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(54) FLUID INLET SLEEVES FOR IMPROVING FLUID FLOW IN EARTH-BORING TOOLS, EARTH-BORING TOOLS HAVING FLUID INLET SLEEVES, AND RELATED METHODS

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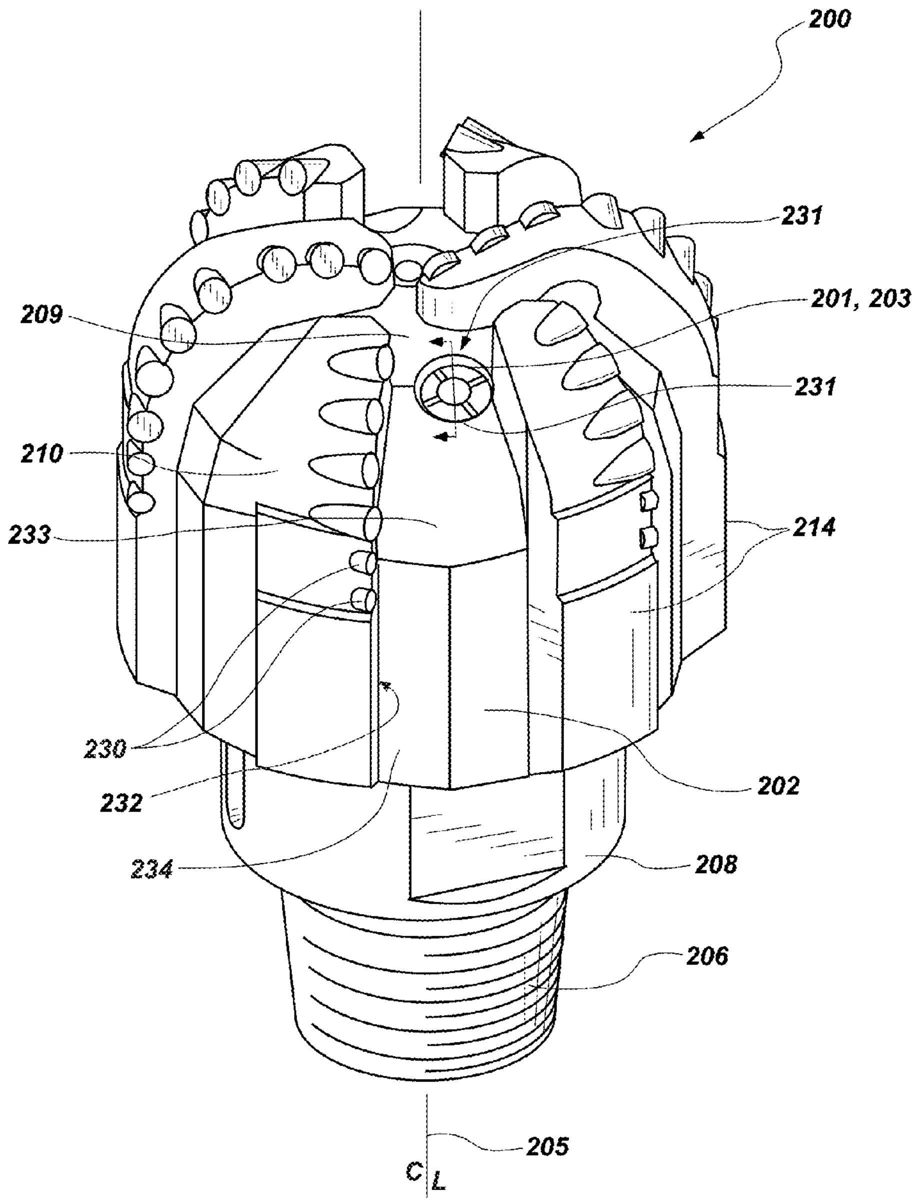
CPC *E21B 10/61* (2013.01)

(57) **ABSTRACT**

An earth-boring tool includes a nozzle port extending from an external surface to an internal fluid plenum of a tool body. A fluid inlet sleeve is disposed within the nozzle port of the tool body. The fluid inlet sleeve includes a hollow cylinder having a longitudinal end oriented within the internal fluid plenum. The longitudinal end of the fluid inlet sleeve includes one surface oriented at an angle within a range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.



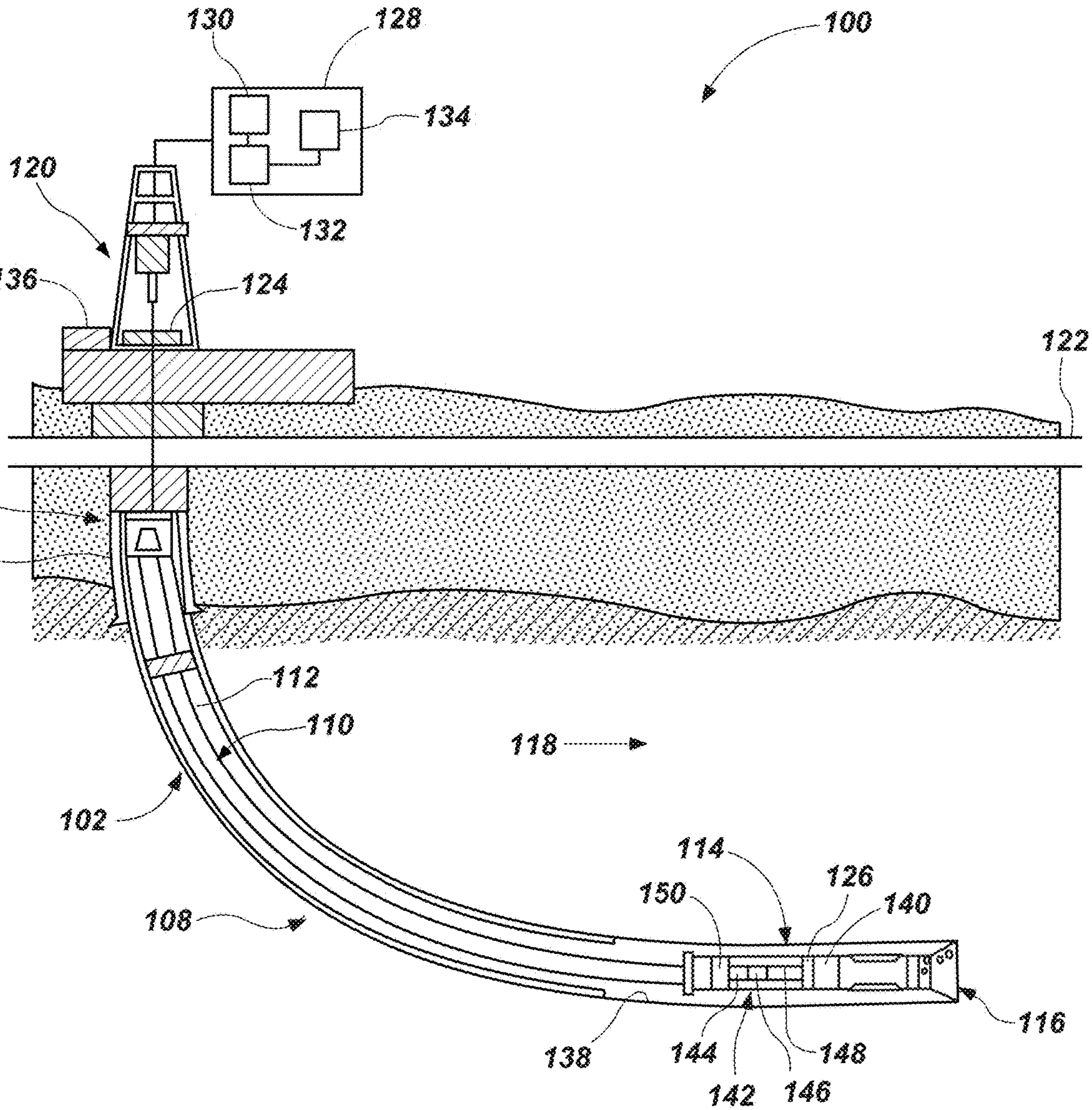

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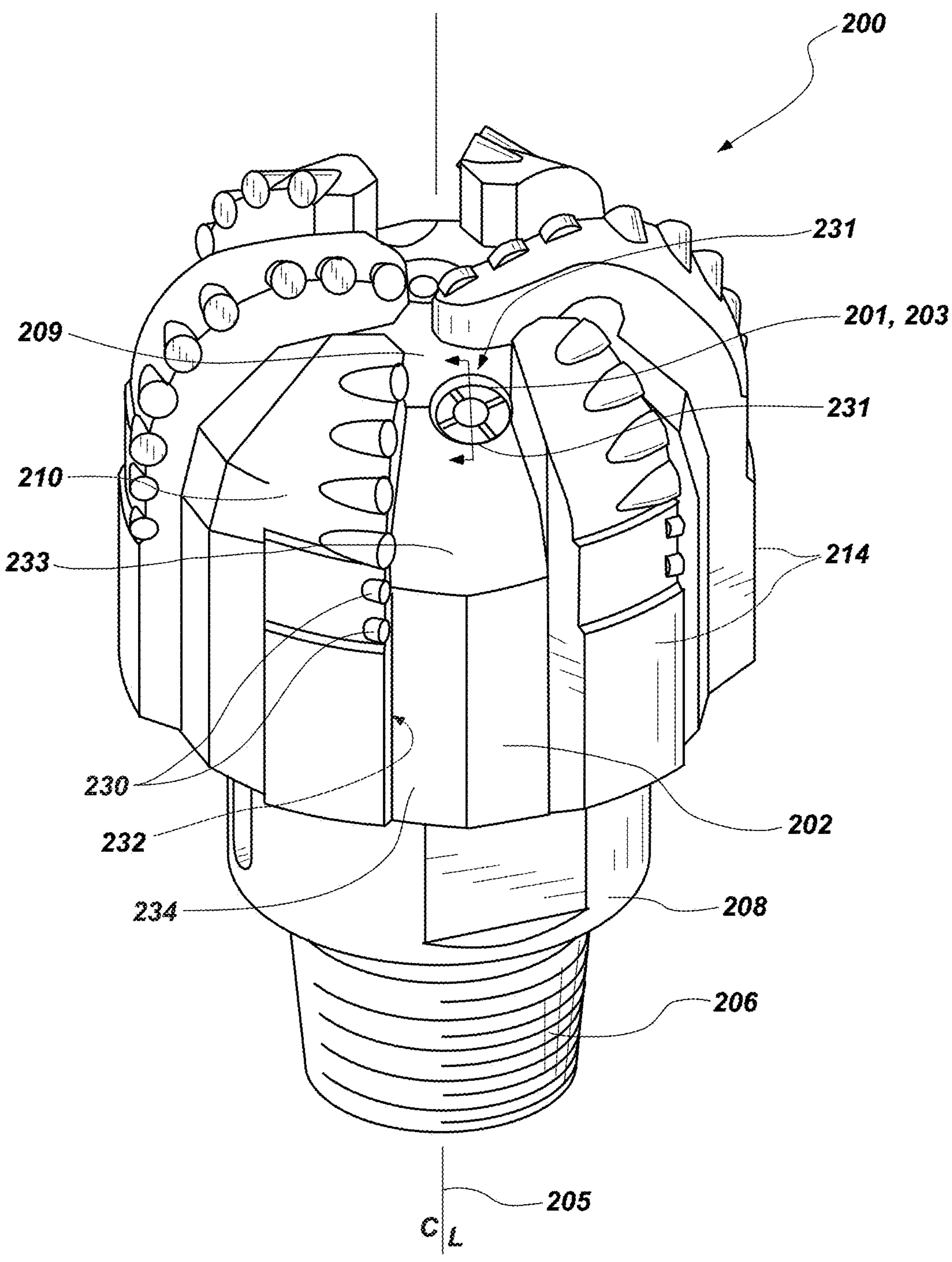
FIG. 1


