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(54) DIRECTIONAL BORING SYSTEMS AND METHODS

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| ***E21B 10/26*** | (2006.01) |
| ***E21B 21/015*** | (2006.01) |

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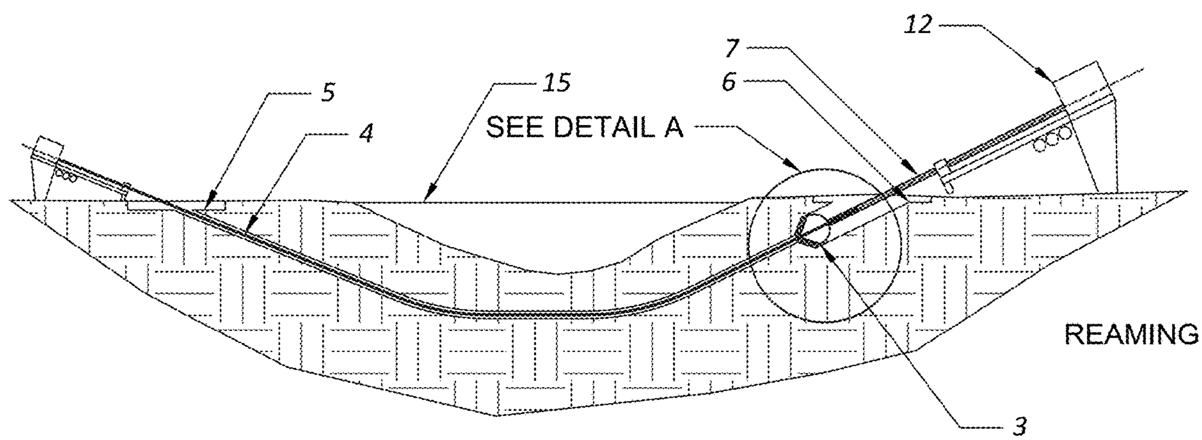
(57) **ABSTRACT**

Directional drilling technologies and methodologies involve/utilize a reamer embodying a pressure vessel configured for directing flows of fresh mud through the reamer/pressure vessel and toward an entry side of a bore hole being drilled by the reamer, facilitating single ream pass directional drilling of bore holes, and preventing the reamer from deviating from the path of the pilot hole.



