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ULAR SHANKS ASSEMBLIES, AND RELATED METHODS

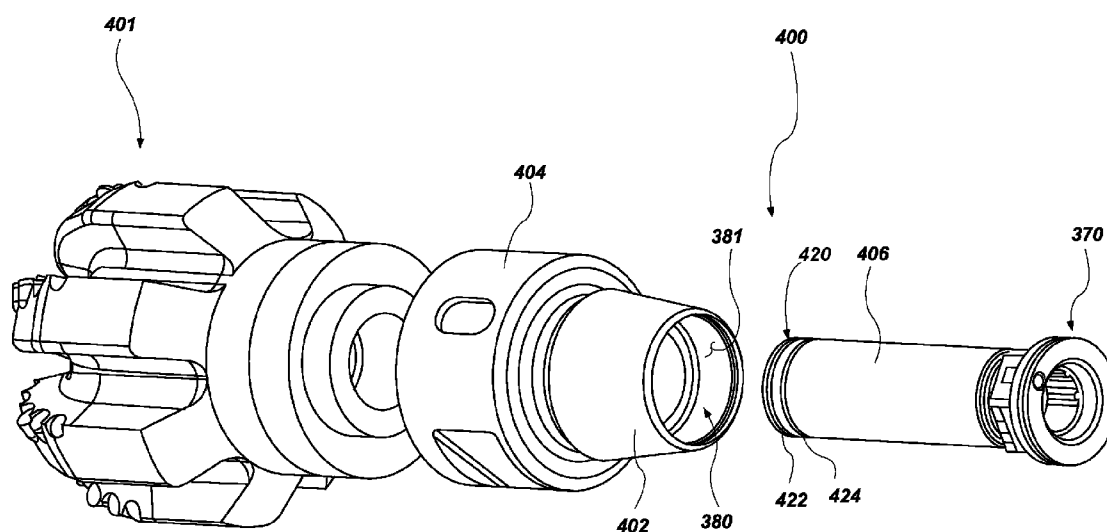


**FIG. 4A**

(57) Abstract: A shank assembly includes a neck portion, a shank portion defining a cylindrical aperture extending therethrough, and an anchor tube secured to the neck portion and extending through the shank portion, the anchor tube and the shank portion defining an annular cavity therebetween, and an electronics module disposed within the annular cavity. The annular cavity is formed to maximize space for electronics while maintaining structural integrity of a crown and shank of an earth-boring tool. A method includes disposing the anchor tube of a shank assembly through the cylindrical aperture and securing the anchor tube to a neck portion of the shank assembly, disposing the electronics module within the annular cavity, and disposing the shank portion and anchor tube of the shank assembly at least partially within a crown of the earth-boring tool such that annular cavity extends into the crown in an axial direction



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## TITLE

5                   **MODULAR SHANK ASSEMBLY FOR AN EARTH-BORING TOOL, EARTH-BORING TOOLS INCLUDING MODULAR SHANKS ASSEMBLIES, AND RELATED METHODS**

## PRIORITY CLAIM

10               This application claims the benefit of the filing date of United States Provisional Patent Application Serial No. 16/216,695, filed December 11, 2018, for “Modular Shank Assembly For An Earth-Boring Tool, Earth-Boring Tools Including Modular Shanks Assemblies, And Related Methods.”

## TECHNICAL FIELD

15               This disclosure relates generally to modular shank assemblies for earth-boring tools for use in drilling wellbores. The disclosure further relates to methods of forming modular shank assemblies.

## BACKGROUND

20               Oil wells (wellbores) are usually drilled with a drill string. The drill string includes a tubular member having a drilling assembly that includes a drill bit at its bottom end. The drilling assembly may also include devices and sensors that provide information relating to a variety of parameters relating to the drilling operations (“drilling parameters”), behavior of the drilling assembly (“drilling assembly parameters”) and parameters relating to the formations penetrated  
25               by the wellbore (“formation parameters”). A drill bit and/or reamer attached to the bottom end of the drilling assembly is rotated by rotating the drill string from the drilling rig and/or by a drilling motor (also referred to as a “mud motor”) in the bottom hole assembly (“BHA”) to remove formation material to drill the wellbore.

## 30                   DISCLOSURE

                  One or more embodiments of the present disclosure include a shank assembly. The shank assembly may include a neck portion, a shank portion extending from the neck portion and defining a cylindrical aperture extending longitudinally therethrough, one or more sealing rings disposed at an interface between the neck portion and the shank portion, an anchor tube  
35               secured to the neck portion and extending through the shank portion, the anchor tube and the

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shank portion defining an annular cavity therebetween, and an electronics module disposed within the annular cavity and including at least one of an accelerometer, a magnetometer, and a temperature sensor.

Some embodiments of the present disclosure include an earth-boring tool. The earth-boring tool may include a shank assembly and a crown secured to the shank assembly. The shank assembly may include a neck portion, a shank portion extending from the neck portion and defining a cylindrical aperture extending longitudinally therethrough, an anchor tube secured to the neck portion and extending through the shank portion, the anchor tube and the shank portion defining an annular cavity therebetween, and an electronics module disposed within the annular cavity configured to measure one or more of an annular pressure, a bore pressure, weight-on-bit, torque-on-bit, or a temperature. The crown may be secured to the shank portion and the anchor portion, wherein the annular cavity extends into the crown in an axial direction a distance that is between about 10% and about 80% of an overall axial length of the crown.

Further embodiments of the present disclosure include a method of forming an earth-boring tool. The method may include disposing an anchor tube of a shank assembly through a cylindrical aperture of a shank portion of the shank assembly and securing the anchor tube to a neck portion of the shank assembly, disposing an electronics module within an annular cavity defined between an inner surface of the shank portion and an outer surface the anchor tube of the shank assembly, and disposing the shank portion and anchor tube of the shank assembly at least partially within a crown of the earth-boring tool such that annular cavity extends into the crown in an axial direction a distance that is between about 10% and about 80% of an overall axial length of the crown.

## BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed understanding of the present disclosure, reference should be made to the following detailed description, taken in conjunction with the accompanying drawings, in which like elements have generally been designated with like numerals, and wherein:

FIG. 1 is a schematic diagram of a wellbore system comprising a drill string that includes one or more sensors according to an embodiment of the present disclosure;

FIG. 2 is a perspective view of a drill bit according to an embodiment of the present disclosure;

FIG. 3A is a perspective view of a shank of a drill bit having an end-cap disposed at least partially therein according to an embodiment of the present disclosure;

FIG. 3B is a cross-sectional view of a shank and an end-cap according to another embodiment of the present disclosure;

5           FIG. 3C is a perspective view of two end-caps disposed adjacent to one another according to one or more embodiments of the present disclosure;

FIG. 4A is a perspective view of a shank assembly according to one or more embodiments of the present disclosure;

FIG. 4B is a partial perspective view of the shank assembly of FIG. 4B;

FIG. 5 is a cross-sectional view of an earth-boring tool including a shank assembly according to one or more embodiments of the present disclosure; and

FIG. 6 is a perspective view of a shank assembly according to one or more embodiments of the present disclosure.

15                   MODE(S) FOR CARRYING OUT THE INVENTION

The illustrations presented herein are not actual views of any particular drilling system, drilling tool assembly, or component of such an assembly, but are merely idealized representations, which are employed to describe the present invention.

As used herein, the terms “bit” and “earth-boring tool” each mean and include earth-  
boring tools for forming, enlarging, or forming and enlarging a wellbore. Non-limiting  
20 examples of bits include fixed-cutter (“drag”) bits, fixed-cutter coring bits, fixed-cutter eccentric  
bits, fixed-cutter bicenter bits, fixed-cutter reamers, expandable reamers with blades bearing  
fixed cutters, and hybrid bits including both fixed cutters and movable cutting structures (roller  
cones).

25 As used herein, any relational term, such as “first,” “second,” “lower,” “upper,” “outer,” “inner,” etc., is used for clarity and convenience in understanding the disclosure and accompanying drawings, and does not connote or depend on any specific preference or order, except where the context clearly indicates otherwise.

As used herein, the terms “comprising,” “including,” “containing,” “characterized by,” and grammatical equivalents thereof are inclusive or open-ended terms that do not exclude additional, un-recited elements or method steps, but also include the more restrictive terms “consisting of,” “consisting essentially of,” and grammatical equivalents thereof.

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As used herein, the term “may” with respect to a material, structure, feature, or method act indicates that such is contemplated for use in implementation of an embodiment of the disclosure, and such term is used in preference to the more restrictive term “is” so as to avoid any implication that other compatible materials, structures, features, and methods usable in combination therewith should or must be excluded.

As used herein, the term “configured” refers to a size, shape, material composition, and arrangement of one or more of at least one structure and at least one apparatus facilitating operation of one or more of the structure and the apparatus in a predetermined way.

As used herein, the singular forms following “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise.

As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

As used herein, the term “substantially” in reference to a given parameter, property, or condition means and includes to a degree that one skilled in the art would understand that the given parameter, property, or condition is met with a small degree of variance, such as within acceptable manufacturing tolerances. For example, a parameter that is substantially met may be at least about 90% met, at least about 95% met, or even at least about 99% met.

As used herein, the term “about” used in reference to a given parameter is inclusive of the stated value and has the meaning dictated by the context (e.g., it includes the degree of error associated with measurement of the given parameter).

FIG. 1 is a schematic diagram of an example of a drilling system 100 that may utilize the apparatuses and methods disclosed herein for drilling wellbores. FIG. 1 shows a wellbore 102 that includes an upper section 104 with a casing 106 installed therein and a lower section 108 that is being drilled with a drill string 110. The drill string 110 may include a tubular member 112 that carries a drilling assembly 114 at its bottom end. The tubular member 112 may be made up by joining drill pipe sections or it may be a string of coiled tubing. A drill bit 116 may be attached to the bottom end of the drilling assembly 114 for drilling the wellbore 102 of a selected diameter in a formation 118.