200
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201, 203
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210
233
214
230
232
202
234
208
206
205
C L

FIG. 2A

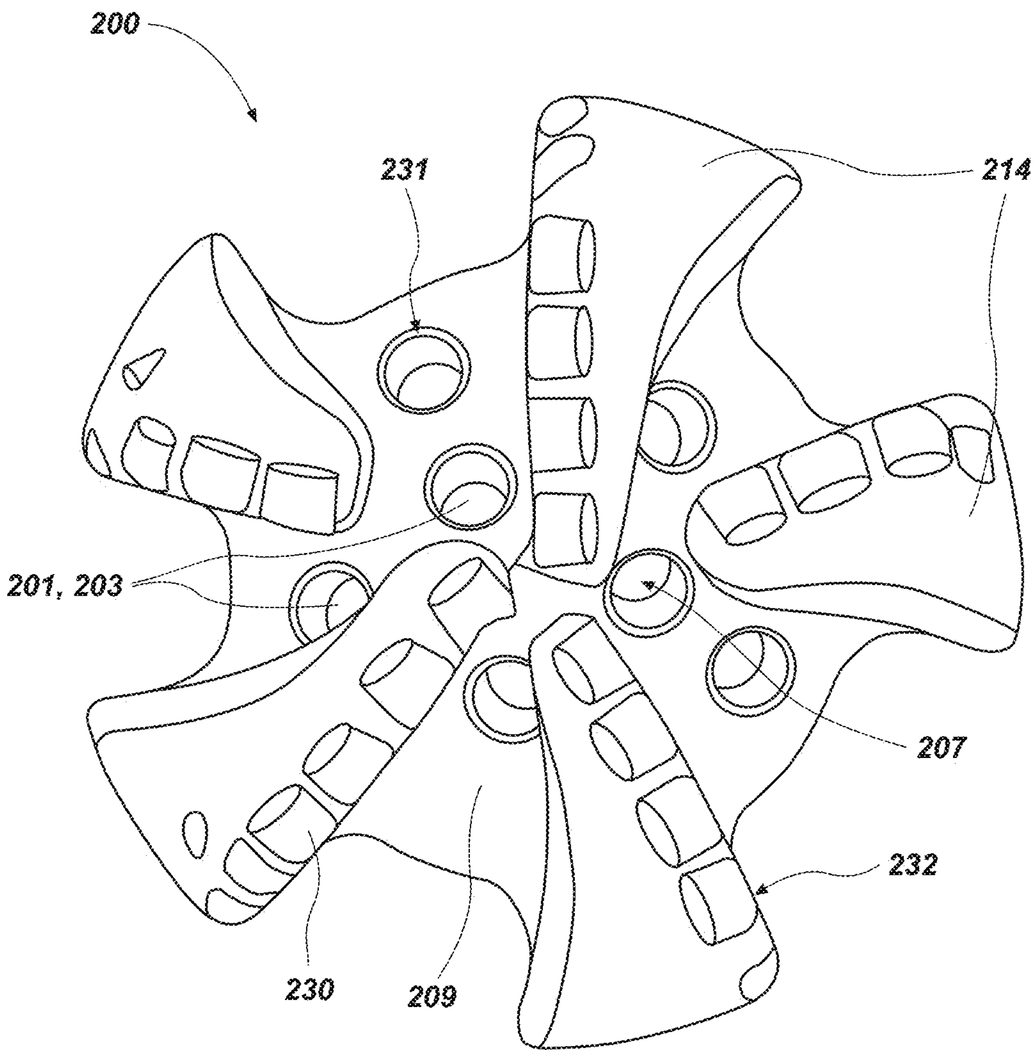


FIG. 2B

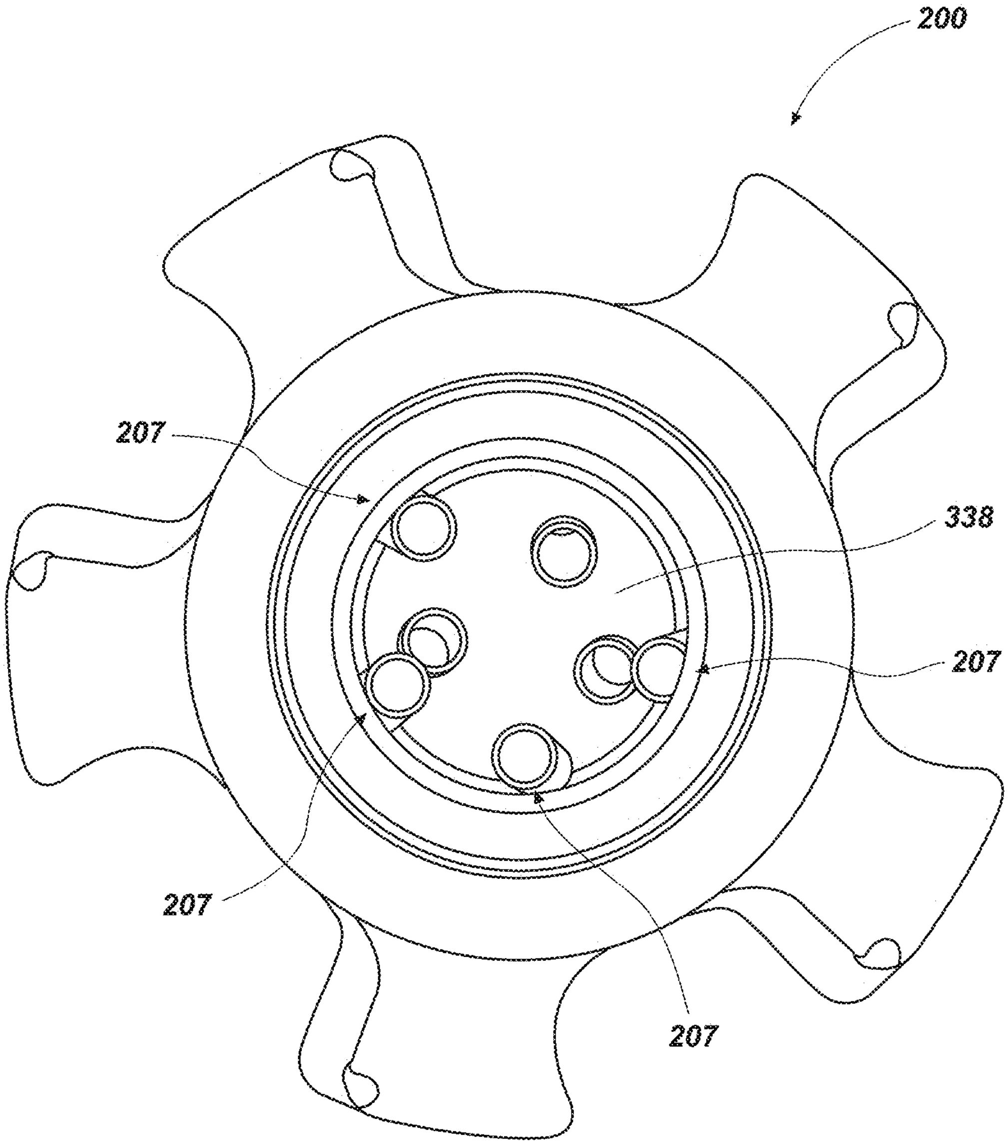


FIG. 3A

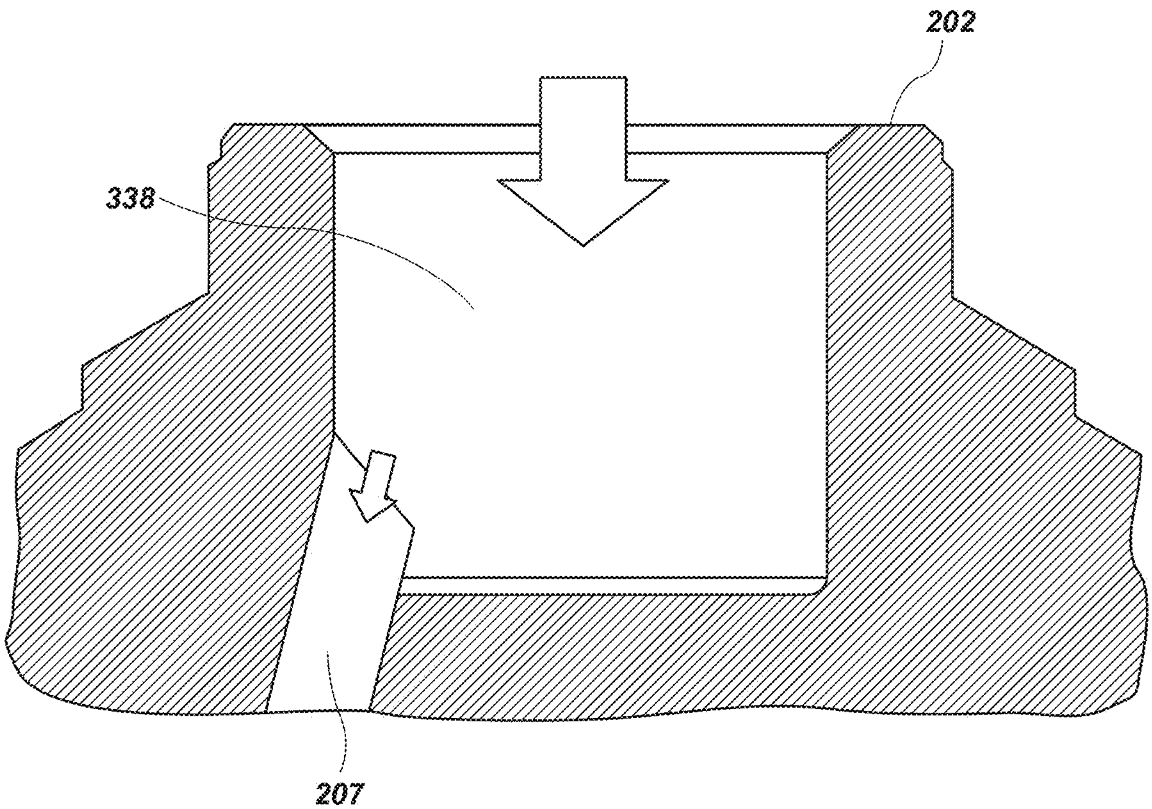