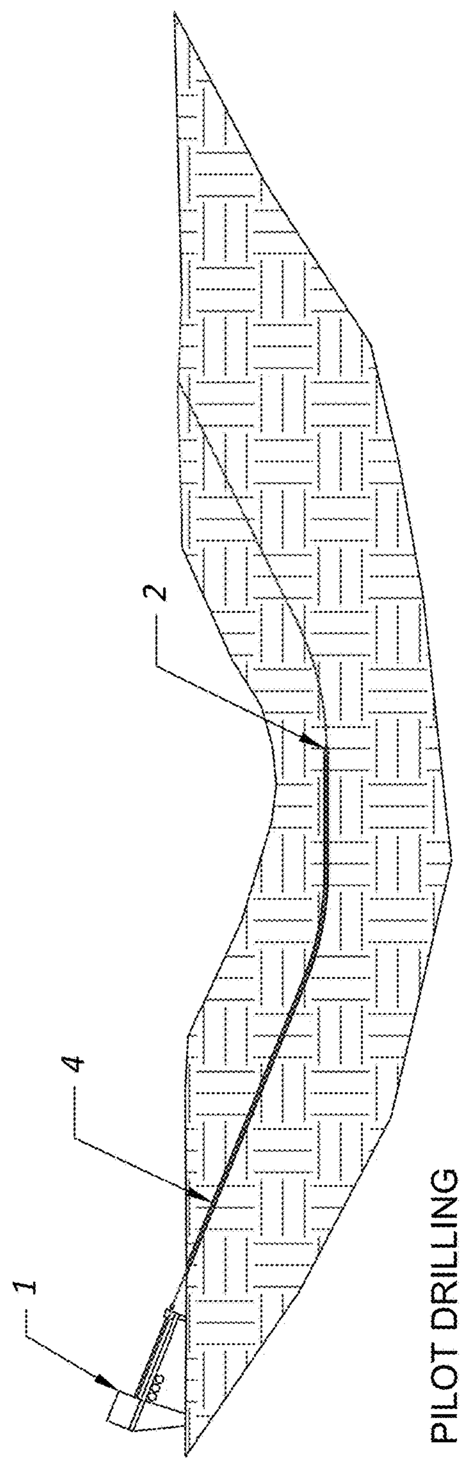



FIG. 1A

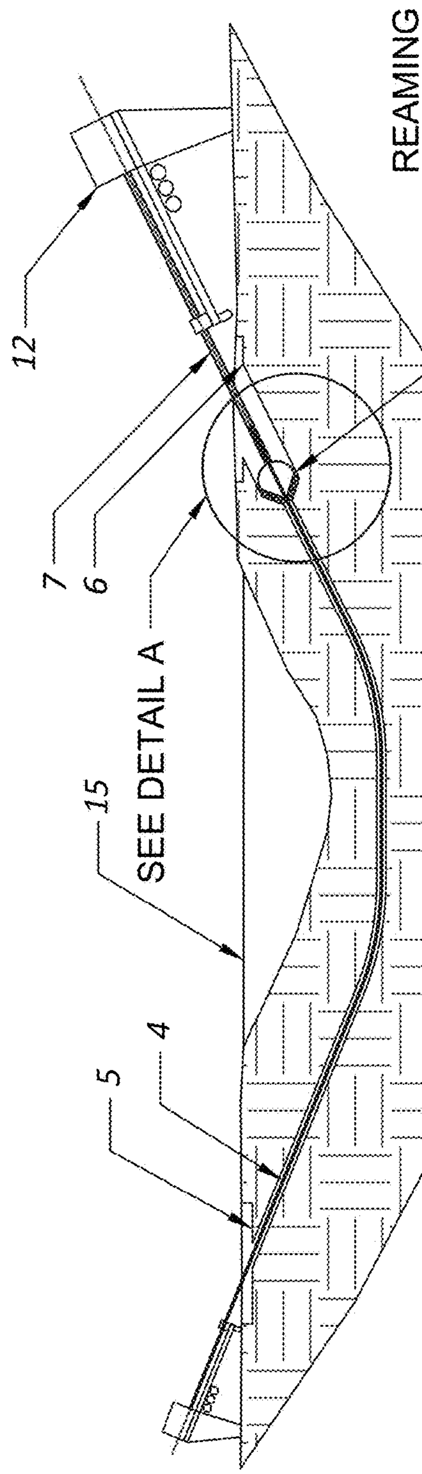