The drill string 110 may extend to a rig 120 at the surface 122. The rig 120 shown is a land rig 120 for ease of explanation. However, the apparatuses and methods disclosed equally apply when an offshore rig 120 is used for drilling wellbores under water. A rotary table 124 or a top drive may be coupled to the drill string 110 and may be utilized to rotate the drill string

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110 and to rotate the drilling assembly 114, and thus the drill bit 116 to drill the wellbore 102. A drilling motor 126 (also referred to as “mud motor”) may be provided in the drilling assembly 114 to rotate the drill bit 116. The drilling motor 126 may be used alone to rotate the drill bit 116 or to superimpose the rotation of the drill bit 116 by the drill string 110. The rig 120  
5 may also include conventional equipment, such as a mechanism to add additional sections to the tubular member 112 as the wellbore 102 is drilled. A surface control unit 128, which may be a computer-based unit, may be placed at the surface 122 for receiving and processing downhole data transmitted by sensors 140 in the drill bit 116 and sensors 140 in the drilling assembly 114, and for controlling selected operations of the various devices and sensors 140 in  
10 the drilling assembly 114. The sensors 140 may include one or more of sensors 140 that determine acceleration, weight on bit, torque, pressure, cutting element positions, rate of penetration, inclination, azimuth formation/lithology, etc. In some embodiments, the surface control unit 128 may include a processor 130 and a data storage device 132 (or a computer-readable medium) for storing data, algorithms, and computer programs 134. The data  
15 storage device 132 may be any suitable device, including, but not limited to, a read-only memory (ROM), a random-access memory (RAM), a Flash memory, a magnetic tape, a hard disk, and an optical disc. During drilling, a drilling fluid from a source 136 thereof may be pumped under pressure through the tubular member 112, which discharges at the bottom of the drill bit 116 and returns to the surface 122 via an annular space (also referred as the “annulus”)  
20 between the drill string 110 and an inside wall 138 of the wellbore 102.

The drilling assembly 114 may further include one or more downhole sensors 140 (collectively designated by numeral 140). The sensors 140 may include any number and type of sensors 140, including, but not limited to, sensors 140 generally known as the measurement-while-drilling (MWD) sensors 140 or the logging-while-drilling (LWD)  
25 sensors 140, and sensors 140 that provide information relating to the behavior of the drilling assembly 114, such as drill bit rotation (revolutions per minute or “RPM”), tool face, pressure, vibration, whirl, bending, and stick-slip. The drilling assembly 114 may further include a controller unit 142 that controls the operation of one or more devices and sensors 140 in the drilling assembly 114. For example, the controller unit 142 may be disposed within the drill  
30 bit 116 (e.g., within a shank and/or crown of a bit body of the drill bit 116). The controller unit 142 may include, among other things, circuits to process the signals from sensor 140, a processor 144 (such as a microprocessor) to process the digitized signals, a data storage device 146 (such as a solid-state-memory), and a computer program 148. The processor 144

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may process the digitized signals, and control downhole devices and sensors 140, and communicate data information with the surface control unit 128 via a two-way telemetry unit 150.

5 The drill bit 116 may include a face section 152 (or bottom section). The face section 152 or a portion thereof may face the undrilled formation 118 in front of the drill bit 116 at the wellbore 102 bottom during drilling. In some embodiments, the drill bit 116 may include one or more cutting elements and, more specifically, a blade projecting from the face section 152.

10 FIG. 2 is perspective view of an earth-boring tool 200 according to an embodiment of the present disclosure. The earth-boring tool 200 may comprise a body 202 including a neck 206, a shank 208, and a crown 210. In some embodiments, the bulk of the body 202 may be constructed of steel, or of a ceramic-metal composite material including particles of hard material (e.g., tungsten carbide) cemented within a metal matrix material. The body 202 of the earth-boring tool 200 may have an axial center defining a center longitudinal axis 205  
15 that may generally coincide with a rotational axis of the earth-boring tool 200. The center longitudinal axis 205 of the body 202 may extend in a direction hereinafter referred to as an “axial direction.”

The body 202 may be connectable to a drill string 110 (FIG. 1). For example, the neck 206 of the body 202 may have a tapered upper end having threads thereon for  
20 connecting the earth-boring tool 200 to a box end of a drilling assembly 114 (FIG. 1). The shank 208 may include a lower straight section that is fixedly connected to the crown 210 at a joint. In some embodiments, the crown 210 may include a plurality of blades 214.

The plurality of blades 214 may also extend from the end of the body 202 opposite the neck 206 and may extend in both the axial and radial directions. Each blade 214 may  
25 have multiple profile regions as known in the art (cone, nose, shoulder, and gage). Each blade 214 of the plurality of blades 214 of the earth-boring tool 200 may include a plurality of cutting elements 230 fixed thereto. The plurality of cutting elements 230 of each blade 214 may be located in a row along a profile of the blade 214 proximate a rotationally leading face 232 of the blade 214.

30 Fluid courses 234 may be formed between adjacent blades 214 of the plurality of blades 214 and may be provided with drilling fluid by ports 218 located at the end of passages leading from an internal fluid plenum extending through the body 202 from a tubular shank 208 at the upper end of the earth-boring tool 200. Nozzles 220 may be secured within

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the ports for enhancing direction of fluid flow and controlling flow rate of the drilling fluid. The fluid courses 234 extend to junk slots extending axially along the longitudinal side of earth-boring tool 200 between blades 214 of the plurality of blades 214.

FIG. 3A is a perspective view of a neck portion 310 of a shank for securing to a drill bit 200 (FIG. 2), an end-cap 370 received within the neck portion 310, and an electronics module 390 (e.g., a first electronics module). FIG. 3B is a side cross-sectional view of the end-cap 370 at least partially disposed within the neck portion 310. Referring to FIGS. 3A and 3B together, the neck portion 310 of the shank may include a central bore 380 formed along a center longitudinal axis of the neck portion 310. As is discussed in greater detail below, the central bore 380 may be sized and shaped to receive at least a portion of the end-cap 370.

The end-cap 370 may include a first flange 371 at a first longitudinal end (e.g., a lower end) of the end-cap 370, a second flange 373 at a second opposite longitudinal end (e.g., an upper end) of the end-cap 370, and a body portion 375 extending between the first flange 371 and the second flange 373. The first flange 371 may include a first sealing ring 372, and the second flange 373 may include a second sealing ring 374. In some embodiments, the end-cap 370 may further include a cap bore 376 extending longitudinally (i.e., along a center longitudinal axis) therethrough. As a result, drilling mud may flow through the end-cap 370, through the central bore 380 of the neck portion 310 of the shank to the other side of the neck portion 310, and then into the body 202 of drill bit 200. Accordingly, the cap bore 376 may be subjected to conditions (e.g., high temperatures and pressures) experienced downhole.

In one or more embodiments, when the end-cap 370 is at least partially disposed within the central bore 380, an interior wall 381 of the central bore 380 and the end-cap 370 may define an at least substantially annular chamber 360. Furthermore, the annular chamber 360 may have a sufficient width to receive (e.g., have disposed therein) the electronics module 390. Furthermore, the central bore 380 may have a sufficiently small diameter as to not detrimentally affect the structural integrity of the neck portion 310 of the shank. As a result, the electronics module 390 may be disposed within the central bore 380 and about the end-cap 370.

The first and second flanges 371, 373 may be sized and shaped to form fluid tight seals with an interior wall 381 of the central bore 380 of the neck portion 310 of the shank. In some instances, the first sealing ring 372 and the second sealing ring 374 may form a protective, fluid-tight seal between the end-cap 370 and the interior wall 381 of the central bore 380 to protect the electronics module 390 from adverse environmental conditions (e.g., high pressures and fluids). The protective seal formed by the first sealing ring 372 and the second sealing ring 374

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may also be configured to maintain the annular chamber 360 at approximately atmospheric pressure.

In one or more embodiments, the first sealing ring 372 and the second sealing ring 374 are formed of material suitable for a high-pressure, high-temperature environment, such as, for example, a Hydrogenated Nitrile Butadiene Rubber (HNBR) O-ring in combination with a PEEK back-up ring. In addition, the end-cap 370 may be secured to the neck portion 310 of the shank with a number of connection mechanisms such as, for example, a secure press-fit using sealing rings 372 and 374, a threaded connection, an epoxy connection, a shape-memory retainer, a welded connection, and/or a brazed connection. It will be recognized by those of ordinary skill in the art that the end-cap 370 may be held in place relatively firmly by a relatively simple connection mechanism due to differential pressure and downward mud flow during drilling operations.

In some embodiments, at least two end caps 370a, 370b may be utilized (e.g., to cross threaded connect) within central bore 380 of the neck portion 310, as depicted in FIG 3C. Furthermore, in one or more embodiments, the two end caps 370 may be oriented with the second flanges 371 of the two end caps 370 facing each other. Additionally, the at least two end caps 370 may include any of the end caps described in, for example, U.S. Application No. 15/888,904, filed February 5, 2018, to Yao et al., the disclosure of which is incorporated in its entirety by reference herein. Additionally, in one or more embodiments, as described in further detail below, one or more of the at least two end caps 370 may be integral with one or more elements of the shank (e.g., an anchor tube (FIG. 4A)).

The electronics module 390 may include a flex-circuit board. The flex-circuit board may include a high-strength reinforced backbone (not shown) to provide acceptable transmissibility of acceleration effects to sensors such as accelerometers. In addition, other areas of the flex-circuit board bearing non-sensor electronic components may be attached to the end-cap 370 in a manner suitable for at least partially attenuating the acceleration effects experienced by the drill bit 200 during drilling operations using a material such as a visco-elastic adhesive. In view of the foregoing, the drill bit 200 (FIG. 2) may include any of the shanks, necks, and electronics modules described in, for example, U.S. Patent 8,100,196, to Pastusek et al., filed February 6, 2009, issued Jun. 24, 2012, U.S. Patent U.S. Patent 7,849,934, to Pastusek et al., filed February 16, 2007, and U.S. Patent 7,604,072, to Pastusek et al., filed June 7, 2005, issued Oct. 20, 2009, the disclosures of which are incorporated in their entireties by this reference herein.