FIG. 3B

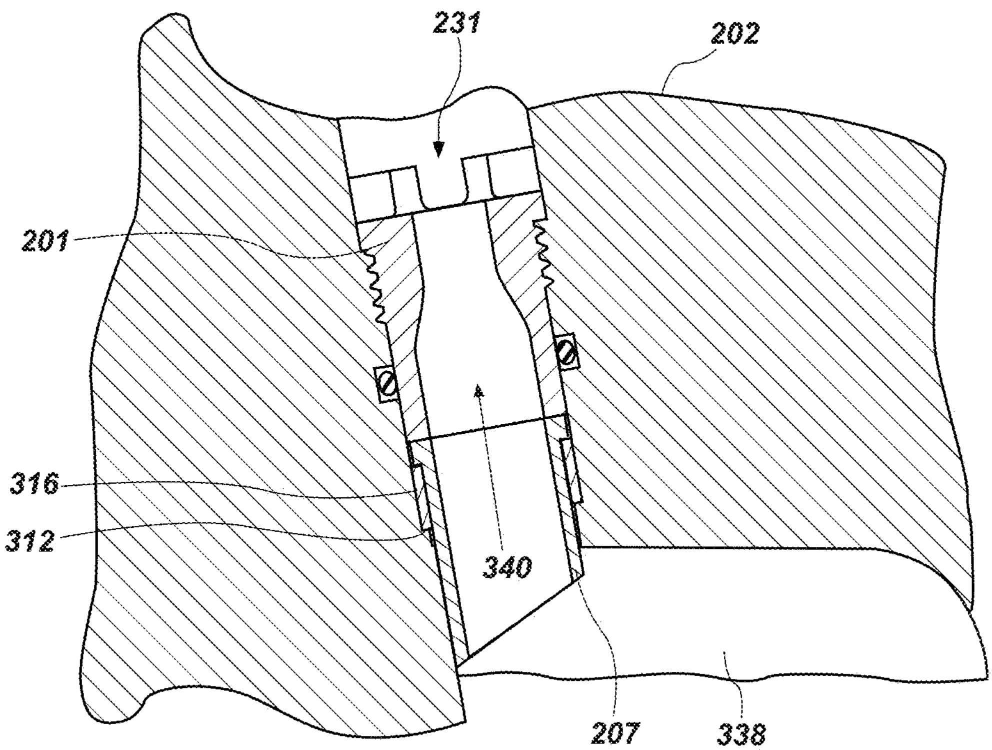


FIG. 3C

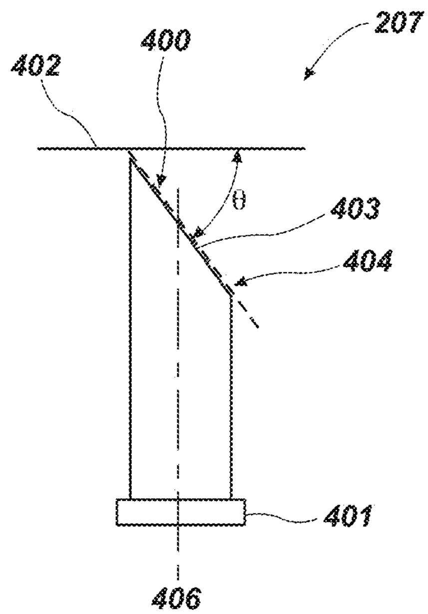


FIG. 4A

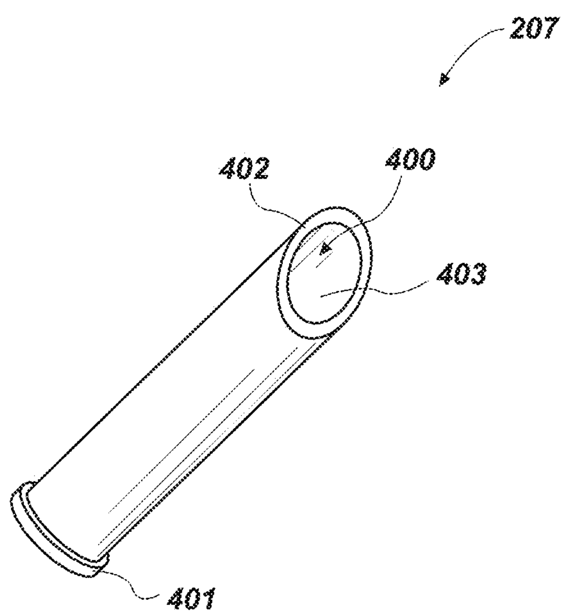


FIG. 4B

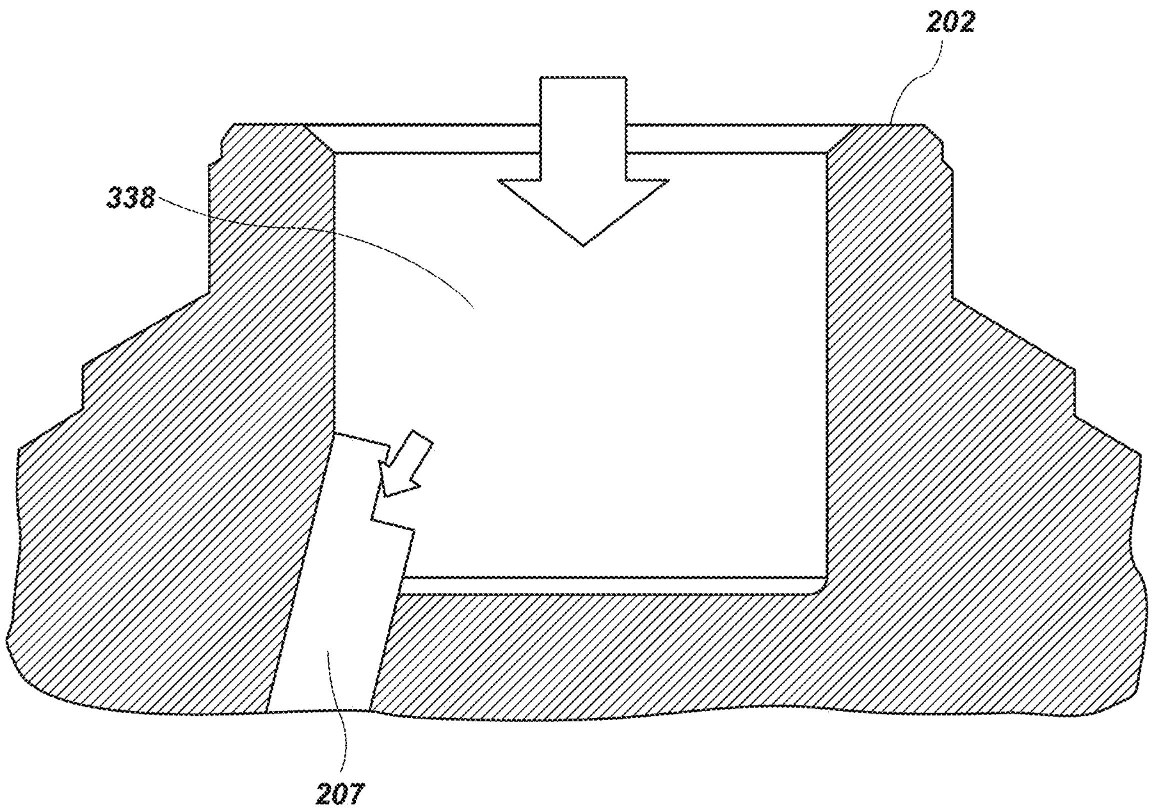


FIG. 5A

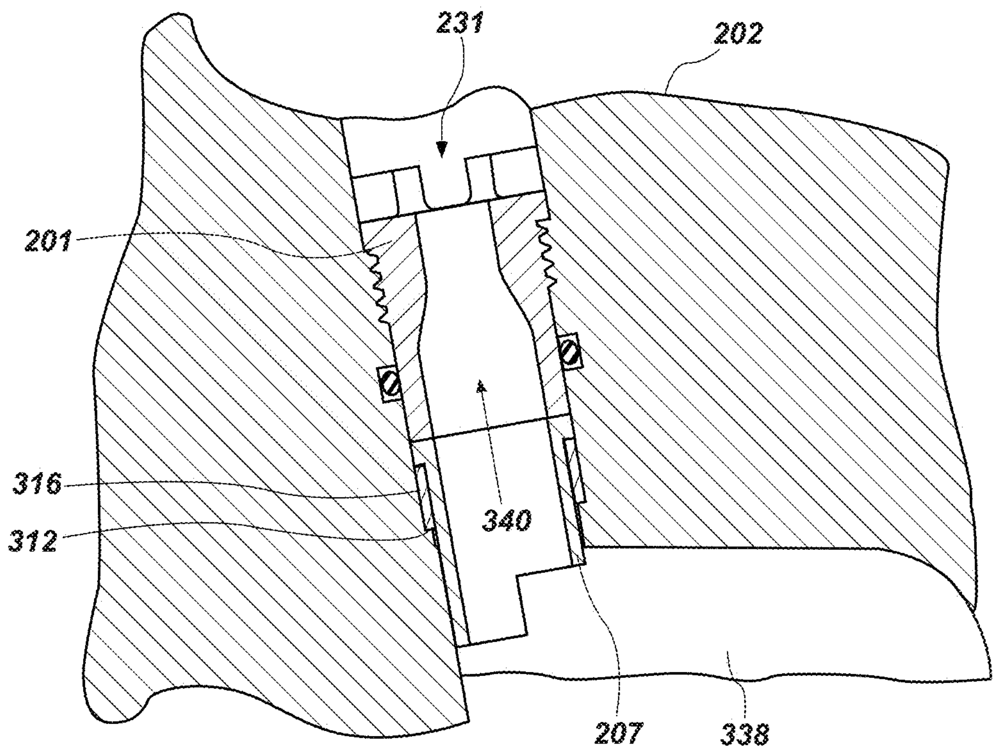
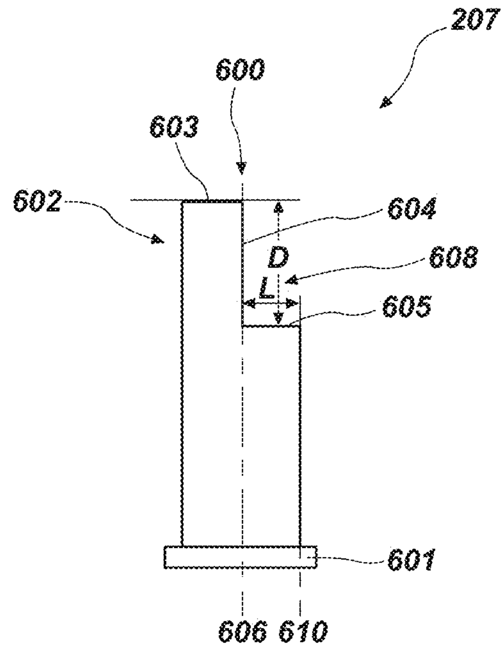