FIG. 1B

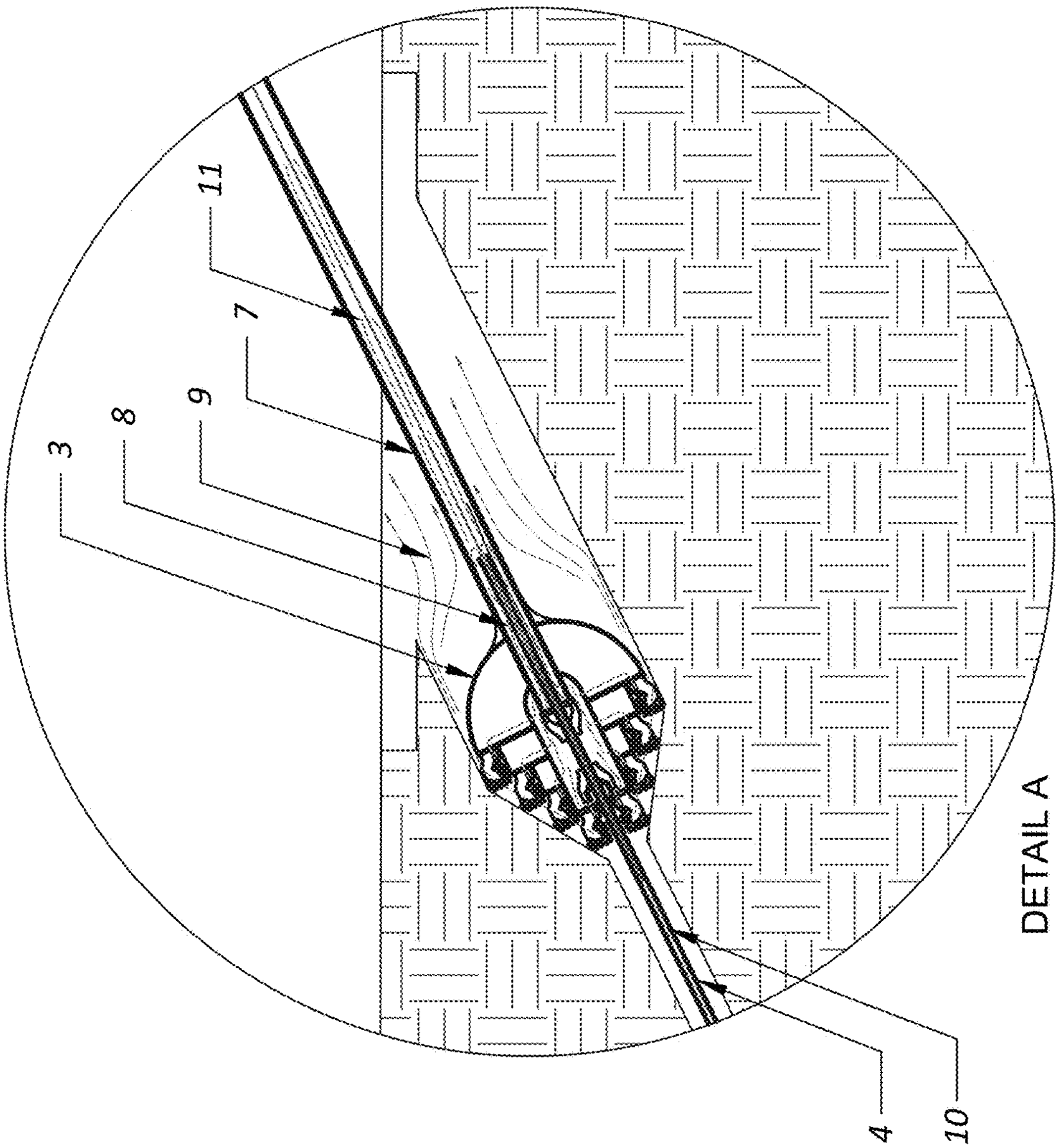



FIG. 2

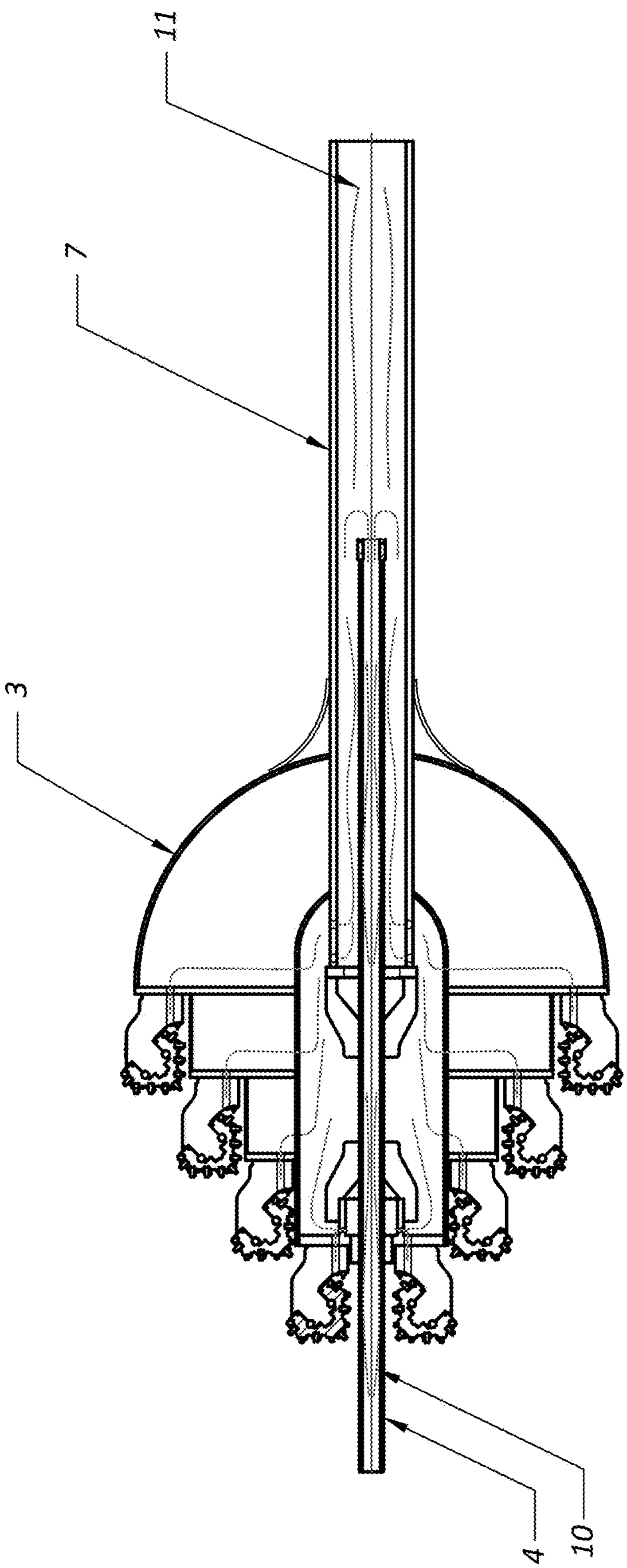