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The electronics module 390 may be utilized to perform a variety of functions. In some embodiments, the electronics module 390 may include a data analysis module, which may sample data in different sampling modes, sample data at different sampling frequencies, and analyze data. Furthermore, in one or more embodiments, the electronics module 390 may include a power supply, a processor, a memory, and at least one sensor for measuring a plurality of physical parameters related to a drilling state, which may include drill bit conditions, drilling operation conditions, and environmental conditions proximate the drill bit 200 (FIG. 2). For example, the sensor may include one or more accelerometers, one or more magnetometers, and at least one temperature sensor.

FIG. 4A is a perspective view of a shank assembly 400 of an earth-boring tool 401 in an exploded configuration according to one or more embodiments of the present disclosure. FIG. 4B is a partial perspective view of the shank assembly 400 of FIG. 4A. FIG. 5 is a cross-sectional view of the shank assembly 400 of an earth-boring tool 401 in an assembled configuration. Referring to FIGS. 4A-5 together, the shank assembly 400 may include a neck portion 402, a shank portion 404, and an anchor tube 406. In some embodiments, the shank assembly 400 may be modular. In other words, the shank assembly 400 may be formed of multiple distinct parts (e.g., pieces). The shank portion 404 may extend from the neck portion 402 opposite an end of the neck portion 402 for connecting to a drill string. Moreover, the anchor tube 406 may extend through the shank portion 404 and may connect to the neck portion 402 of the shank assembly 400.

The neck portion 402 may include any of the neck portions described above in regard to FIGS. 3A and 3B, and any of the above-described end caps 370 and electronics module 390 may be disposed within a borehole of the neck portion 402. For instance, two end caps may be disposed within the neck portion 402, and the two end caps may be oriented with the second flanges of the two end caps facing each other, as depicted in FIG. 3C. In additional embodiments, the neck portion 402 may include a single end cap 370 disposed therein. Moreover, as noted above, the end cap 370 may be integral with or attachable to the anchor tube 406, as depicted in FIGS. 4A, 4B, and 5.

In one or more embodiments, the shank portion 404 may include a hollow cylinder defining a cylindrical aperture 408 extending along a longitudinal axis 409 of the shank assembly 400. The shank portion 404 may be at least substantially centered about the longitudinal axis 409 of the shank assembly 400. In some embodiments, the shank portion 404 may be integral with the neck portion 402. For instance, the shank portion 404 and the neck

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portion 402 of the shank assembly 400 may form an integral member (e.g., part or piece). As a non-limiting example, the shank portion 404 and the neck portion 402 may form a bell shaped member.

As noted above, in some embodiments, the anchor tube 406 may extend through the shank portion 404 and through the cylindrical aperture 408 of the shank portion 404. Together, the shank portion 404 and the anchor tube 406 may define an annular cavity 410 between an inner surface of the shank portion 404 and an outer surface of the anchor tube 406. A width of the annular cavity 410 (i.e., a distance between an inner diameter and an outer diameter of the annular cavity 410) may be between about 10% and about 70% of an overall radius of the shank portion 404. In some embodiments, the width of the annular cavity 410 may be between about 30% and about 50% of the overall radius of the shank portion 404. For instance, the width of the annular cavity 410 may be 40% of the overall radius of the shank portion 404.

In some embodiments, the annular cavity 410 defined by the shank portion 404 and the anchor tube 406 may be sized and shaped to receive an electronics module 412 (e.g., a second electronics module 412). In some embodiments, the electronics modules 412 may include a flexible printed circuit board ("PCB") mounted to circular (e.g., annular) frame. The frame may include a high-strength reinforced backbone to provide acceptable transmissibility of acceleration effects to sensors such as accelerometers. In addition, other areas of the electronics module 412 bearing non-sensor electronic components may be attached to the inner surface of the shank portion 404 and/or the outer surface of the anchor tube 406 in a manner suitable for at least partially attenuating the acceleration effects experienced by the drill bit 20 (FIG.2) during drilling operations using a material such as a visco-elastic adhesive. As non-limited example, the electronics module 412 may include any of the electronics modules described in, for example, U.S. Patent 8,100,196, to Pastusek et al., filed February 6, 2009, issued Jun. 24, 2012, U.S. Patent U.S. Patent 7,849,934, to Pastusek et al., filed February 16, 2007, and U.S. Patent 7,604,072, to Pastusek et al., filed June 7, 2005, issued Oct. 20, 2009, the disclosures of which are incorporated in their entireties by this reference herein.

The electronics module 412 may be utilized to perform a variety of functions. In some embodiments, the electronics module 412 may include a data analysis module, which may sample data in different sampling modes, sample data at different sampling frequencies, and analyze data. Furthermore, in one or more embodiments, the electronics module 412 may include a power supply, a processor, a memory, and at least one sensor for measuring a plurality of physical parameters related to a drilling state, which may include drill bit conditions, drilling

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operation conditions, and environmental conditions proximate the drill bit 200 (FIG. 2). For example, the sensor may include one or more accelerometers, one or more magnetometers, and at least one temperature sensor. Additionally, the electronics module 412 may include sensors for measuring and determining one or more of weight-on-bit (WOB), torque-on-bit (TOB), and  
5 bore and annular pressures.

In some embodiments, the electronics module 412 may further include one or more strain gauges secured to the inner surface of the shank portion 404 and/or the outer surface of the anchor tube 406. For example, the electronics module 412 may include a piezoelectric gauge. For instance, the electronics module 412 may include a sensor that utilizes a piezoelectric  
10 effect (as is known in the art) to measure changes in pressure, acceleration, temperature, strain, and/or force by converting them into an electric charge. In such embodiments, the one or more strain gauges may be secured to the inner surface of the shank portion 404 and/or the outer surface of the anchor tube 406 via one or more of adhesives, welds, cements, etc. As another non-limiting example, the one or more strain gauges may be secured to the inner surface of the  
15 shank portion 404 and/or the outer surface of the anchor tube 406 via an epoxy. In other embodiments, the one or more strain gauges may be secured to the inner surface of the shank portion 404 and/or the outer surface of the anchor tube 406 via one or more tack welds or ceramic cements.

Furthermore, in one or more embodiments, the shank portion 404 may include one or  
20 more integrated sensors 430 within or on a wall of the shank portion 404. For example, the shank portion 404 may include one or more integrated sensors 430 for measuring WOB, TOB, and bore and annular pressure. For instance, the shank portion 404 may include any of the sensors and sensor assemblies described in U.S. Application No. 15/888,904, filed February 5, 2018, to Yao et al., the disclosure of which is incorporated in its entirety by reference herein.

25 In one or more embodiments, the annular cavity 410, in which the electronics module 412 is disposed, may not be subject to the high pressures and/or other environmental conditions experienced downhole. However, an interior of the anchor tube 406 and an exterior of the shank portion 404 may be subjected to the high pressures, temperatures and other environmental conditions experienced downhole during a drilling operation. Furthermore, in  
30 some embodiments, the shank portion 404 and/or the anchor tube 406 may flex (e.g., bow outward or outward, bulge, etc.) due to the disparity between the high pressure within the anchor tube 406 and/or exterior to the shank portion 404 and the atmospheric pressure within the annular cavity 410. Moreover, due to the flexing of the shank portion 404 and/or the anchor

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tube 406, strain gauges of the electronics module 412 may be used to measure a strain exhibited by the shank portion 404 and/or the anchor tube 406, and based on the measured strain and a known thickness of the shank portion 404 and/or the anchor tube 406, the surface control unit 128 (FIG. 1), an external controller, and/or an operator can determine one or more of a  
5 borehole pressure, an annulus pressure, a pressure drop across the drill bit 200 (FIG. 2) (e.g., a drill bit 200 including multiple sensors at different locations), etc. Furthermore, determining one or more of the borehole pressure and the annulus pressure enables the surface control unit 128 (FIG. 1) to measure torque on bit (“TOB”) and weight on bit (“WOB”).

As shown in FIG. 5, the shank portion 404 may be connected to a crown 414 of the  
10 earth-boring tool 401. In some embodiments, the shank portion 404 may be at least partially disposed within a receiving aperture of the crown 414. In additional embodiments, the crown 414 may be at least partially received into a portion of the shank portion 404. In one or more embodiments, one or more ring seals 417 may be disposed between a longitudinal end of the shank portion 404 opposite the neck portion 402 and the crown 414. In some instances, the  
15 one or more ring seals 417 may form a protective, fluid-tight seal between the crown 414 and the shank portion 404 of the shank assembly to protect the electronics module 412 from adverse environmental conditions (e.g., high pressures). The protective seal formed by the one or more ring seals 417 may also be configured to maintain the annular cavity 410 at approximately atmospheric pressure. In one or more embodiments, the one or more ring seals 417 are formed  
20 of material suitable for a high-pressure, high-temperature environment, such as, for example, an HNBR O-ring in combination with a PEEK back-up ring. In additional embodiments, the shank assembly may or may not include one or more ring seals 417, and the shank portion 404 may be secured to the crown 414 with a number of connection mechanisms such as, for example, a secure press-fit using ring seals 417, a threaded connection, an epoxy connection, a  
25 shape-memory retainer, a welded connection, and/or a brazed connection. Additionally, the shank portion 404 and/or the neck portion 402 may have one or more cable (e.g., wire) pathways extending therethrough for connection to the electronics module 412 and other sensors (e.g., sensors integrated with the shank portion 404).