FIG. 5B



207
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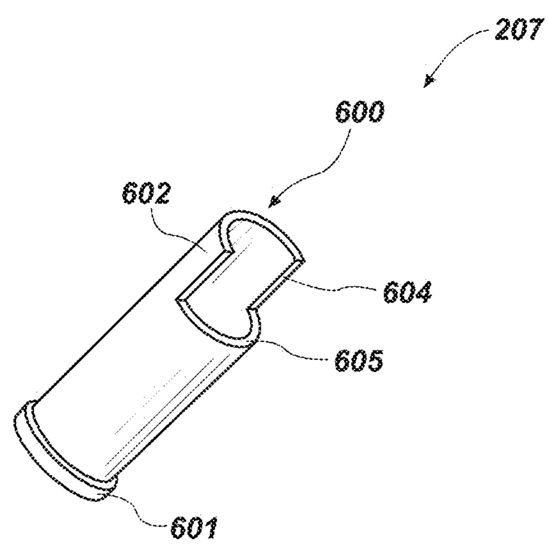
606 610

FIG. 6A



207
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602
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601

FIG. 6B

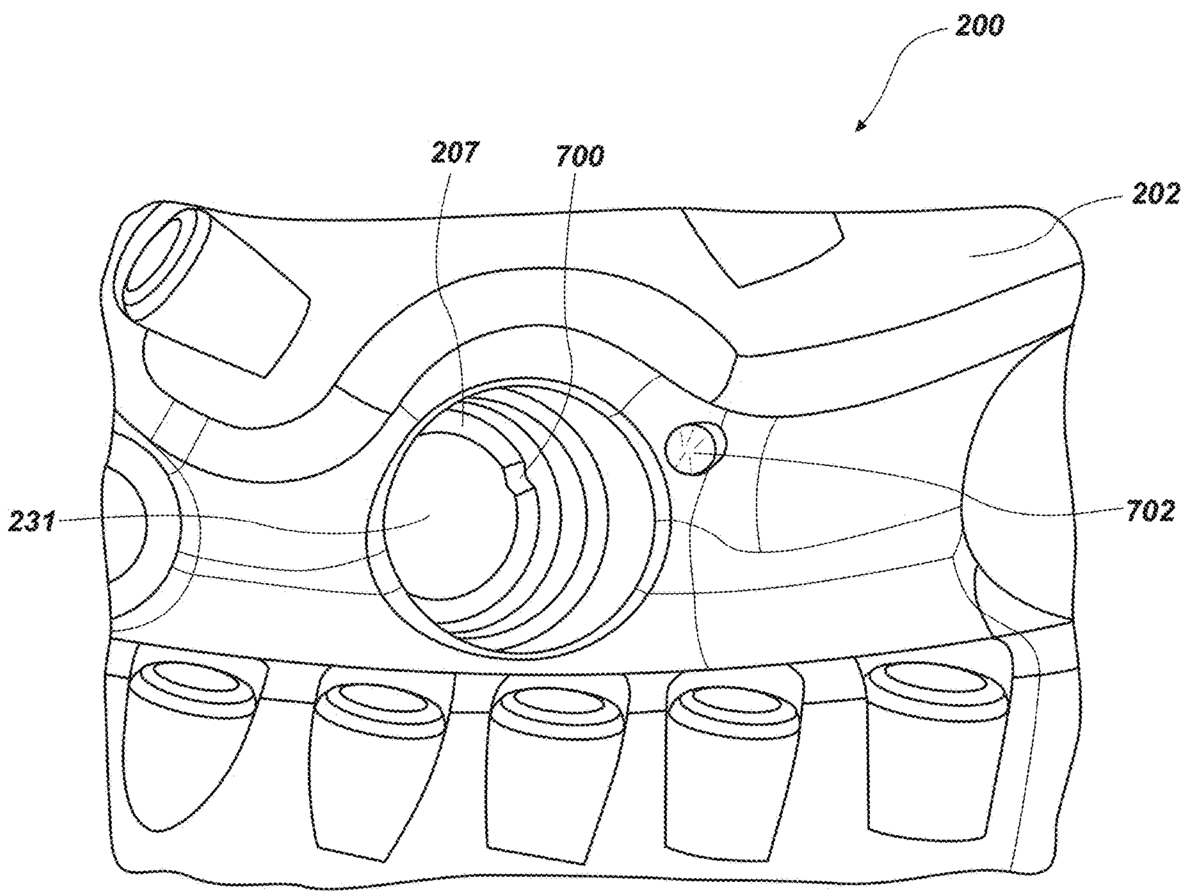
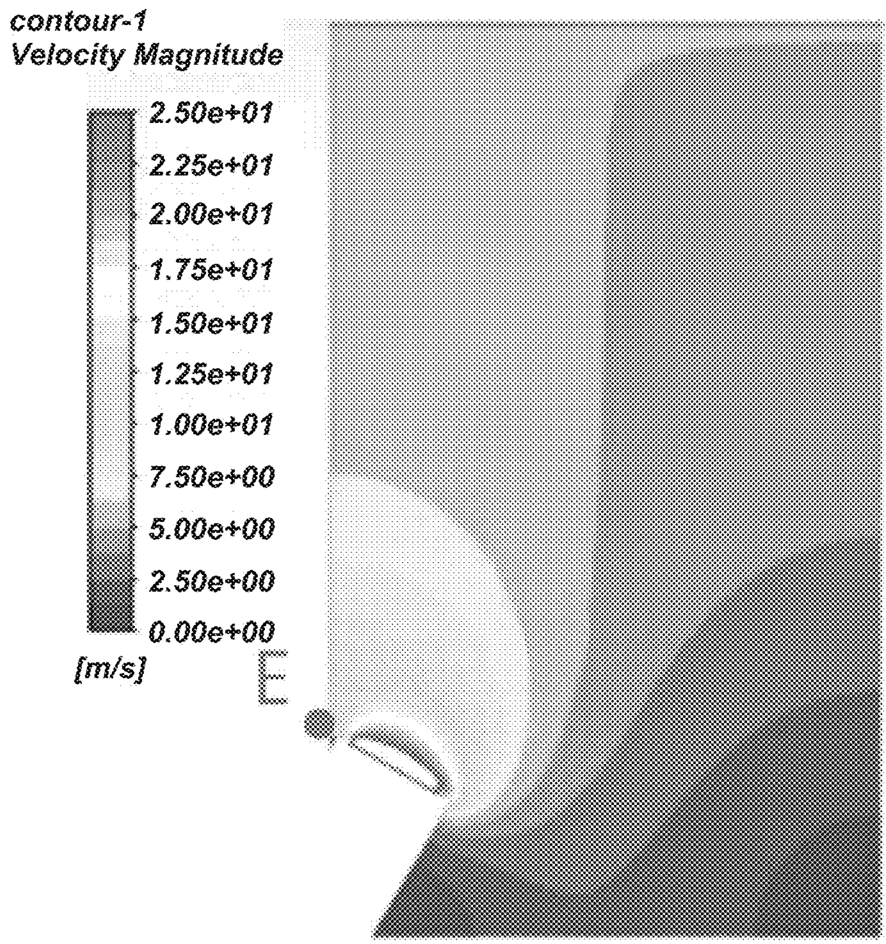


FIG. 7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2.50e+00
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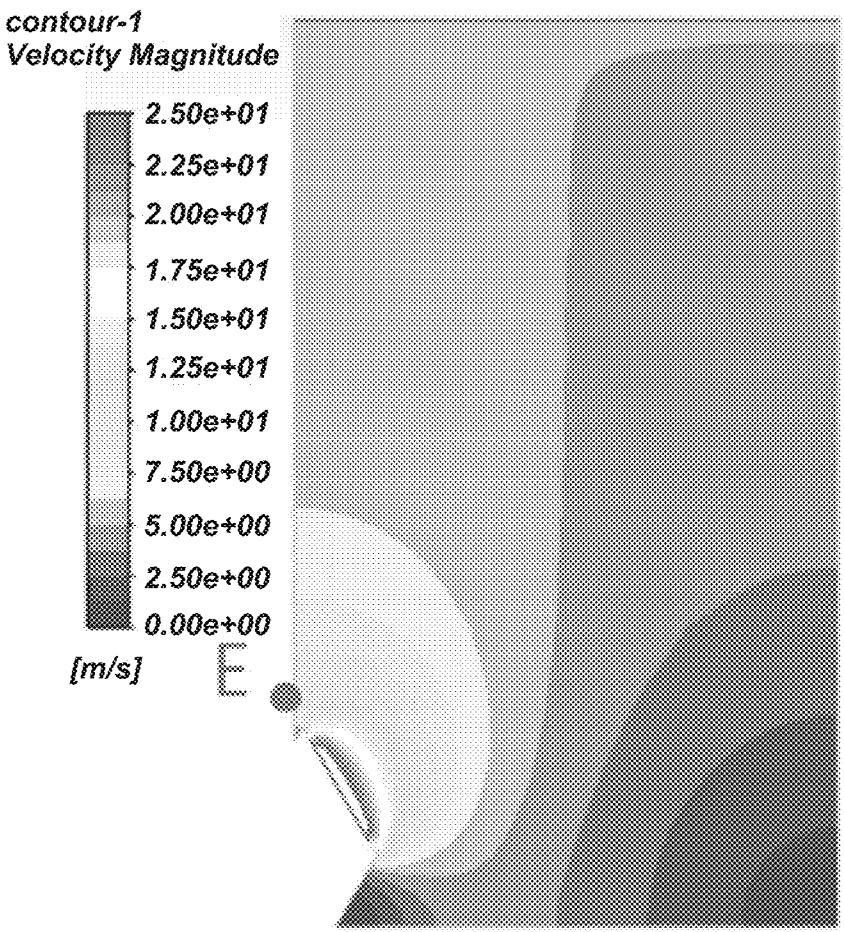
[m/s]
E

