers **215**. Slip segments **202** continue to travel radially outwards until engagement members **206** contact and couple to the inner surface **14** of casing string **12**, locking downhole plug **100** to casing string **12** at the desired location in wellbore **4**. Additionally, each end of packer **170** is compressed via contact between frustoconical surfaces **174** of packer **170** and frustoconical surfaces **164**, **182** of clamping members **160**, **180**, respectively. The axially directed compressive force applied to packer **170** forces the outer surface **172** of packer **170** into sealing engagement with the inner surface **14** of casing string **12**. With outer surface **172** of packer **170** sealing against the inner surface **14** of casing string **12**, the only fluid flow permitted between the uphole and downhole ends of downhole plug **100** is permitted via passage **104** of mandrel **102**.
(42) Following the coupling of slip segments **202** with casing string **12** and the sealing of packer **170** against casing string **12** (shown in FIG. **13**), setting tool **36** may be disconnected from downhole plug **100**, allowing setting tool **36** and the other components of tool string **20** to be retrieved to the surface of wellbore **4**, with downhole plug **100** remaining at the desired location in wellbore **4**. Once setting tool **36** is released from downhole plug **100**, contact between frustoconical surface **162** of first clamping member **160** and the frustoconical surfaces **148** of lock ring segments **142** applies an axial and radially inwards force against each lock ring segment **142**. However, engagement between ratchet teeth **144** of lock ring segments **142** and ratchet teeth **120** of mandrel **102** prevent lock ring segments **142** from moving axially uphole relative to mandrel **102**. With lock ring segments **142** prevented from travelling uphole in the direction of the upper end **102**A of mandrel **102**, downhole plug **100** is held in the set position shown in FIG. **13**. Additionally, with lock ring assembly **140** comprising a plurality of arcuate lock ring segments **142**, instead of a single lock ring (e.g., a C-ring), the radially inwards directed force applied by the frustoconical surface **162** of first clamping member **160** is evenly applied against each lock ring segment **142**. The relatively even distribution of the radially inwards to each lock ring segment **142** assists in securing downhole plug **100** in the set position.
(43) After tool string **20** has been retrieved from the wellbore **4**, ball **300** may be pumped into and through wellbore **4** until ball **300** lands against seat **110** of mandrel **102**. With ball **300** seated on seat **110** of mandrel **102**, fluid flow through passage **104** of mandrel **102** is restricted which, in conjunction with the seal formed by packer **170** against the inner surface **14** of casing string **12**, seals the portion of wellbore **4** extending downhole from downhole plug **100** from the surface. Thus, additional fluid pumped into wellbore **4** from the surface is then directed through the perforations previously formed in casing string **12** by one or more of the perforating guns **30**, thereby hydraulically fracturing the formation **6** at the desired location in wellbore **4**.
(44) In some embodiments, the hydraulic fracturing process described above is repeated a plurality of times at a plurality of desired locations in wellbore **4** moving towards the surface of wellbore **4**. After the formation **6** has been hydraulically fractured at each desired location in wellbore **4**, a tool may be deployed in wellbore **4** to drill out each downhole plug **100** disposed therein to allow fluids in formation **6** to flow to the surface via wellbore **4**. With conventional downhole plugs, issues may arise during this drilling process if relative rotation is permitted either between components of each plug, or between separate plugs as the drill proceeds to drill out each conventional plug disposed in the borehole. However, in this embodiment, downhole plug **100** includes anti-rotation features configured to prevent, or at least inhibit, relative rotation between components thereof and between separate downhole plugs **100** disposed in wellbore **4**. Particularly, as described above: hexagonal shoulder **132** and hexagonal recess **166** of engagement disk **130** and first clamping member **160**, respectively, restrict relative rotation therebetween; frictional engagement between packer **170** and clamping members **160**, **180** restrict or inhibit relative rotation therebetween; planar engagement