Additionally, in some embodiments, the annular cavity 410 may extend longitudinally  
30 at least partially into the crown 414. For instance, the annular cavity 410 may extend into the crown 414 in an axial direction a distance D that is between about 5% and about 80% of an overall axial length of the crown 414. As used herein, the term “overall axial length” of the crown 414 may refer to a length extending from an uppermost surface the crown 414 (e.g., a

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surface at the interface of the crown 414 and the shank portion 404) to a lowermost surface of the nose region of the crown 414 in the axial direction. In some embodiments, the distance D may be between about 30% and about 60% of the overall axial length of the crown 414. For example, the distance D may be between about 45% of the overall axial length of the crown 414.

5 Additionally, in some embodiments, the distance D may be within a range of about 6.35 mm and about 12.7 cm. For example, the distance D may be within a range of about 3.81 cm and about 7.62 cm. For instance, the distance D may be about 5.08 cm. In view of the foregoing, in some embodiments, at least a portion of the electronics module 412 may be disposed within annular cavity 410 and at least partially within the crown 414 of the earth-boring tool 401.

10 Referring still to FIGS. 4A-5, the anchor tube 406 may be attached to the neck portion 402 and the crown 414 of the earth-boring tool 401 and may be at least substantially centered about the longitudinal axis 409 of the shank assembly 400. In some embodiments, the anchor tube 406 may be threaded on a longitudinal end attached to the neck portion 402 and may be connected to the neck portion 402 via a threaded connection. In additional embodiments,  
15 the anchor tube 406 may be connected to the neck portion 402 via one or more of an epoxy connection, a shape-memory retainer, a welded connection, and/or a brazed connection. Furthermore, the anchor tube 406 may be connected to the neck portion 402 via any combination of the above-described connections. Additionally, in some embodiments, as described above, the anchor tube 406 may be integral with the end cap 370, as shown in  
20 FIGS. 4A-5. For example, the anchor tube 406 and the end cap 370 may form a single integral member. As a non-limiting example, the anchor tube 406 may be connected to the end cap 370 via a circumferential weld. In further embodiments, the end cap 370 and anchor tube 406 may be separate and distinct from each other, as shown in FIG. 6 and described below.

In some embodiments, a longitudinal end 420 of the anchor tube 406 opposite the neck  
25 portion 402 of the shank assembly 400 may include one or more annular recesses 422, 424 for receiving one or more sealing rings 426, 428. Furthermore, in some embodiments, the longitudinal end 420 of the anchor tube 406 may be secured to the crown 414 via a press-fit using the one or more sealing rings 426, 428. In additional embodiments, the longitudinal end 420 of the anchor tube 406 may be secured to the crown via one or more of a threaded  
30 connection, an epoxy connection, a shape-memory retainer, a welded connection, and/or a brazed connection.

Additionally, the anchor tube 406 may include a cylindrical aperture 416 extending along a longitudinal length of the anchor tube 406. For instance, the cylindrical aperture 416

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may be defined by an inner surface of the anchor tube 406. In some embodiments, a ratio of a diameter of the cylindrical aperture 416 and an outer diameter of the shank portion 404 may be within a range of about 0.10 and about 0.40. In one or more embodiments, the cylindrical aperture 416 may define a fluid flow pathway (i.e., an internal fluid plenum) for drilling fluid (e.g., drilling fluid from the source (FIG. 1)). Furthermore, the fluid flow pathway may be connected to the nozzles 220 (FIG. 2) disposed within ports 218 (FIG. 2) of the crown 414 via internal fluid passageways within the crown 414. Furthermore, the cylindrical aperture 416 may have a sufficient diameter to permit a conventional amount of drilling fluid to flow through anchor tube 406 and through the nozzles 220 during a drilling operation.

10 In some embodiments, the anchor tube 406 may maintain at least substantially a same diameter throughout a longitudinal length of the anchor tube extending through the shank portion 404 of the shank assembly 400 and into the crown 414 of the earth-boring tool 401.

Additionally, the annular cavity 410 may have a sufficiently small width to maintain sufficient dimensions of the earth-boring tool 401 along a main load path and shoulder region (FIG. 2) for performing conventional earth-boring tool operations. In other words, the shank assembly 400 described herein may maintain a structural integrity of the earth-boring tool 401. For instance, a ratio of a cross-sectional area of material (e.g., a combination of the material of the shank portion 404 and the anchor tube 406) (referred to hereinafter as the “material cross-sectional area”) extending through a plane to which the longitudinal axis of the shank assembly 400 is orthogonal and an overall cross-sectional area defined by the outer diameter of the shank portion 404 is within a range of 0.50 and about 0.90. For example, a ratio of the material cross-sectional area and the overall cross-sectional area may be within a range of about 0.60 and about 0.80. As another non-limiting example, a ratio of the material cross-sectional area and the overall cross-sectional area may be about 0.70. Additionally, a thickness of the wall of the shank portion 404 (e.g., a radial distance between an inner surface and an outer surface of the shank portion 404) may be between about 15% and about 75% of an overall radius of the of the shank portion 404 (e.g., a radial distance between the longitudinal axis 409 of the shank assembly 400 and the outer surface of the shank portion 404). For example, the thickness of the shank portion 404 may be between about 25% and about 65% of the overall radius of the shank portion 404. For instance, the thickness of the shank portion 404 may be about 45% of the overall radius of the shank portion 404.

Referring to FIGS. 3A-5 together, in some embodiments, a ratio of a volume of the annular chamber 360 and a volume the annular cavity 410 may be within a range of about 1.25

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and about 0.75. In some embodiments, a ratio of the volume of the annular chamber 360 and the volume the annular cavity 410 may be about 1.0.

Additionally, in some embodiments, the shank assembly 400 may have minimal to no increase in shank length in comparison to conventional earth-boring tools. As result, the shank assembly 400 described herein and earth-boring tools utilizing the shank assembly 400 described herein may provide better steering and directional drilling in comparison to earth-boring tools having relatively longer shanks.

FIG. 6 is a perspective exploded view of a modular shank assembly 600 according to one or more additional embodiments of the present disclosure. Similar the shank assembly 400 described above in regard to FIGS. 4A, 4B, and 5, the shank assembly 600 may include a neck portion 602, a shank portion 604, and an anchor tube 606. Furthermore, the shank assembly 600 may generally have the same orientation and configuration of the shank assembly 400 described above. However, the shank portion 604 may be separate and distinct from the neck portion 602. For example, the shank assembly 600 may include one or more sealing rings disposed between an upper longitudinal end 652 of the shank portion 604 (i.e., a longitudinal end of the shank portion 604 opposite a crown) and the neck portion 602. Furthermore, the shank portion 604 may be removably secured to the neck portion 602 a secure press-fit using the one or more sealing rings. In additional embodiments, the shank portion 604 may be removably secured to the neck portion 602 via one or more welds. In additional embodiments, the shank portion 604 may be removably secured to the neck portion 602 through a threaded connection. In further embodiments, the shank portion 604 may be removably secured to the neck portion 602 through one or more of an epoxy connection, a shape-memory retainer, one or more fasteners (e.g., bolts), and/or a brazed connection. Additionally, the shank portion 604 may be removably secured to the neck portion 602 via any other conventional connection.

Referring to FIGS. 4A-6 together, the modular shank assemblies and associated earth-boring tools of the present disclosure may provide increased space for electronics and sensors downhole in comparison to conventional earth-boring tools while minimizing size increases of the earth-boring tools. Additionally, because the shank assemblies of the present disclosure are modular (e.g., made from multiple distinct parts), the shank assemblies may enable faster installation times of electronics and sensors within the shank assemblies. Furthermore, the shank assemblies may provide improved direct load transfer in comparison to conventional shank assemblies.

Embodiments of the present disclosure further include the following embodiments.

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Embodiment 1: A shank assembly, comprising a neck portion; a shank portion extending from the neck portion and defining a cylindrical aperture extending longitudinally therethrough; one or more sealing rings disposed at an interface between the neck portion and the shank portion; an anchor tube secured to the neck portion and extending through the shank portion, the anchor tube and the shank portion defining an annular cavity therebetween; and an electronics module disposed within the annular cavity and comprising at least one of an accelerometer, a magnetometer, and a temperature sensor.

Embodiment 2: The shank assembly of embodiment 1, wherein the shank portion is secured to the neck portion via a press-fit.

Embodiment 3: The shank assembly of embodiments 1 and 2, wherein the electronics module comprises one or more sensors mounted directly to one or more of an outer surface of the anchor tube and an inner surface of the shank portion.

Embodiment 4: The shank assembly of embodiment 3, wherein the one or more sensors comprise a strain gauge.

Embodiment 5: The shank assembly of embodiments 1-3, wherein the neck portion comprises: a central bore extending through the neck portion; an end-cap at least partially disposed within the central bore of the neck portion and comprising: a first flange; and a second flange; and a body portion extending between the first flange and the second flange, wherein an annular chamber is defined between the body portion of the end-cap and an interior wall of the central bore of the shank.

Embodiment 6: The shank assembly of embodiment 5, further comprising at least one additional electronics module disposed within the annular chamber of the neck portion.

Embodiment 7: The shank assembly of embodiments 5 and 6, wherein a ratio of a volume of the annular chamber and the annular cavity is within a range of about 1.25 and about 0.75.

Embodiment 8: The shank assembly of embodiments 5-7, wherein the anchor tube and the end cap form a single integral unit.

Embodiment 9: An earth-boring tool, comprising: a shank assembly, comprising: a neck portion; a shank portion extending from the neck portion and defining a cylindrical aperture extending longitudinally therethrough; an anchor tube secured to the neck portion and extending through the shank portion, the anchor tube and the shank portion defining an annular cavity therebetween; and an electronic module disposed within the annular cavity configured to measure one or more of an annular pressure, a bore pressure, weight-on-bit, torque-on-bit, or a

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temperature; and a crown secured to the shank portion and the anchor portion, wherein the annular cavity extends into the crown in an axial direction a distance that is between about 10% and about 80% of an overall axial length of the crown.