FIG. 8A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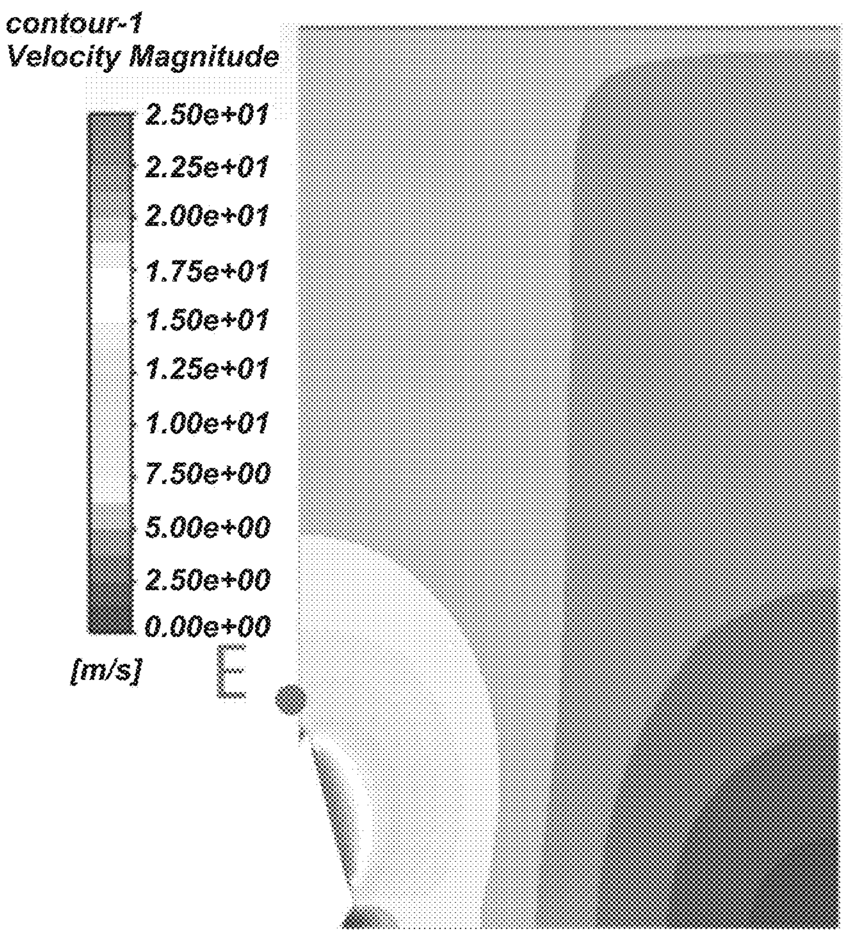
5.00e+00
2.50e+00
0.00e+00
[m/s]
E

FIG. 8B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Velocity Magnitude
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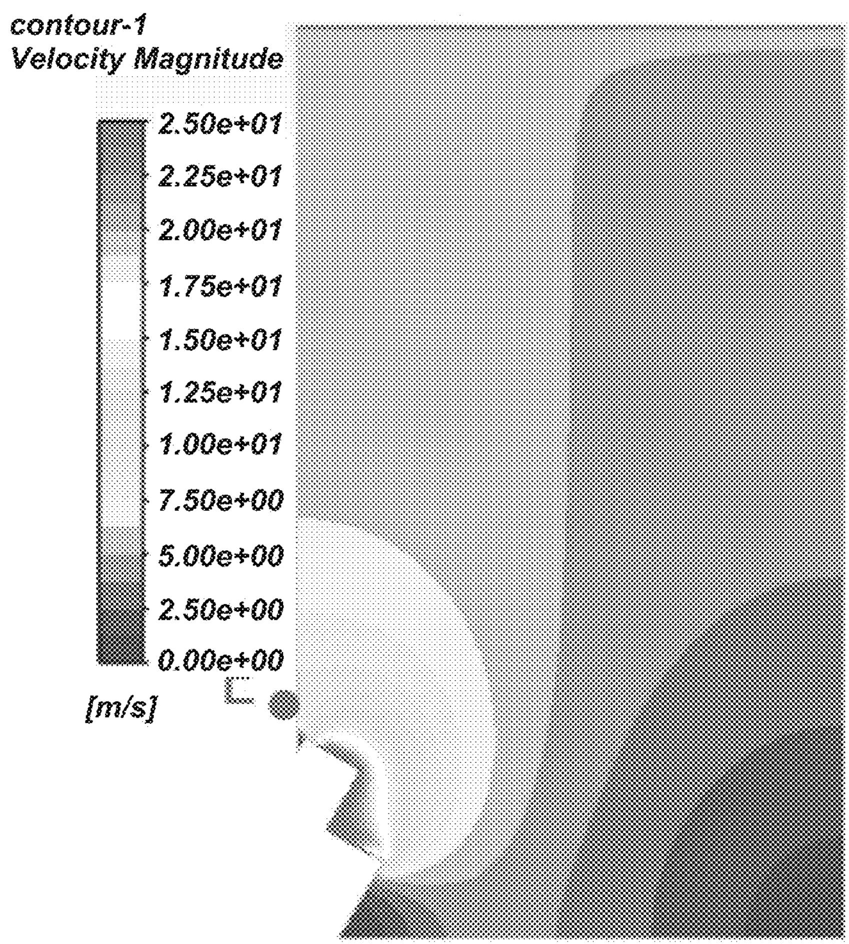
[m/s]
E

FIG. 8C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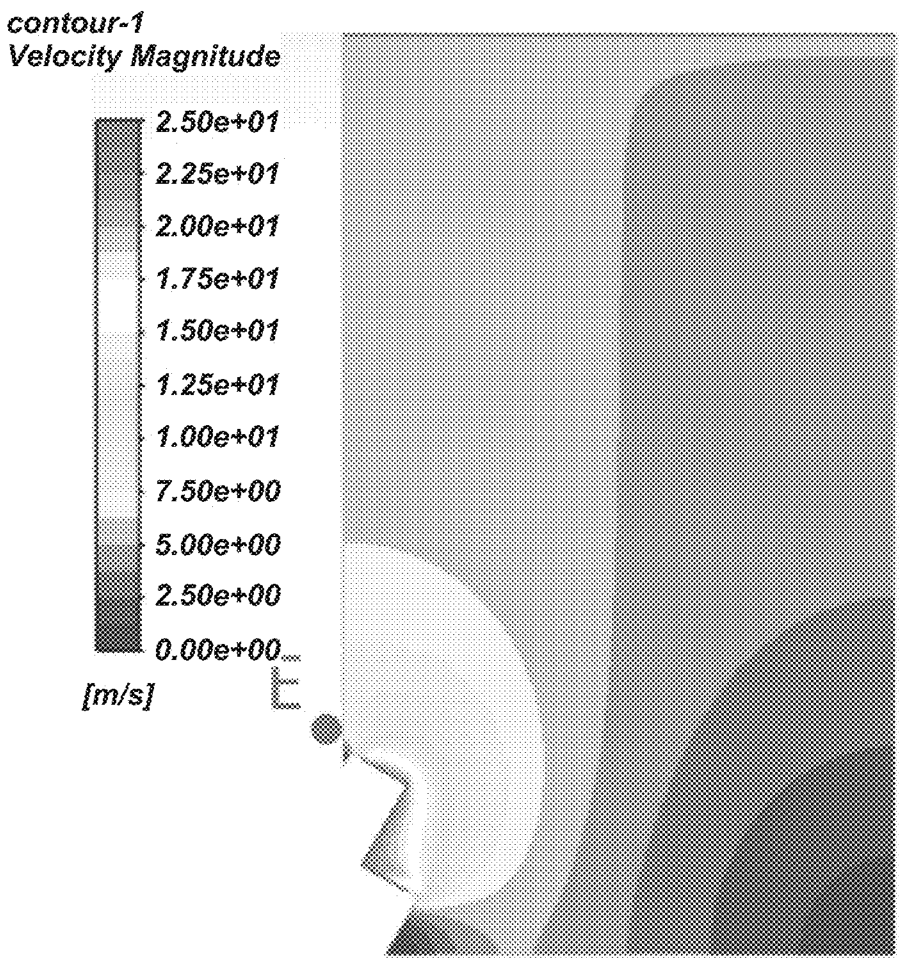
[m/s]

FIG. 9A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Velocity Magnitude
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0.00e+00
[m/s]

FIG. 9B

FLUID INLET SLEEVES FOR IMPROVING FLUID FLOW IN EARTH-BORING TOOLS, EARTH-BORING TOOLS HAVING FLUID INLET SLEEVES, AND RELATED METHODS

TECHNICAL FIELD

[0001] The present disclosure relates to earth-boring tools containing fluid inlet sleeves having tapered or stepped ends for adjusting fluid flow and related methods of making earth-boring tools comprising the fluid inlet sleeves.

BACKGROUND

[0002] Many different tools used in the oil exploration and production industry utilize bodies or components comprising steel which are exposed to very abrasive and erosive environments. For example, subterranean drilling operations generally employ a rotary drill bit that is rotated while being advanced through rock formations. Cutting elements or structures affixed to the rotary drill bit cut the rock while drilling fluid removes formation debris and carries it back to the surface. The drilling fluid is pumped from the surface through the drill string and out through one or more (usually a plurality of) nozzles located on the drill bit. The nozzles direct jets or streams of the drilling fluid to clean and cool cutting surfaces of the drill bit and for the aforementioned debris removal.

[0003] The number of nozzles on the drill bit depends on the bit size and the arrangement of the cutting elements on the face of the individual drill bit. Accordingly, the total flow area of the nozzles is determined by first evaluating the requirements of hydraulics for the particular drilling application. Moreover, the life of a drill bit having PDC cutting elements is typically extended when it is adequately lubricated and cooled during the drilling process. In contrast, having inadequate fluid flow to the face of a drill bit allows formation cuttings to collect on the faces of the cutting elements. This collection of cuttings isolates the cutting elements from the drilling fluid. This also reduces the rate of penetration of the drill bit and if the debris collection is sufficiently high the cutting elements may overheat which increases the wear rate. Adequate fluid flow is critical to the success of the drill bit. The repeated exposure to hydraulic fluid may cause severe erosion on the interior of the drill bit exposed to the continuous fluid flow. Excessive erosion may lead to complete failure of the drill bit. Accordingly, there exists a continuing need for developments in steel tool bodies to improve the erosion and/or wear resistance of the tool body without compromising the strength/toughness of the tool body and without increasing the difficulty of the manufacturing process.