between planar surfaces **184** of second clamping member **180** and planar surfaces **204** of slip segments **202** restrict relative rotation therebetween; pockets **208** of slip segments **202** and protrusions **234** of nose cone **220** restrict relative rotation therebetween; and engagement between notches **236** of the nose cone **220** of an uphole-positioned downhole plug **100** and slots **112** of the mandrel **102** of a downhole-positioned downhole plug **100** restrict relative rotation between the uphole and downhole positioned downhole plugs **100**. Although in this embodiment nose cone **220** comprises notches **236** and mandrel **102** comprises slots **112**, in other embodiments, mandrel **102** of a first downhole plug **100** may comprise notches or protrusions while a nose cone **220** of a second downhole plug **100** comprises corresponding slots or recesses configured to receive the notches of the mandrel **102** of the first downhole plug **100**. Additionally, although in this embodiment nose cone **220** comprises notches **234** and slip segments **202** comprise pockets **208**, in other embodiments, slip segments **202** may include notches or protrusions while nose cone **220** comprises corresponding pockets or recesses configured to receive the notches of slip segments **202**.

(45) Referring to FIGS. **14-17**, another embodiment of a downhole plug **400** for use with the tool string **20** of FIG. **1** (in lieu of the downhole plug **100** shown in FIGS. **2-13**) is shown in FIGS. **14-17**. In the embodiment of FIGS. **14-17**, downhole plug **400** has a central or longitudinal axis **405** and includes features in common with the downhole plug **100** shown in FIGS. **2-13**, and shared features are labeled similarly. Particularly, downhole plug **400** is similar to downhole plug **100** except that downhole plug **400** includes a mandrel **402** that receives a plurality of circumferentially spaced arcuate inserts **430**, as will be described further herein.

(46) In this embodiment, mandrel **402** of downhole plug **400** has a first end **402**A, a second end **402**B, a central bore or passage **404** defined by a generally cylindrical inner surface **406** extending between ends **402**A, **402**B, and a generally cylindrical outer surface **408** extending between ends **402**A, **402**B. The inner surface **406** of mandrel **402** includes a frustoconical seat **410** proximal first end **402**A. In this embodiment, the first end **402**A of mandrel **402** includes a pair of circumferentially spaced arcuate slots or recesses **412**. Additionally, in this embodiment, the outer surface **408** of mandrel **402** includes an expanded diameter portion **414** at first end **402**A that forms an annular shoulder **416**. Expanded diameter portion **414** of outer surface **408** includes a plurality of circumferentially spaced apertures **418** configured to receive a plurality of connecting members for coupling mandrel **102** with setting tool **36**. Additionally, mandrel **402** includes a plurality of ratchet teeth **420** that extend along a portion of outer surface **408** proximal shoulder **416**. In some embodiments, the outer surface **408** of mandrel **402** may include a connector located proximal to second end **402**B for releasably or threadably coupling with the connector **228** of nose cone **200**.

(47) Unlike the mandrel **102** of the downhole plug **100** shown in FIGS. **2-13**, the mandrel **402** of downhole plug **400** includes a plurality of circumferentially spaced, arcuate recesses **422** (shown in FIG. **16**) formed in the outer surface **508** of mandrel **402** that axially overlap the ratchet teeth **420**. As shown particularly in FIGS. **15** and **16**, ratchet teeth **420** extend between a first end **420**A and a second end **420**B, where each arcuate recess **422** extends axially from the second end **420**B of ratchet teeth **420** towards the first end **420**A. Each arcuate recess **422** of mandrel **402** is configured to matingly receive one of the arcuate inserts **430**, as shown particularly in FIG. **15**. In this embodiment, mandrel **402** includes four circumferentially spaced arcuate recesses **422** that matingly receive four arcuate inserts **430**; however, in other embodiments, the mandrel **402** of downhole plug **400** may include varying numbers of arcuate recesses **422** and corresponding arcuate inserts **430**. In this embodiment, each arcuate insert **430** includes an arcuate inner surface **432** that matingly engages a corresponding arcuate recess **422** of mandrel **402**, and an arcuate outer surface **434** that includes a plurality of arcuate ratchet teeth **436** formed thereon. When arcuate inserts **430** are matingly received in the arcuate recesses **422** of mandrel **402**, the ratchet teeth **436** of each arcuate insert **430** axially aligns with the ratchet teeth **420** formed on the outer surface **408** of mandrel **402**. In this embodiment, arcuate inserts **430** are each molded and comprise a