Embodiment 10: The earth-boring tool of embodiment 9, wherein the neck portion of  
5 the shank assembly comprises: a central bore extending through the neck portion; at least one end-cap at least partially disposed within the central bore of the shank and comprising: a first flange; a second flange; and a body portion extending between the first flange and the second flange, wherein an annular chamber is defined between the body portion of the end-cap and an interior wall of the central bore of the shank.

10 Embodiment 11: The earth-boring tool of embodiment 10, further comprising at least one additional electronics module disposed within the annular chamber of the neck portion.

Embodiment 12: The earth-boring tool of embodiments 10 and 11, wherein a ratio of a volume of the annular chamber and the annular cavity is within a range of about 1.25 and about 0.75.

15 Embodiment 13: The earth-boring tool of embodiments 9-12, wherein the shank assembly further comprises at least one sensor integral with a wall of the shank portion of the shank assembly and configured to measure weight-on-bit, torque-on-bit, bore pressure, or annular pressure.

20 Embodiment 14: The earth-boring tool of embodiments 9-13, wherein the shank portion and the neck portion form a single integral unit.

Embodiment 15: The earth-boring tool of embodiments 9-13, wherein the shank portion and the neck portion comprise separate and distinct parts.

25 Embodiment 16: The earth-boring tool of embodiments 9-15, wherein the anchor tube maintains an at least substantially uniform diameter throughout a length of the anchor tube extending through the shank portion and into the crown.

Embodiment 17: A method of forming an earth-boring tool, the method comprising: disposing an anchor tube of a shank assembly through a cylindrical aperture of a shank portion of the shank assembly and securing the anchor tube to a neck portion of the shank assembly; disposing an electronics module within an annular cavity defined between an inner surface of  
30 the shank portion and an outer surface the anchor tube of the shank assembly; and disposing the shank portion and anchor tube of the shank assembly at least partially within a crown of the earth-boring tool such that annular cavity extends into the crown in an axial direction a distance that is between about 10% and about 80% of an overall axial length of the crown.

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Embodiment 18: The method of embodiment 17, further comprising securing the anchor tube of the shank assembly to the crown of the earth-boring tool.

Embodiment 19: The method of embodiments 17 and 18, further comprising securing the shank portion of the shank assembly to a neck portion of the shank assembly, the neck portion comprising: a central bore extending through the neck portion; and at least one end-cap at least partially disposed within the central bore of the shank and comprising: a first flange; a second flange; and a body portion extending between the first flange and the second flange, wherein an annular chamber is defined between the body portion of the end-cap and an interior wall of the central bore of the shank.

Embodiment 20: The method of embodiment 19, further comprising disposing at least one additional electronics module within the annular chamber of the neck portion.

The embodiments of the disclosure described above and illustrated in the accompanying drawings do not limit the scope of the disclosure, which is encompassed by the scope of the appended claims and their legal equivalents. Any equivalent embodiments are within the scope of this disclosure. Indeed, various modifications of the disclosure, in addition to those shown and described herein, such as alternative useful combinations of the elements described, will become apparent to those skilled in the art from the description. Such modifications and embodiments also fall within the scope of the appended claims and equivalents.

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## CLAIMS

What is claimed is:

- 5           1.       An earth-boring tool, comprising:  
a shank assembly, comprising:  
a neck portion;  
a shank portion extending from the neck portion and defining a cylindrical aperture  
extending longitudinally therethrough;  
10       an anchor tube secured to the neck portion and extending through the shank portion, the  
anchor tube and the shank portion defining an annular cavity therebetween; and  
an electronics module disposed within the annular cavity configured to measure one or  
more of an annular pressure, a bore pressure, weight-on-bit, torque-on-bit, or a  
temperature; and  
15       a crown secured to the shank portion and the anchor portion, wherein the annular cavity extends  
into the crown in an axial direction a distance that is between about 10% and about 80%  
of an overall axial length of the crown.
- 20           2.       The earth-boring tool of claim 1, wherein the neck portion of the shank assembly  
comprises:  
a central bore extending through the neck portion; and  
at least one end-cap at least partially disposed within the central bore of the neck portion and  
comprising:  
a first flange;  
25       a second flange; and  
a body portion extending between the first flange and the second flange, wherein an  
annular chamber is defined between the body portion of the end-cap and an  
interior wall of the central bore of the shank.
- 30           3.       The earth-boring tool of claim 2, further comprising at least one additional  
electronics module disposed within the annular chamber of the neck portion.

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4. The earth-boring tool of claim 2, wherein a ratio of a volume of the annular chamber and the annular cavity is within a range of about 1.25 and about 0.75.

5. The earth-boring tool of any one of claims 1 through 4, wherein the shank assembly further comprises at least one sensor integral with a wall of the shank portion of the shank assembly and configured to measure weight-on-bit, torque-on-bit, bore pressure, or annular pressure.

6. The earth-boring tool of any one of claims 1 through 4, wherein the shank portion and the neck portion form a single integral unit.

7. The earth-boring tool of any one of claims 1 through 4, wherein the shank portion and the neck portion comprise separate and distinct parts.

8. The earth-boring tool of any one of claims 1 through 4, further comprising at least one sealing ring disposed at an interface between the neck portion and the shank portion.

9. The earth-boring tool of any one of claims 1 through 4, wherein the anchor tube maintains an at least substantially uniform diameter throughout a length of the anchor tube extending through the shank portion and into the crown.

10. The earth-boring tool of any one of claims 1 through 4, wherein the electronics module comprises at least one of an accelerometer, a magnetometer, and a temperature sensor.

11. The earth-boring tool of any one of claims 1 through 4, wherein a ratio of a cross-sectional area of material defined by the shank portion and the anchor portion extending through a plane to which a longitudinal axis of the shank assembly is orthogonal and an overall cross-sectional area defined by an outer diameter of the shank portion is within a range of 0.50 and about 0.90.

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12. A method of forming an earth-boring tool, the method comprising:  
disposing an anchor tube of a shank assembly through a cylindrical aperture of a shank portion  
of the shank assembly and securing the anchor tube to a neck portion of the shank  
assembly;  
5 disposing an electronics module within an annular cavity defined between an inner surface of  
the shank portion and an outer surface the anchor tube of the shank assembly; and  
disposing the shank portion and anchor tube of the shank assembly at least partially within a  
crown of the earth-boring tool such that annular cavity extends into the crown in an axial  
direction a distance that is between about 10% and about 80% of an overall axial length  
10 of the crown.

13. The method of claim 12, further comprising securing the anchor tube of the  
shank assembly to the crown of the earth-boring tool.

14. The method of any one of claims 12 and 13, further comprising securing the  
shank portion of the shank assembly to a neck portion of the shank assembly, the neck portion  
comprising:  
a central bore extending through the neck portion; and  
at least one end-cap at least partially disposed within the central bore of the neck portion and  
20 comprising:  
a first flange;  
a second flange; and  
a body portion extending between the first flange and the second flange, wherein an  
annular chamber is defined between the body portion of the end-cap and an  
25 interior wall of the central bore of the shank.

15. The method of claim 14, further comprising disposing at least one additional  
electronics module within the annular chamber of the neck portion.

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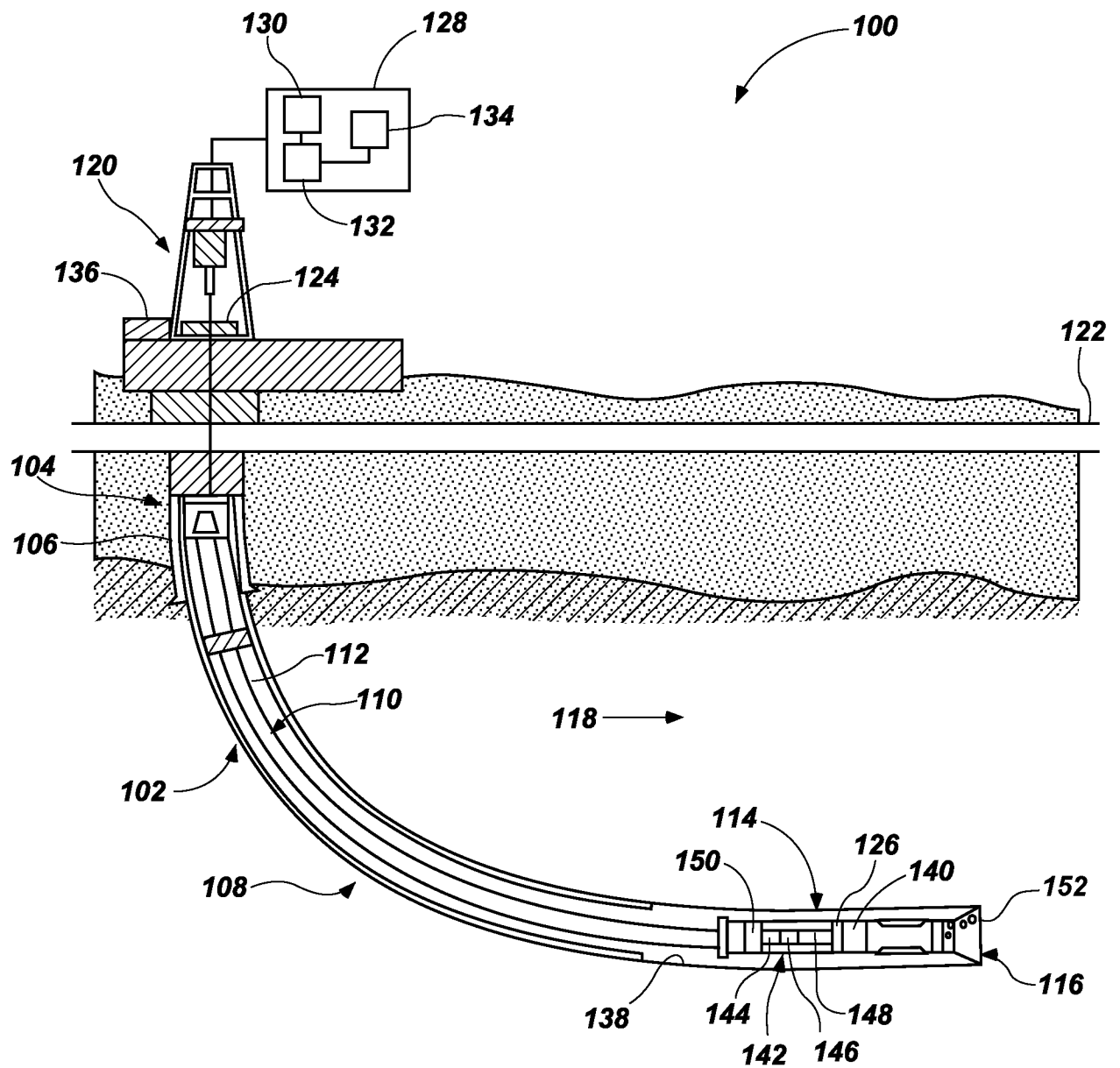