BRIEF SUMMARY

[0004] Some embodiments of the present disclosure include earth-boring tools. The earth-boring tools may include a body including at least one nozzle port extending from an external surface to an internal fluid plenum. The earth-boring tools may further include at least one fluid inlet sleeve disposed within the at least one nozzle port of the tool body, the at least one fluid inlet sleeve comprising a hollow cylinder having a longitudinal end oriented at least partially within the internal fluid plenum, the longitudinal end comprising at least one surface oriented at an angle within a range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

[0005] Some embodiments of the present disclosure include a fluid inlet sleeve. The fluid inlet sleeve may include a hollow cylinder having a longitudinal end configured to be at least partially disposed within an internal fluid plenum of an earth-boring tool, the longitudinal end comprising at least one surface oriented at an angle within a range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

[0006] Some embodiments of the present disclosure include a method of forming an earth-boring tool. The method may include disposing a nozzle within in a nozzle port of a body of the earth-boring tool, the nozzle port extending from an external surface of the body and an internal fluid plenum within the body; and disposing at least one fluid inlet sleeve within the nozzle port of the body adjacent to the nozzle such that a longitudinal end of the at least one fluid inlet sleeve is oriented at least partially within the internal fluid plenum, the longitudinal end comprising at least one surface oriented at an angle within the range from greater than 0 degrees and less than 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a schematic diagram of an example of a drilling system that may utilize the apparatuses and methods disclosed herein for drilling boreholes;

[0008] FIG. **2**A is a perspective view of an earth-boring tool that may be used with the drilling assembly of FIG. **1** according to one or more embodiments of the present disclosure;

[0009] FIG. **2**B is a bottom side view of the earth-boring tool within one or more elements removed to better show internal components of the earth-boring tool according to one or more embodiments of the present disclosure;

[0010] FIG. **3**A is a top view of the body of the earth-boring tool disconnected from the string of FIG. **1** including a fluid inlet sleeve according to one or more embodiments of the present disclosure;

[0011] FIG. **3**B is a side cross-sectional view of the body of the earth-boring tool including a fluid inlet sleeve according to one or more embodiments of the present disclosure;

[0012] FIG. **3**C is another side cross-sectional view of the body of the earth-boring tool including the fluid inlet sleeve of FIG. **3**B according to one or more embodiments of the present disclosure;

[0013] FIG. **4**A is a schematic side view of the fluid inlet sleeve of FIGS. **3**A-**3**C according to one or more embodiments of the present disclosure;

[0014] FIG. **4**B is a perspective view of the fluid inlet sleeve of FIG. **4**A according to one or more embodiments of the present disclosure;

[0015] FIG. **5**A is a side cross-sectional view of the body of the earth-boring tool including a fluid inlet sleeve according to one or more embodiments of the present disclosure;

[0016] FIG. **5**B is another side cross-sectional view of the body of the earth-boring tool including the fluid inlet sleeve of FIG. **5**A according to one or more embodiments of the present disclosure;

[0017] FIG. **6**A is a schematic side view of the fluid inlet sleeve of FIGS. **5**A and **5**B according to one or more embodiments of the present disclosure;

[0018] FIG. **6**B is a perspective view of the fluid inlet sleeve of FIG. **5**A according to one or more embodiments of the present disclosure;

[0019] FIG. **7** is a partial perspective view of a body of an earth-boring tool including a nozzle port and a fluid inlet sleeve disposed within the nozzle port according to one or more embodiments of the present disclosure; and

[0020] FIGS. **8**A, **8**B, **8**C, **9**A, and **9**B show the results from a Computational Fluid Dynamic (CFD) analysis performed by the inventors and used to analyze the fluid flow velocity at various locations inside the body of the earth-boring tool including the fluid inlet sleeve according to one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

[0021] The illustrations presented herein are not meant to be actual views of any particular component, device, or system, but are merely idealized representations which are employed to describe embodiments of the present invention.

[0022] As used herein, the terms "earth-boring tool" means and includes earth-boring tools for forming, enlarging, or forming and enlarging a borehole. Non-limiting examples of earth-boring tools include fixed cutter (drag) bits, fixed cutter coring bits, fixed cutter eccentric bits, fixed cutter bi-center bits, fixed cutter reamers, expandable reamers with blades bearing fixed cutters, and hybrid bits including both fixed cutters and rotatable cutting structures (e.g., roller cones).

[0023] As used herein, the term "cutting elements" means and includes, for example, superabrasive (e.g., polycrystalline diamond compact or "PDC") cutting elements employed as fixed cutting elements, as well as tungsten carbide inserts and superabrasive inserts employed as cutting elements mounted to a body of an earth-boring tool.

[0024] 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.

[0025] 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.

[0026] As used herein, any relational term, such as "first," "second," "top," "bottom," "upper," "lower," 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. For example, these terms may refer to an orientation of elements of an earth-boring tool when disposed within a borehole in a conventional manner. Furthermore, these terms may refer to an orientation of elements of an earth-boring tool when as illustrated in the drawings.

[0027] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0028] As used herein, the term "substantially" in reference to a given parameter, property, or condition means and includes to a degree that one of ordinary skill in the art would understand that the given parameter, property, or condition is met with a degree of variance, such as within acceptable tolerances. By way of example, depending on the particular parameter, property, or condition that is substantially met, the parameter, property, or condition may be at least 90.0 percent met, at least 95.0 percent met, at least 99.0 percent met, at least 99.9 percent met, or even 100.0 percent met.

[0029] 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, as well as variations resulting from manufacturing tolerances, etc.).

[0030] 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 boreholes. FIG. **1** shows a borehole **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, for example. A drill bit **116** may be attached to the bottom end of the drilling assembly **114** for drilling the borehole **102** of a selected diameter in a formation **118**.

[0031] The drill string **110** may extend to a rig **120** at 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 boreholes 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 **110** and to rotate the drilling assembly **114**, and thus the drill bit **116** to drill the borehole **102**. A drilling motor **126** 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** may also include conventional equipment, such as a mechanism to add additional sections to the tubular member **112** as the borehole **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 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 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 disk. 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") between the drill string **110** and an inside sidewall **138** of the borehole **102**.

[0032] 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 generally known as the measurement-while-drilling (MWD) sensors or the logging-while-drilling (LWD) sensors, 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 bit **116** (e.g., within a shank **208** and/or crown **210** 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** 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**.

[0033] FIG. **2**A shows a perspective view an earth-boring tool **200** that may be used with the drilling assembly **114** of FIG. **1** according to one or more embodiments of the present disclosure. Other types of earth-boring tools, such as roller cone bits, percussion bits, hybrid bits, reamers, etc., FIG. **2**B is a bottom side view of the earth-boring tool **200** of FIG. **2**A with one or more elements removed to better show internal components of the earth-boring tool **200**. Referring to FIGS. **2**A and **2**B together, the earth-boring tool **200** may include 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** 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."

[0034] 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 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**.

[0035] 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**. In some embodiments, the plurality of cutting elements **230** of the plurality of blades **214** may include PDC cutting elements **230**. Moreover, the plurality of cutting elements **230** of the plurality of blades **214** may include any suitable cutting element configurations and materials for drilling and/or enlarging boreholes.

[0036] The plurality of blades **214** may extend from the end of the body **202** opposite the neck **206** and may extend in both the axial and radial directions.

[0037] The earth-boring tool **200** includes a plurality of nozzles **201** and/or nozzle assemblies **203** disposed within the body **202**. The nozzles **201** and/or nozzle assemblies **203** may include inlet sleeves **207** for at least partially directing fluid flow and for protecting the nozzles **201** and/or nozzle assemblies **203** during operation. For example, the body **202** may include an external surface **209** and the plurality of nozzles **201** and/or nozzle assemblies **203** may extend from the external surface **209** to an interior (e.g., an internal fluid plenum) of the body **202** (e.g., to a fluid pathway). As is known in the art, during drilling, drilling fluid may be discharged through nozzles **201** and/or nozzle assemblies **203** disposed in nozzle ports **231** to cool the cutting elements **230**. The drilling fluid is also utilized to move formation cuttings through passages **233** and junk slots **234**. As is described in greater detail herein, the nozzle ports **231** of the present disclosure may have different configurations to accommodate the use of a plurality of nozzles **201** or nozzle assemblies **203**, as described herein.

[0038] FIG. **3**A shows a top view of the body **202** of the earth-boring tool **200** disconnected from the string **110** (FIG. **1**) according to one or more embodiments of the present disclosure. FIG. **3**B shows a side cross-sectional view of the body **202** of the earth-boring tool **200** of FIG. **3**A. FIG. **3**C shows another side cross-sectional view of the body **202** of the earth-boring tool **200** of FIG. **3**A. Referring to FIGS. **3**A-**3**C together, as will be recognized by one of ordinary skill in the art, a nozzle port **231** may extend from an internal fluid plenum **338** within the body **202** to the external surface **209** of the body **202**, and a nozzle **201** and the fluid inlet sleeve **207** may be disposed within the nozzle port **231**. Additionally, the nozzle **201** and the fluid inlet sleeve **207** may provide protection to the material of the body **202** against erosive drilling fluid effects by providing a hard, abrasion-resistant and erosion-resistant passageway **340** within the body **202**.

[0039] In some embodiments, the nozzle **201** may be removably inserted into and retained within the nozzle port **231** by a threaded connection or any other conventional connection. In some embodiments, the nozzle port **231** may define a seat **312** against which the fluid inlet sleeve **207** may be seated. Additionally, the earth-boring tool **200** may include one or more seal assemblies between the nozzle **201** and inlet sleeve **207** and the body **202** of the earth-boring tool. In some embodiments, the fluid inlet sleeve **207** may be removably disposed and retained within the nozzle port **231** by a threadless connection **316**. In some embodiments, the fluid inlet sleeve **207** may extend substantially an entire length of the nozzle port **231**.

[0040] FIG. **4**A shows a schematic side view of fluid inlet sleeve **207** of FIGS. **3**A-**3**C. FIG. **4**B shows a perspective view of the fluid inlet sleeve **207** of FIG. **4**A. Referring to FIGS. **3**A-**4**B together, the fluid inlet sleeve **207** may include a hollow cylinder **400** having a flanged longitudinal end **401** (referred to hereinafter as "flanged end") and an opposite tapered longitudinal end **402** (referred to hereinafter as "tapered end"). An internal surface of the hollow cylinder **400** may define an internal passageway or bore extending through the fluid inlet sleeve **207** and through which drilling fluid may flow from the internal fluid plenum **338** (FIG. **3**C) and to the external surface **209** (FIG. **2**B) of the nozzle **201**.

[0041] In some embodiments, the tapered end **402** of the fluid inlet sleeve **207** may include an angled end defining an end surface **403**, which defines a fluid entry plane **404**. The end surface **403** may extend within a plane (e.g., the fluid entry plane **404**) that forms an angle θ with a plane **404** to which a longitudinal axis **406** of the fluid inlet sleeve **207** is normal. In some embodiments, the angle θ may be within a range from greater than zero degrees (0°) to about ninety degrees (90°). In some embodiments, the angle θ may be within a range extending from about thirty degrees (30°) to about seventy-five degrees (75°), about thirty degrees (30°) to about sixty degrees (60°), about forty-five degrees (45°) to about seventy-five degrees (75°), or from about seventy-five degrees (75°) to about ninety degrees (90°).