nonmetallic material. In this embodiment, the inner surface **432** of each arcuate insert **430** is adhered or glued to one of the recesses **422** of mandrel **402**; however, in other embodiments, other mechanisms may be employed for coupling arcuate inserts **430** with mandrel **402**.
(48) In this embodiment, arcuate inserts **430** are generally configured to provide additional shear strength so that ratchet teeth **420** are not inadvertently stripped or otherwise damaged during the operation of downhole plug **400**. For instance, in some embodiments, mandrel **402** comprises fiber or filament wound tubing while arcuate inserts **430** each comprise a composite material; however, in other embodiments, the mandrel **402** and arcuate inserts **430** may comprise varying materials. The material from which mandrel **402** is formed may have a relatively high tensile strength to sustain the tensile loads applied to it by setting tool **36**, but may be relatively weak in shear. Thus, arcuate inserts **430** may comprise a material that is relatively stronger in shear (e.g., a composite material) than the material of which mandrel **402** is comprised. In other words, in an embodiment, mandrel **402** comprises a first material having a first shear strength while each arcuate insert **430** comprises a second material having a second shear strength, where the second shear strength is greater than the first shear strength.
(49) During the operation of downhole plug **400**, shear loads may be transferred from ratchet teeth **142** of lock ring segments **140** to the relatively strong or shear resistant ratchet teeth **434** of arcuate inserts **430** which matingly engage ratchet teeth **142**, thereby mitigating the risk of ratchet teeth **420** of mandrel **402** being sheared off or otherwise damaged by the shear loads transferred from ratchet teeth **142**. In some embodiments, a majority of the shear loads transferred from ratchet teeth **142** of lock ring segments **140** may be applied against the ratchet teeth **436** of arcuate inserts **430**.
(50) While exemplary embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teachings herein. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the systems, apparatus, and processes described herein are possible and are within the scope of the disclosure presented herein. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims. Unless expressly stated otherwise, the steps in a method claim may be performed in any order. The recitation of identifiers such as (a), (b), (c) or (1), (2), (3) before steps in a method claim are not intended to and do not specify a particular order to the steps, but rather are used to simplify subsequent reference to such steps.

Claims

1. A system for completing a wellbore, comprising: a first plug, comprising: a first mandrel extending between an uphole end defining an uphole end of the first plug, and a downhole end opposite the uphole end of the first mandrel; a first slip assembly extending around the first mandrel and comprising a plurality of arcuate first slip segments for locking the first plug against a casing string positioned in the wellbore when the first plug is in a locked configuration; a first nose coupled to the downhole end of the first mandrel and defining a downhole end of the first plug, wherein the first nose comprises an uphole end coupled to the downhole end of the first mandrel and a downhole end opposite the uphole end of the first nose and defining a downhole end of the first plug; and a first packer extending around the first mandrel and comprising a first configuration configured to permit fluid flow across the first plug when the first plug is received in the wellbore, and a second configuration configured to seal the wellbore when the first plug is positioned in the wellbore; a second plug, comprising: a second mandrel extending between an uphole end defining an uphole end of the second plug, and a downhole end opposite the uphole end of the second mandrel; a second slip assembly extending around the second mandrel and comprising a plurality