FIG. 1

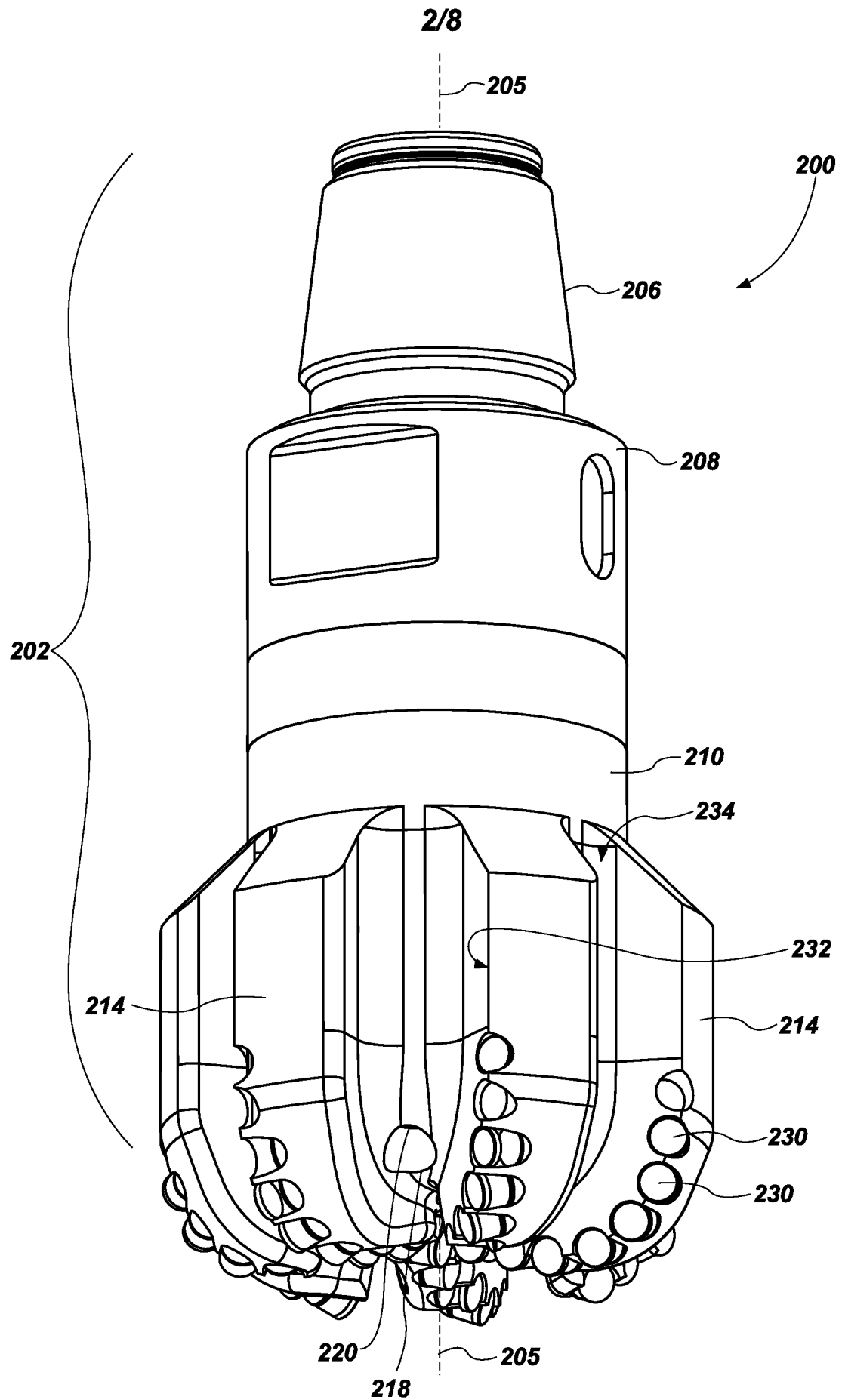
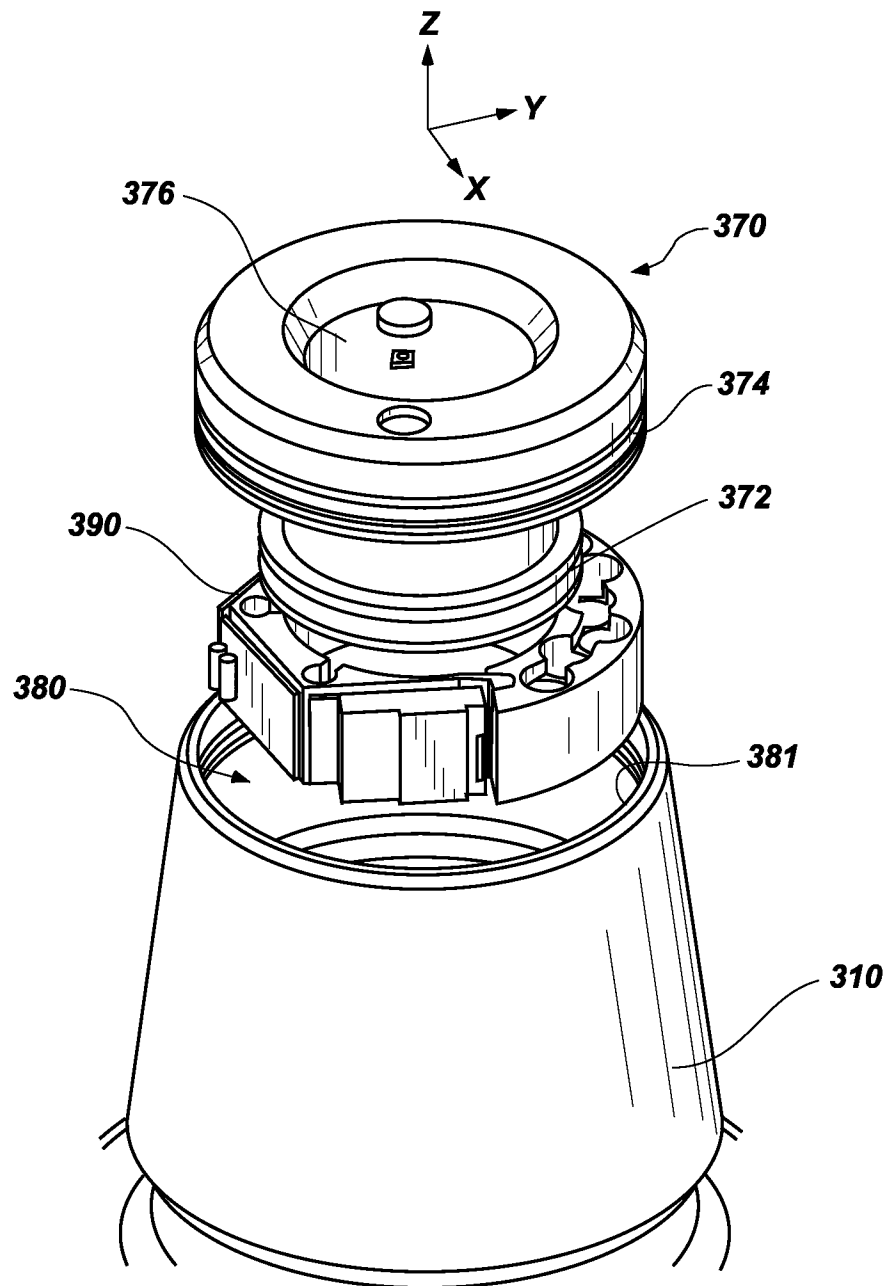


**FIG. 2**

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**FIG. 3A**

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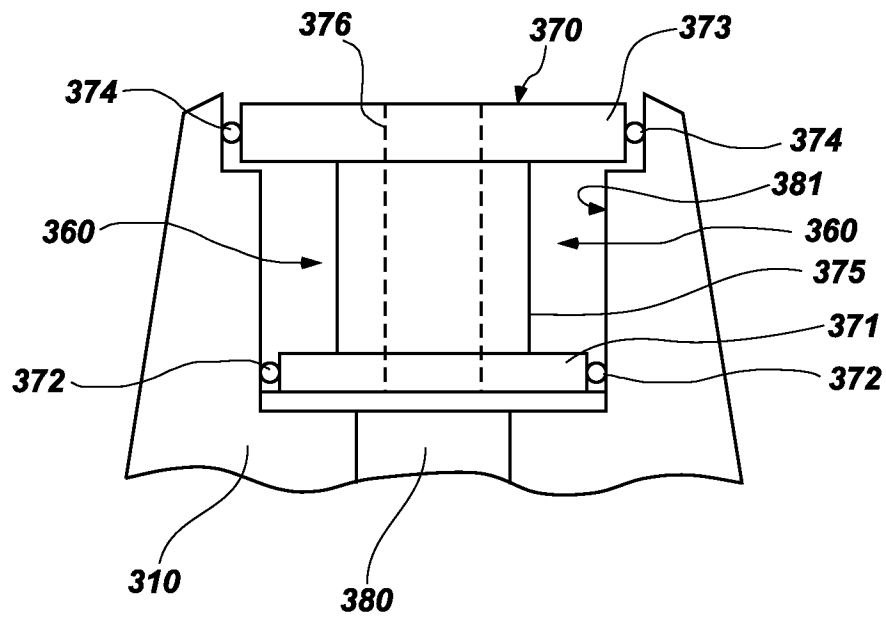