[0042] As is described in greater detail below, the end surface **403** of the tapered end **402** of the fluid inlet sleeve **207**, which defines a fluid entry plane **404** that is oblique to the longitudinal axis **406** of the fluid inlet sleeve **207**, may reduce velocities of hydraulic fluid that are experienced by portions of an interior surface (e.g., wall) of the body **202** defining the internal fluid plenum **338**. In particular, by increasing a size of an opening of the fluid inlet sleeve **207** along the fluid entry plane **404** by forming the end surface **403** at an angle relative (i.e., oblique to) the longitudinal axis **406** of the fluid inlet sleeve **207** and by adjusting an angle at which fluid enters the fluid inlet sleeve **207** relative to conventional fluid inlet sleeves, the fluid inlet sleeves **207** of the present disclosure manipulate fluid flow away from the interior surface of the body **202** defining the internal fluid plenum **338**, thereby reducing velocities of the hydraulic fluid experienced by portions of an interior surface of the body **202**. Furthermore, by reducing the velocities of the hydraulic fluid experienced by portions of an interior surface of the body **202**, the fluid inlet sleeves **207** of the present disclosure may reduce wear and increase a lifetime of the body **202**. Increasing the lifetime of the body **202** increases reliability of the earth-boring tool and reduces operating costs.

[0043] FIG. **5**A shows a side cross-sectional view of the body **202** of the earth-boring tool **200** including a fluid inlet sleeve according to one or more embodiments of the present disclosure. FIG. **5**B shows another side cross-sectional view of the body **202** of the earth-boring tool **200** including the fluid inlet sleeve of FIG. **5**A. Referring to FIGS. **5**A-**5**B together as will be recognized by one of ordinary skill in the art, a nozzle port **231** may extend from an internal fluid plenum **338** within the body **202** to the external surface **209** (FIG. **2**B) of the body **202**, and a nozzle **201** and the fluid inlet sleeve **207** may be disposed within the nozzle port **231**. Additionally, the nozzle **201** and the fluid inlet sleeve **207** may provide protection to the material of the body **202** against erosive drilling fluid effects by providing a hard, abrasion-resistant and erosion-resistant passageway **340** within the body **202**.

[0044] In some embodiments, the nozzle **201** may be removably inserted into and retained within the nozzle port **231** by a threaded connection or any other conventional connection. In some embodiments, the nozzle port **231** may define a seat **312** against which the fluid inlet sleeve **207** may be seated. Additionally, the earth-boring tool **200** may include one or more seal assemblies between the nozzle **201** and inlet sleeve **207** and the body **202** of the earth-boring tool. In some embodiments, the fluid inlet sleeve **207** may be removably disposed and retained within the nozzle port **231** by a threadless connection **316**. In some embodiments, the fluid inlet sleeve **207** may extend substantially an entire length of the nozzle port **231**.

[0045] FIG. **6**A shows a schematic side view of fluid inlet sleeve **207** of FIGS. **5**A and **5**B. FIG. **6**B shows perspective view of the fluid inlet sleeve **207** of FIG. **5**A. Referring to FIGS. **6**A-**6**B together, similar to the fluid inlet sleeve of FIGS. **3**A-**4**B, the fluid inlet sleeve **207** may include a hollow cylinder **600** having a flanged longitudinal end **601** (referred to hereinafter as "flanged end") and an opposite stepped longitudinal end **602** (referred to hereinafter as "stepped end"). An internal surface of the hollow cylinder **600** may define an internal passageway or bore extending through the fluid inlet sleeve and through which drilling fluid may flow from the internal fluid plenum **338** (FIG. **5**B) and to the external surface **209** (FIG. **2**B) of the nozzle **201**.

[0046] In some embodiments, the stepped end **602** of the fluid inlet sleeve **207** may include an end surface **603**, a riser surface **604**, and a step surface **605**. The end surface **603**, the riser surface **604**, and the step surface **605** may define the stepped end **602** of the fluid inlet sleeve **207**. In some embodiments, the end surface **603** and the step surface **605** may be parallel to each other, and the riser surface **604** may extend between the end surface **602** and the step surface **605** in a direction at least substantially perpendicular to the end surface **603** and the step surface **605**. For example, the riser surface **604** and the step surface **605** may define a cutout from the stepped longitudinal end of the fluid inlet sleeve **207**. Additionally, together, the end surface **603**, the riser surface **604**, and the step surface **605** may define a fluid entry surface **608** that exhibits a general stepped shape. A longitudinal axis **606** of the fluid inlet sleeve **207** extends from the stepped end **602** to the flange end **601** of the fluid inlet sleeve **207**. The fluid inlet sleeve **207** may include a side surface **610** parallel to the longitudinal axis **606** and extends along an external surface of the hollow cylinder **600**.

[0047] In some embodiments, a distance D between the end surface **603** and the step surface **605** (e.g., a depth of the cutout in a direction parallel to the longitudinal axis **606** of the fluid inlet sleeve **207**) may be greater than 0 inch and less than 1.000 inch. The distance D may be within the range of about 0.250 inch to about 0.800 inch, from about 0.375 inch to about 0.750 inch, or from about 0.400 inch to about 0.600 inch. The distance D may be 0.500 inch.

[0048] In some embodiments, a distance L between the side surface **610** and the riser surface **604** (e.g., a depth of the cutout in a direction perpendicular to the longitudinal axis **606** of the fluid inlet sleeve **207**) may be greater than 0 inch and less than the maximum cross-sectional dimension of fluid inlet sleeve **207**. In some embodiments, fluid inlet sleeve **207** may have a maximum cross-sectional dimension of 2.000 inch. Furthermore, the fluid inlet sleeve **207** may be round and have a diameter of 2.000 inch. In some embodiments, the distance L may be greater than 0 inch and less than 2.000 inch.

[0049] As is described in greater detail below, the end surface **603**, the riser surface **604**, and the step surface **605** may define the stepped end **602** of the fluid inlet sleeve **207**, which defines a fluid entry surface **608**, may reduce velocities of hydraulic fluid that are experienced by portions of an interior surface (e.g., wall) of the body **202** defining the internal fluid plenum **338**. In particular, by increasing a size of an opening of the fluid inlet sleeve **207** along the fluid entry surface **608** by forming the end surface **603**, the riser surface **604**, and the step surface **605** and by adjusting angles at which fluid enters the fluid inlet sleeve **207** relative to conventional fluid inlet sleeves, the fluid inlet sleeves **207** of the present disclosure manipulate fluid flow away from the interior surface of the body **202** defining the internal fluid plenum **338**, thereby reducing velocities of the hydraulic fluid experienced by portions of an interior surface of the body **202**. Furthermore, as noted above, by reducing the velocities of the hydraulic fluid experienced by portions of an interior surface of the body **202**, the fluid inlet sleeves **207** of the present disclosure may reduce wear and increase a lifetime of the body **202**. Increasing the lifetime of the body **202** increases reliability of the earth-boring tool and reduces operating costs.

[0050] FIG. **7** shows a partial perspective view of a body **202** of an earth-boring tool **200** including a nozzle port **231** and a fluid inlet sleeve **207** disposed within the nozzle port **231** according to one or more embodiments of the present disclosure. As shown, in some embodiments, the fluid inlet sleeve **207** may include an alignment recess **700** formed in the longitudinal end therefore (e.g., formed in a longitudinal end of the fluid inlet sleeve opposite the tapered end or the stepped end of the fluid inlet sleeve, as discussed above). Additionally, an alignment mark **702** (e.g., a marking or indentation) formed in the body **202** of the earth-boring tool **200**. The alignment recess **700** and the alignment mark **702** may be utilized to properly orient the fluid inlet sleeve **207** within the nozzle port **231**. For example, during assembly of the earth-boring tool **200**, the alignment recess **700** and the alignment mark **702** may be aligned to ensure that the tapered end or the stepped end is properly oriented relative to an internal fluid plenum (e.g., internal fluid plenum **338**) (e.g., an interior surface of the body **202** of the earth-boring tool **200** defining the internal fluid plenum).

[0051] In some embodiments, the fluid inlet sleeve **207** may include a carbide material. For example, the fluid inlet sleeve **207** may include tungsten carbide. However, the fluid inlet sleeve **207** may be any suitable erosion-resistant material such as blends, diamond-impregnated materials, steel, hardfacing, etc.

[0052] Conventional manufacturing techniques, such as, but not limited to, machining or Electrical Discharge Machining, may be utilized to form the modified fluid inlet sleeves **207** of FIGS. **3A-7**. Different manufacturing techniques may result in variations in the geometry of the fluid entry plane, including but not limited to, sharp edges of the fluid inlet planes, or rounded edges of the fluid inlet planes.

[0053] FIGS. **8**A, **8**B, **8**C, **9**A, and **9**B show the results from a Computational Fluid Dynamic (CFD) analysis performed by the inventors to analyze the fluid flow velocity at locations inside the body of the earth-boring tool including fluid inlet sleeves according to one or more embodiments of the present disclosure. Throughout FIGS. **8A-9**B, point E is a point on the interior surface of the body of the earth-boring tool and represents an area or point in the internal fluid plenum where erosion has been previously observed. For purpose of FIGS. **8A-9**B, the fluid flow velocity is measured at point E in each scenario and is described below. In FIG. **8**A, a conventional fluid inlet sleeve having an end surface with a plane to which a longitudinal axis of the fluid inlet sleeve is normal is represented. The results show a fluid flow velocity of 12.1 m/s at point E. In FIG. **8**B, a fluid inlet sleeve including an end surface orientated about thirty degrees (30°) relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal is represented. The results show a fluid flow velocity of 9.7 m/s at point E. In FIG. **8**C, a fluid inlet sleeve including an end surface orientated about forty-five degrees (45°) relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal is represented. The results show a fluid flow velocity of 8.8 m/s at point E.

[0054] In FIG. **9**A, a fluid inlet sleeve such as the fluid inlet sleeve described above in relation to FIGS. **5**A-**6**B where the distance between the end surface and the step surface is about 0.375" is represented. The results show a fluid flow velocity of 9.0 m/s at point E. In FIG. **9**B, a fluid inlet sleeve such as the fluid inlet sleeve described above in relation to FIGS. **5**A-**6**B where the distance between the end surface and the step surface is about 0.500" is represented. The results show a fluid flow velocity of 8.4 m/s at point E. The fluid inlet sleeve of FIGS. **8**C and **9**B resulted in reduced velocity of the hydraulic fluid experienced by portions of the interior surface of the body. Furthermore, by reducing the velocities of the hydraulic fluid experienced by portions of the interior surface of the body, the fluid inlet sleeves of the present disclosure may reduce wear and increase the lifetime of the body. Increasing the lifetime of the body increases reliability of the earth-boring tool and reduces operating costs.