of arcuate second slip segments for locking the second plug against the casing string when the second plug is in a locked configuration; a second nose coupled to the downhole end of the second mandrel and defining a downhole end of the second plug, wherein the second nose comprises an uphole end coupled to the downhole end of the second mandrel and a downhole end opposite the uphole end of the second nose and defining a downhole end of the second plug; and a second packer extending around the second mandrel and comprising a first configuration configured to permit fluid flow across the second plug when the second plug is received in the wellbore, and a second configuration configured to seal the wellbore when the second plug is positioned in the wellbore; wherein one of the downhole end of the second nose and the uphole end of the first mandrel comprises a plurality of axially extending notches circumferentially spaced about a central axis of the plug; wherein the other of the downhole end of the second nose and the uphole end of the first mandrel which does not comprise the plurality of notches comprises a plurality of axially extending recesses circumferentially spaced about the central axis of the plug configured to interlockingly receive the plurality of notches to restrict relative rotation between the second nose and the first mandrel; and wherein the second plug is drillable when in the locked configuration to release the second nose from the second slip assembly whereby the second nose is permitted to travel through the casing string and land against and interlock with the first mandrel of the first plug whereby relative rotation between the second nose and the first mandrel is restricted.
2. The system of claim 1, wherein the plurality of notches are each arcuate in shape, and wherein the plurality of recesses are each arcuate in shape.
3. The system of claim 1, wherein the plurality of notches and the plurality of recesses are positioned along a common diameter extending around the central axis of the plug.
4. The system of claim 1, wherein one of the uphole end of the first nose and a downhole end of the first slip assembly comprises a plurality of notches circumferentially spaced about the central axis of the first plug while the other of the uphole end of the first nose and the downhole end of the first slip assembly comprises a plurality of pockets circumferentially spaced about the central axis of the first plug and configured to interlockingly receive the plurality of notches to restrict relative rotation between the first nose and the first slip assembly.
5. The system of claim 1, wherein relative rotation about the central axis of the first plug is restricted between the first nose and the first packer.
6. The system of claim 1, wherein the plurality of notches defines a first set of castellations and the plurality of recesses define a second set of castellations interlockingly engageable with the first set of castellations.
7. A method for completing a wellbore, comprising: (a) positioning a first plug at a first location within the wellbore, wherein the first plug comprises a first slip assembly for locking the first plug against a casing string; (b) setting the first plug to lock the first plug at the first location to the casing string extending through wellbore and to seal the wellbore at the first location; (c) positioning a second plug at a second location within the wellbore that is uphole from the first location, wherein the second plug comprises a second slip assembly for locking the second plug against the casing string; (d) setting the second plug to lock the second plug at the second location to the casing string and to seal the wellbore at the second location; (e) releasing a nose of the second plug from the second slip assembly permitting the nose of the second plug to travel through the wellbore, wherein a downhole end of the nose defines a downhole end of the second plug; and (f) interlocking the downhole end of nose of the second plug with an uphole end of a mandrel of the first plug to restrict relative rotation between the nose of the second plug and the mandrel of the first plug; wherein one of the downhole end of the nose of the second plug and the uphole end of the mandrel of the first plug comprises a plurality of axially extending and circumferentially spaced protrusions and the other of the downhole end of the nose of the second plug and the uphole end of the mandrel of the first plug which does not comprise the plurality of notches comprises a plurality of axially extending and circumferentially spaced recesses to interlockingly receive the plurality of

notches to restrict relative rotation between the nose of the second plug and the mandrel of the first plug at (f).

8. The method of claim 7, wherein (e) comprises drilling into an uphole end of the second plug with a drill positioned in the wellbore to release the nose of the second plug from a slip assembly of the second plug.

9. The method of claim 7, wherein (f) comprises interlockingly receiving a plurality of circumferentially spaced protrusions of one of the nose of the second plug and the mandrel of the first plug in a plurality of circumferentially spaced recesses of the other of the nose of the second plug and the mandrel of the first plug, and wherein at least one of the plurality of circumferentially spaced protrusions and the plurality of the circumferentially spaced recesses comprise molded non-metallic materials.

10. The method of claim 9, wherein the plurality of protrusions are each arcuate in shape, and wherein the plurality of recesses are each arcuate in shape.

11. The method of claim 9, wherein the plurality of protrusions and the plurality of recesses are positioned along a common diameter extending around a central axis of the plug.

12. The method of claim 7, further comprising: (g) pumping the nose of the second plug through the wellbore following (e) whereby the downhole end of the nose lands against the uphole end of the mandrel of the first plug.

13. The method of claim 7, further comprising: (g) pumping a fracturing fluid through the wellbore following (d) to form one or more fractures in an earthen subterranean formation through which the wellbore extends at one or more locations located along the wellbore uphole from the second location.

14. The method of claim 7, further comprising: (g) pumping a fracturing fluid through the wellbore following (b) to form one or more fractures in an earthen subterranean formation through which the wellbore extends at one or more locations located along the wellbore between the first location and the second location.

15. The method of claim 7, further comprising: (g) drilling into an uphole end of the nose of the second plug following (f) with a drill positioned in the wellbore while the nose is interlocked with the mandrel of the first plug.

16. The method of claim 15, further comprising: (h) releasing a nose of the first plug from the casing string following (g) to permit the nose of the first plug to travel through the wellbore.

17. The method of claim 7, wherein the plurality of notches defines a first set of castellations and the plurality of recesses define a second set of castellations interlockingly engageable with the first set of castellations.