FIG. 3

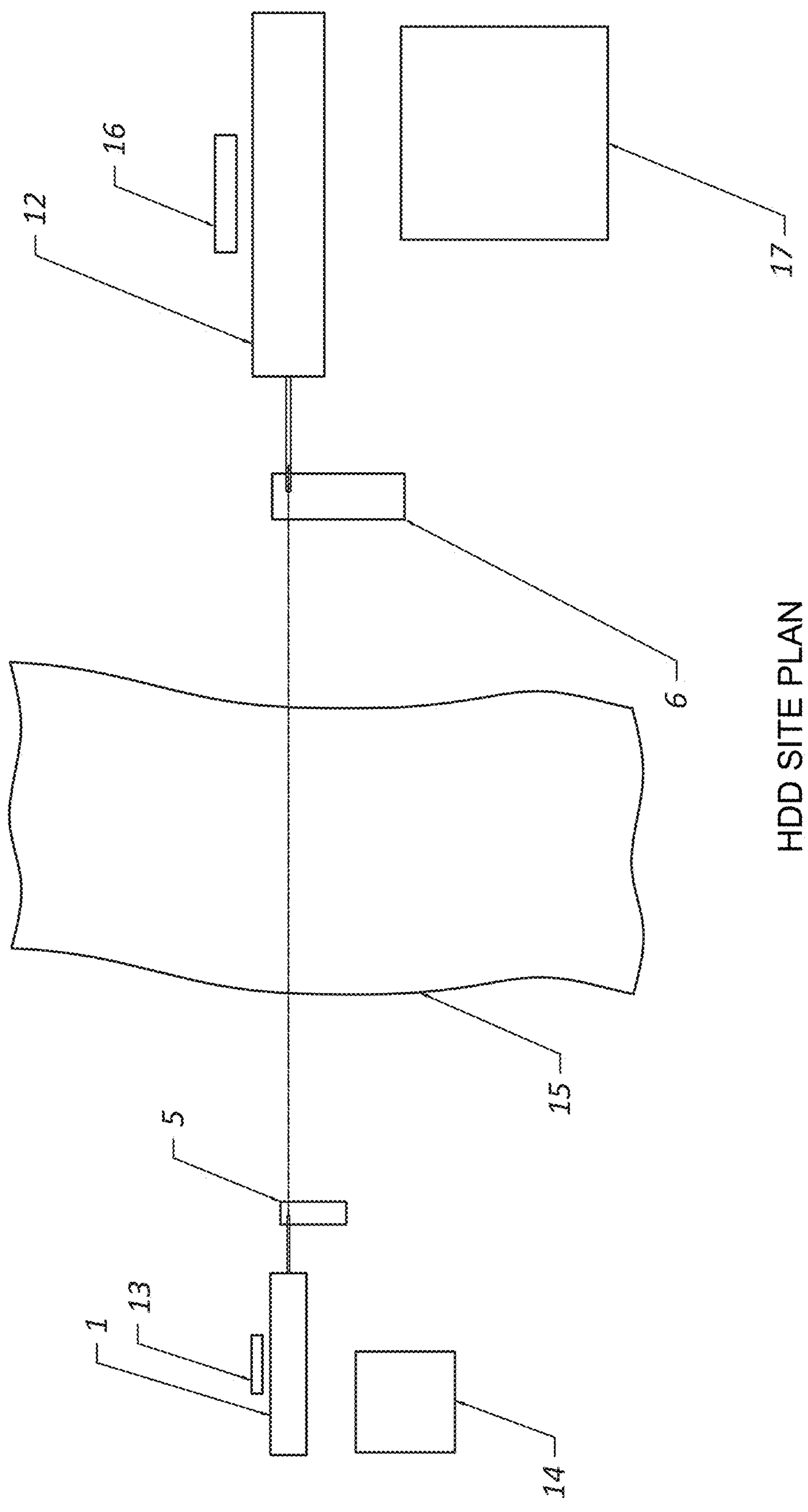



FIG. 4