[0055] Referring again to FIG. **1**, a method of forming an earth-boring tool as shown in the embodiments described above is now discussed. The method of forming an earth-boring tool **200** includes providing a body **202** (such as, for example, a steel bit body). The nozzles **201** and/or nozzle assemblies **203** are disposed in nozzle ports **231** of the body **202** of the earth-boring tool **200**. A fluid inlet sleeve as depicted in FIGS. **2**B-**7** is disposed in nozzle ports **231** as part of the nozzles **201** or nozzle assemblies **203** of the body **202**. The fluid inlet sleeve may be secured in the nozzle ports using a threadless connection. For example, the threadless connection may be a sealant, including but not limited to epoxy or an O-ring, or may be a shape memory material. The alignment mark is formed in the body **202** prior to assembly of the fluid inlet sleeves. The alignment mark aids the assembly process by providing a guide as to the correct orientation for installing the fluid inlet sleeve to reduce the amount of fluid velocity experienced on inner walls of the body. Orientating the fluid inlet sleeve such that the alignment recess aligns with the alignment mark of the tool body.

[0056] Additional non-limiting example embodiments of the disclosure are described below.

[0057] Embodiment 1: An earth-boring tool comprising a tool body. The tool body comprising at least one nozzle port extending from an external surface to an internal fluid plenum. The at least one nozzle port comprising at least one fluid inlet sleeve disposed within the at least one nozzle port of the tool body. The at least one fluid inlet sleeve comprising a hollow cylinder having a longitudinal end oriented at least partially within the internal fluid plenum of the tool body, the longitudinal end comprising at least one surface oriented at an angle within the range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

[0058] Embodiment 2: The earth-boring tool of embodiment 1, wherein the longitudinal end of the at least one fluid inlet sleeve comprises an angled end defining the at least one surface, the at least one surface comprising end surface of the fluid inlet sleeve that is oblique to the longitudinal axis of the fluid inlet sleeve.

[0059] Embodiment 3: The earth-boring tool of embodiment 1 or embodiment 2, wherein the end surface of the fluid inlet sleeve lies within a fluid entry plane of the fluid inlet sleeve.

[0060] Embodiment 4: The earth-boring tool of any of embodiments 1 through 3, wherein the angle is within the range of about 30 degrees to about 60 degrees.

[0061] Embodiment 5: The earth-boring tool of any of embodiments 1 through 4, wherein the angle is about 45 degrees.

[0062] Embodiment 6: The earth-boring tool of any of embodiments 1 through 5, wherein the longitudinal end of the at least one fluid inlet sleeve comprises a stepped end. The stepped end comprises an end surface, a step surface oriented parallel to the end surface, and the at least one surface comprising a riser surface and extending from the end surface to the step surface in a direction at least substantially perpendicular to the end surface of the step surface.

[0063] Embodiment 7: The earth-boring tool of any of embodiments 1 through 6 wherein a distance between the end surface and the step surface, in a direction parallel to the longitudinal axis of the at least one fluid inlet sleeve, is greater than 0 inch and less than 1.000 inch.

[0064] Embodiment 8: The earth-boring tool of any of embodiments 1 through 7, wherein the distance is about 0.500 inch.

[0065] Embodiment 9: The earth-boring tool of any of embodiments 1 through 8, further comprising a nozzle disposed adjacent to the at least one fluid inlet sleeve within the nozzle port.

[0066] Embodiment 10: The earth-boring tool of any of embodiments 1 through 9, wherein the tool body further comprises an alignment mark on an external surface of the tool body and wherein the at least one fluid inlet sleeve comprises an alignment recess formed in another longitudinal end of the at least one fluid inlet sleeve opposite the longitudinal end.

[0067] Embodiment 11: A fluid inlet sleeve comprising a hollow cylinder having a longitudinal end configured to be at least partially disposed within an internal fluid plenum of an earth-boring tool, the longitudinal end comprising at least one surface oriented at an angle within a range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

[0068] Embodiment 12: The fluid inlet sleeve of embodiment 11, wherein the longitudinal end of the fluid inlet sleeve comprises an angled end defining the at least one surface, the at least one surface comprising end surface of the fluid inlet sleeve that is oblique to the longitudinal axis of the fluid inlet sleeve.

[0069] Embodiment 13: The fluid inlet sleeve of embodiment 11 or embodiment 12, wherein the end surface of the fluid inlet sleeve lies within a fluid entry plane of the fluid inlet sleeve.

[0070] Embodiment 14: The fluid inlet sleeve of any of embodiments 11 through 13, wherein the angle is within the range of about 30 degrees to about 60 degrees.

[0071] Embodiment 15: The fluid inlet sleeve of any of embodiments 11 through 14, wherein the angle is about 45 degrees.

[0072] Embodiment 16: The fluid inlet sleeve of any of embodiments 11 through 15, wherein the longitudinal end comprises a stepped end comprising: an end surface, a step surface oriented parallel to the end surface, and the at least one surface comprising a riser surface and extending from the end surface to the step surface in a direction at least substantially perpendicular to the end surface of the step surface.

[0073] Embodiment 17: The fluid inlet sleeve of embodiment 16, wherein a distance between the end surface and the step surface, in a direction parallel to the longitudinal axis of the fluid inlet sleeve, is greater than 0 inch and less than 1.000 inch.

[0074] Embodiment 18: The fluid inlet sleeve of embodiment 16 or embodiment 17, wherein the distance is about 0.500 inch.

[0075] Embodiment 19: A method of forming an earth-boring tool, the method comprising: disposing a nozzle within in a nozzle port of a body of the earth-boring tool, the nozzle port extending from an external surface of the body and an internal fluid plenum within the body; and disposing at least one fluid inlet sleeve within the nozzle port of the body adjacent to the nozzle such that a longitudinal end of the at least one fluid inlet sleeve is oriented at least partially within the internal fluid plenum, the longitudinal end comprising at least one surface oriented at an angle within a range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

[0076] Embodiment 20: The method of embodiment 19, wherein disposing at least one fluid inlet sleeve comprises aligning the at least one fluid inlet sleeve within the nozzle port by aligning an alignment recess formed in the at least one fluid inlet sleeve with an alignment mark formed in the external surface of the body of the earth-boring tool.

[0077] While the disclosed device structures and methods are susceptible to various modifications and alternative forms in implementation thereof, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the present disclosure is not limited to the particular forms disclosed. Rather, the present invention encompasses all modifications, combinations, equivalents, variations, and alternatives falling within the scope of the present disclosure as defined by the following appended claims and their legal equivalents.

What is claimed is:

1. An earth-boring tool, comprising:

a tool body comprising at least one nozzle port extending from an external surface to an internal fluid plenum; and

at least one fluid inlet sleeve disposed within the at least one nozzle port of the tool body, the at least one fluid inlet sleeve comprising a hollow cylinder having a longitudinal end oriented at least partially within the internal fluid plenum of the tool body, the longitudinal end comprising at least one surface oriented at an angle within a range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

2. The earth-boring tool of claim **1**, wherein the longitudinal end of the at least one fluid inlet sleeve comprises an angled end defining the at least one surface, the at least one surface comprising end surface of the fluid inlet sleeve that is oblique to the longitudinal axis of the fluid inlet sleeve.

3. The earth-boring tool of claim **2**, wherein the end surface of the fluid inlet sleeve lies within a fluid entry plane of the fluid inlet sleeve.

4. The earth-boring tool of claim **2**, wherein the angle is within the range of about 30 degrees to about 60 degrees.

5. The earth-boring tool of claim **1**, wherein the angle is about 45 degrees.

6. The earth-boring tool of claim **1**, wherein the longitudinal end of the at least one fluid inlet sleeve comprises a stepped end comprising:

an end surface;

a step surface oriented parallel to the end surface; and

the at least one surface comprising a riser surface and extending from the end surface to the step surface in a direction at least substantially perpendicular to the end surface of the step surface.

7. The earth-boring tool of claim **6**, wherein a distance between the end surface and the step surface, in a direction parallel to the longitudinal axis of the at least one fluid inlet sleeve, is greater than 0 inch and less than 1.000 inch.

8. The earth-boring tool of claim **7**, wherein the distance is about 0.500 inch.

9. The earth-boring tool of claim **1**, further comprising a nozzle disposed adjacent to the at least one fluid inlet sleeve within the nozzle port.

10. The earth-boring tool of claim **1**, wherein the tool body further comprises an alignment mark on an external surface of the tool body and wherein the at least one fluid inlet sleeve comprises an alignment recess formed in another longitudinal end of the at least one fluid inlet sleeve opposite the longitudinal end.

11. A fluid inlet sleeve comprising a hollow cylinder having a longitudinal end configured to be at least partially disposed within an internal fluid plenum of an earth-boring tool, the longitudinal end comprising at least one surface oriented at an angle within the range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

12. The fluid inlet sleeve of claim **11**, wherein the longitudinal end of the fluid inlet sleeve comprises an angled end defining the at least one surface, the at least one surface comprising end surface of the fluid inlet sleeve that is oblique to the longitudinal axis of the fluid inlet sleeve.

13. The fluid inlet sleeve of claim **12**, wherein the end surface of the fluid inlet sleeve lies within a fluid entry plane of the fluid inlet sleeve.

14. The fluid inlet sleeve of claim **12**, wherein the angle is within the range of about 30 degrees to about 60 degrees.

15. The fluid inlet sleeve of claim **11**, wherein the angle is about 45 degrees.

16. The fluid inlet sleeve of claim **11**, wherein the longitudinal end comprises a stepped end comprising:

an end surface;

a step surface oriented parallel to the end surface; and

the at least one surface comprising a riser surface and extending from the end surface to the step surface in a direction at least substantially perpendicular to the end surface of the step surface.

17. The fluid inlet sleeve of claim **16**, wherein a distance between the end surface and the step surface, in a direction parallel to the longitudinal axis of the fluid inlet sleeve, is greater than 0 inch and less than 1.000 inch.

18. The fluid inlet sleeve of claim **16**, wherein the distance is about 0.500 inch.

19. A method of forming an earth-boring tool, the method comprising:

disposing a nozzle within in a nozzle port of a body of the earth-boring tool, the nozzle port extending from an external surface of the body and an internal fluid plenum within the body; and

disposing at least one fluid inlet sleeve within the nozzle port of the body adjacent to the nozzle such that a longitudinal end of the at least one fluid inlet sleeve is oriented at least partially within the internal fluid plenum, the longitudinal end comprising at least one surface oriented at an angle within a range from greater than 0 degrees to about 90 degrees relative to a plane to which a longitudinal axis of the fluid inlet sleeve is normal.

20. The method of claim **11**, wherein disposing at least one fluid inlet sleeve comprises aligning the at least one fluid inlet sleeve within the nozzle port by aligning an alignment recess formed in the at least one fluid inlet sleeve with an alignment mark formed in the external surface of the body of the earth-boring tool.

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