**FIG. 3B**

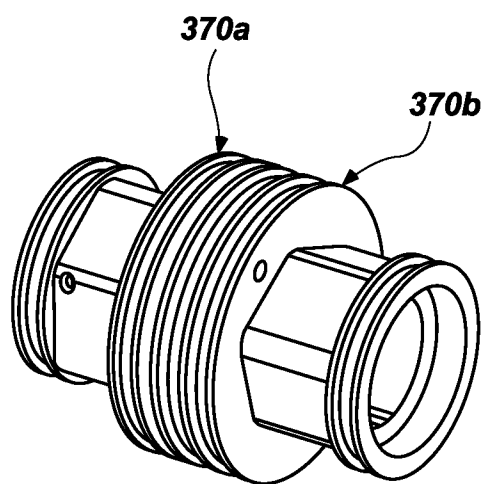


**FIG. 3C**

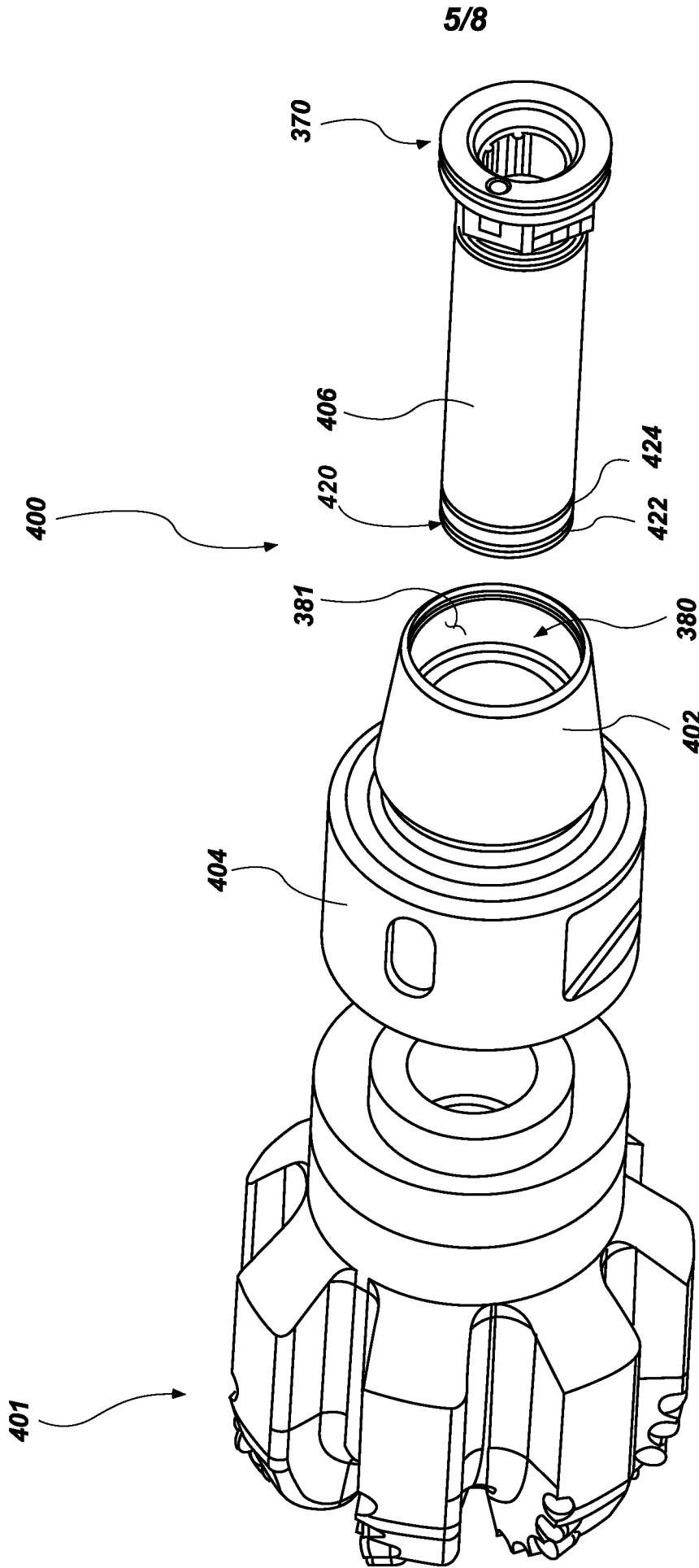


FIG. 4A

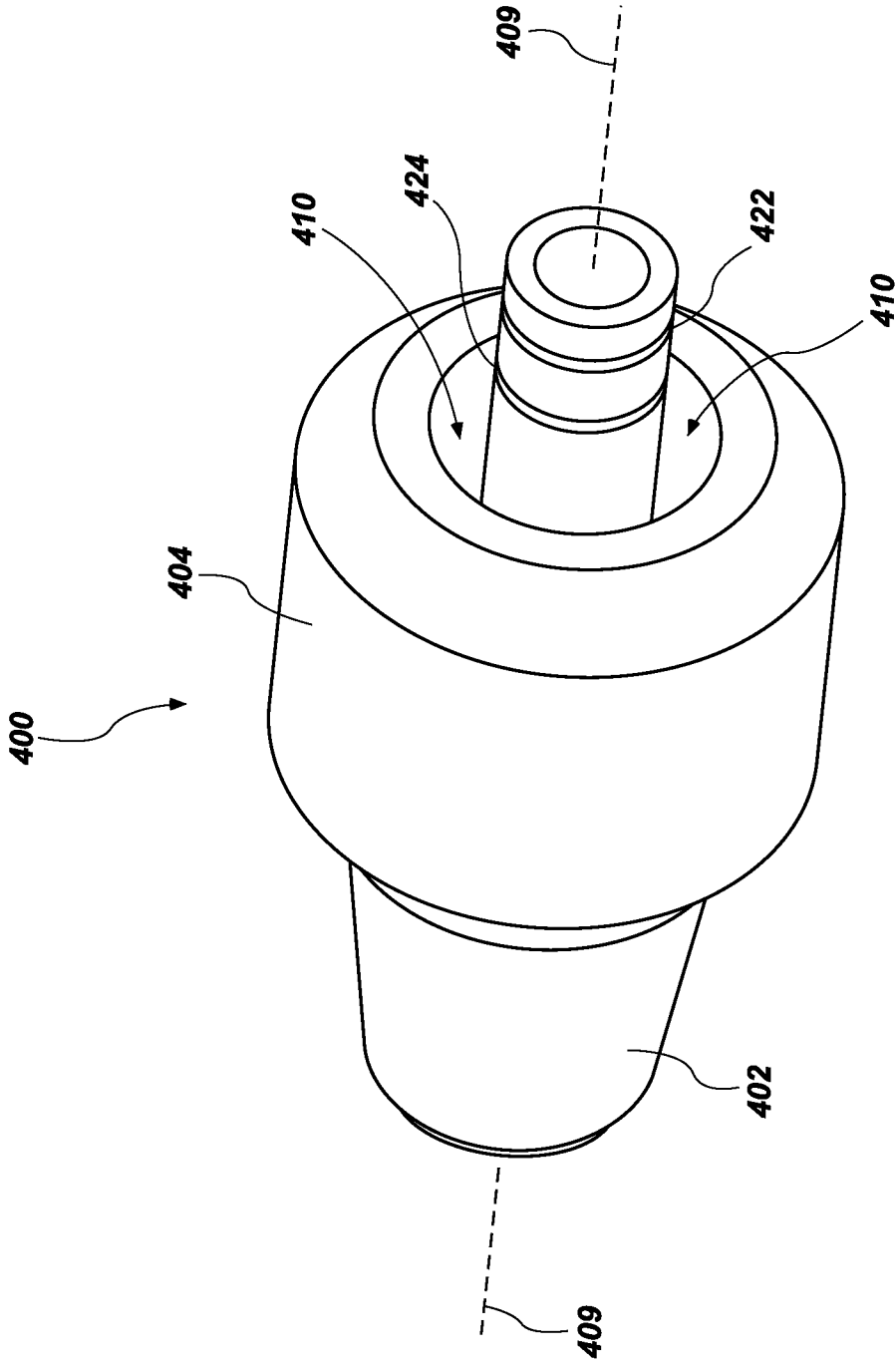


FIG. 4B

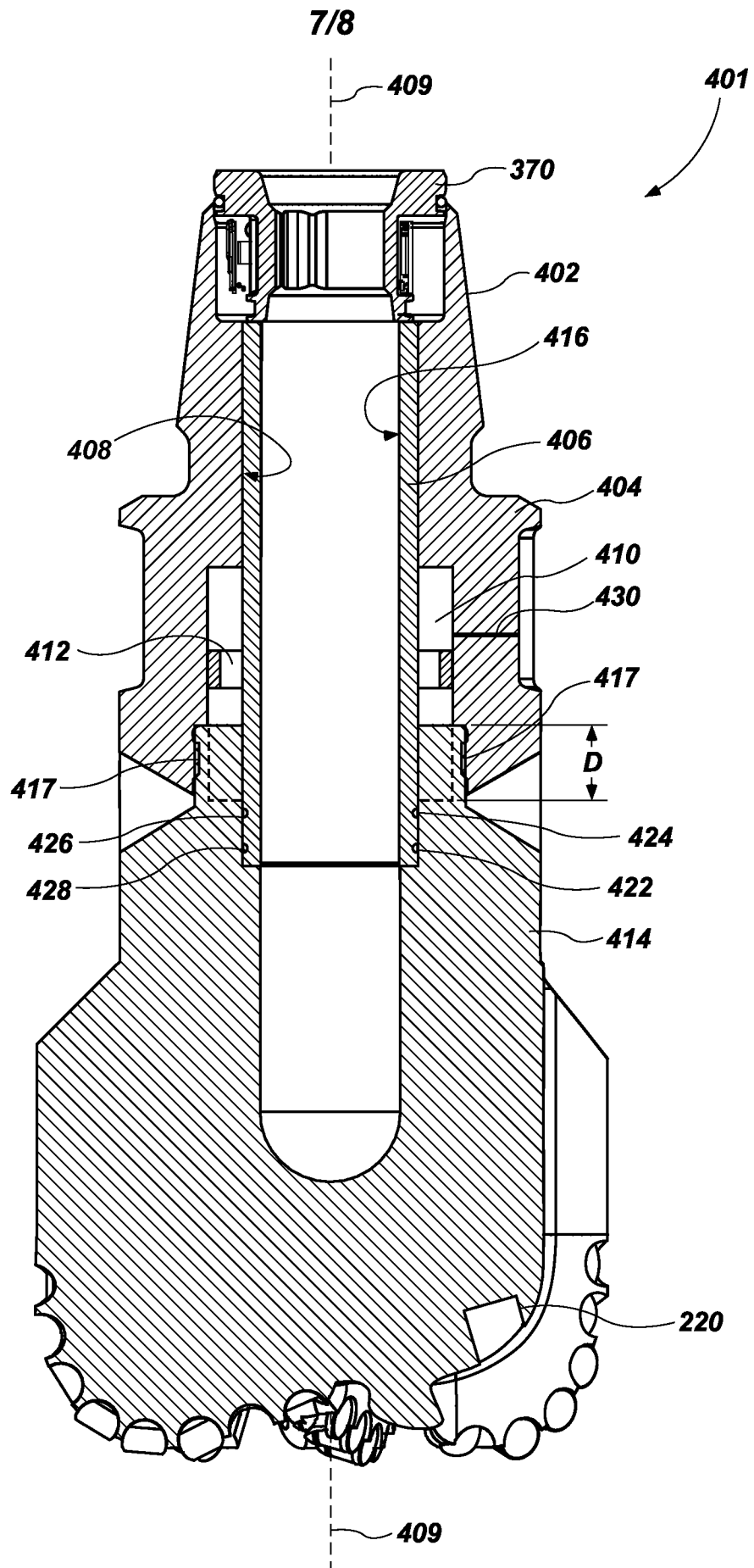


**FIG. 5**

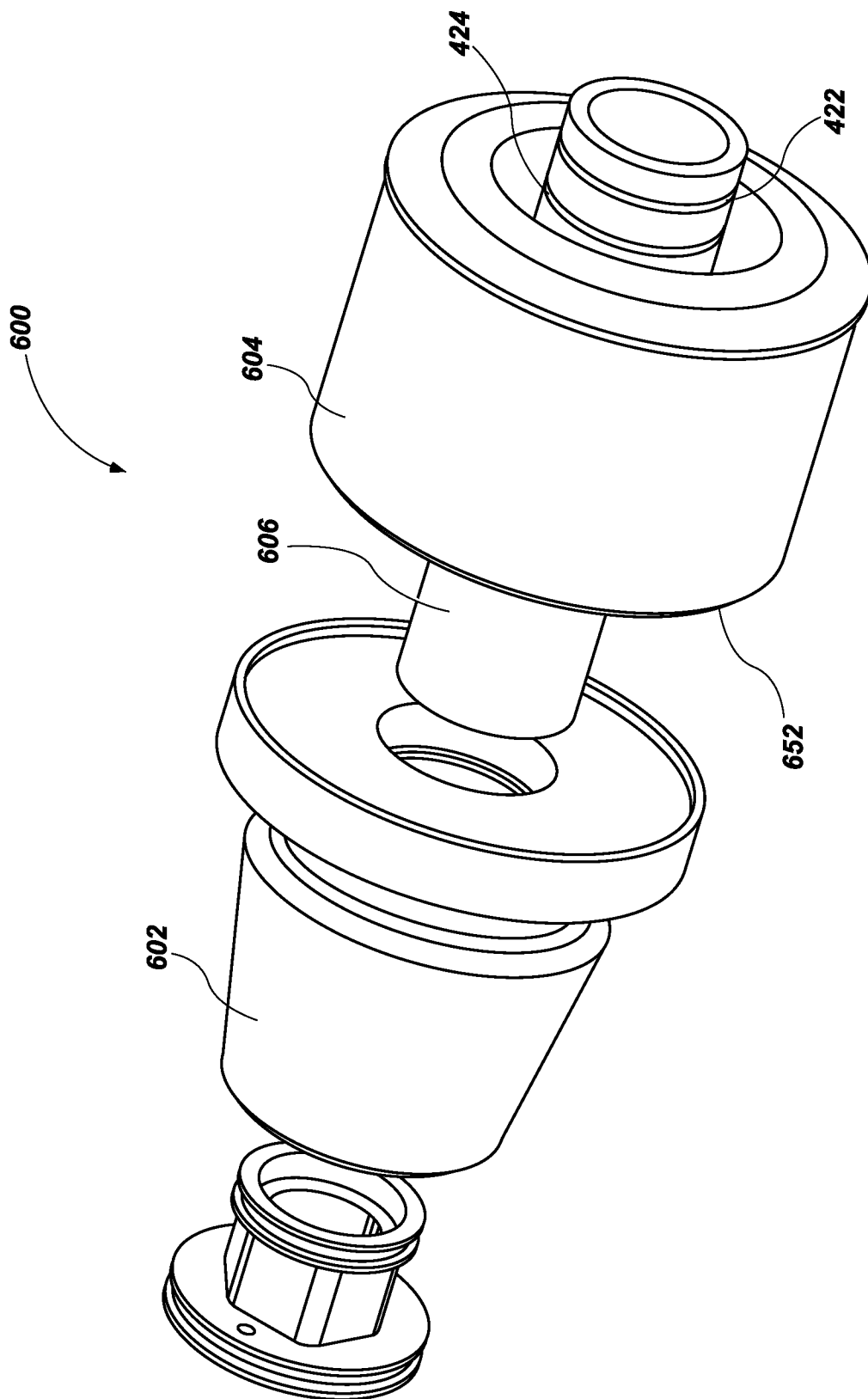


FIG. 6

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2019/065728****A. CLASSIFICATION OF SUBJECT MATTER****E21B 12/00(2006.01)i, E21B 10/00(2006.01)i**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

E21B 12/00; E21B 10/00; E21B 10/02; E21B 25/02; E21B 47/00; E21B 7/00; G01V 1/44; G06F 17/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) &amp; keywords: earth-boring tool, shank portion, neck portion, anchor tube, electronics module, crown, end-cap, annular cavity

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                          | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 5720355 A (LAMINE et al.) 24 February 1998<br>column 6, lines 11-30, column 20, lines 59-65 and figure 1 | 1,6-13                |
| Y         |                                                                                                             | 2-5,14-15             |
| Y         | US 2010-0078216 A1 (RADFORD et al.) 01 April 2010<br>paragraphs [0122]-[0123] and figure 5                  | 2-4,14-15             |
| Y         | US 8215384 B2 (TRINH et al.) 10 July 2012<br>column 4, lines 24-47 and figure 2                             | 5                     |
| A         | US 2012-0031672 A1 (TRINH et al.) 09 February 2012<br>paragraph [0025]-[0026] and figure 5                  | 1-15                  |
| A         | US 5568838 A (STRUTHERS et al.) 29 October 1996<br>column 5, lines 56-67 and figure 3                       | 1-15                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

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

"D" document cited by the applicant in the international application

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

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

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

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

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

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

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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

10 April 2020 (10.04.2020)

Date of mailing of the international search report

**10 April 2020 (10.04.2020)**

Name and mailing address of the ISA/KR

International Application Division

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2019/065728**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                                                                                                                                                                                                                    | Publication<br>date                                                                                                                                                                              |
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| US 8215384 B2                             | 10/07/2012          | BR PI0921219 A2<br>BR PI0921219 B1<br>CA 2742479 A1<br>CA 2742479 C<br>EP 2347287 A2<br>EP 2347287 B1<br>US 2010-0118657 A1<br>WO 2010-054353 A2<br>WO 2010-054353 A3                                                                                         | 23/02/2016<br>06/08/2019<br>14/05/2010<br>16/09/2014<br>27/07/2011<br>19/07/2017<br>13/05/2010<br>14/05/2010<br>19/08/2010                                                                       |
| US 2012-0031672 A1                        | 09/02/2012          | BR 112013002943 A2<br>BR 112013002943 B1<br>CA 2807155 A1<br>CA 2807155 C<br>CN 103069108 A<br>CN 103069108 B<br>EP 2601379 A1<br>EP 2601379 B1<br>MX 2013001242 A<br>RU 2013109736 A<br>SG 187726 A1<br>US 9004161 B2<br>WO 2012-019183 A1<br>ZA 201300629 B | 07/06/2016<br>28/01/2020<br>09/02/2012<br>29/08/2017<br>24/04/2013<br>08/02/2017<br>12/06/2013<br>21/11/2018<br>18/03/2013<br>20/09/2014<br>28/03/2013<br>14/04/2015<br>09/02/2012<br>26/03/2014 |
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