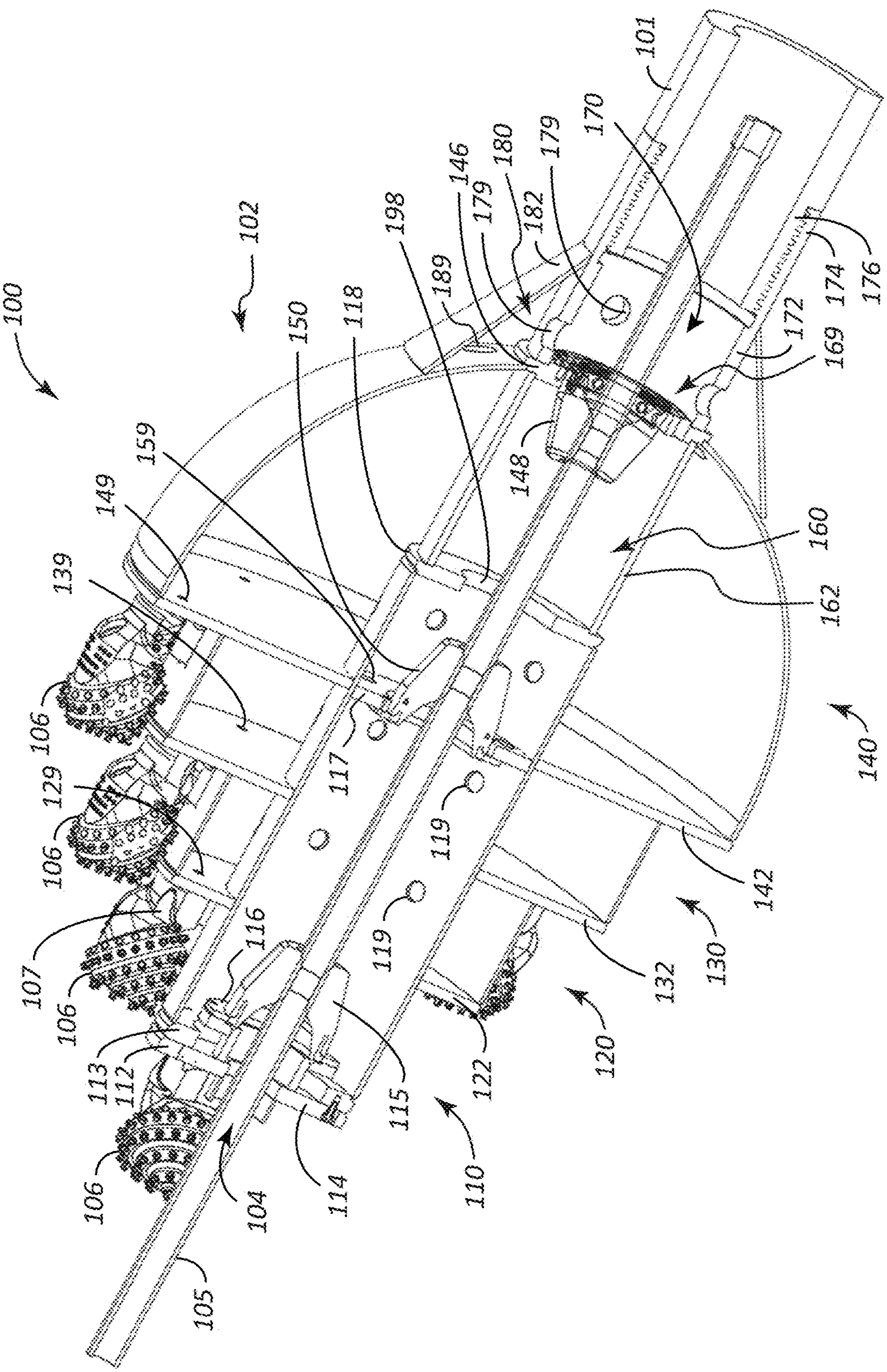

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FIG. 5

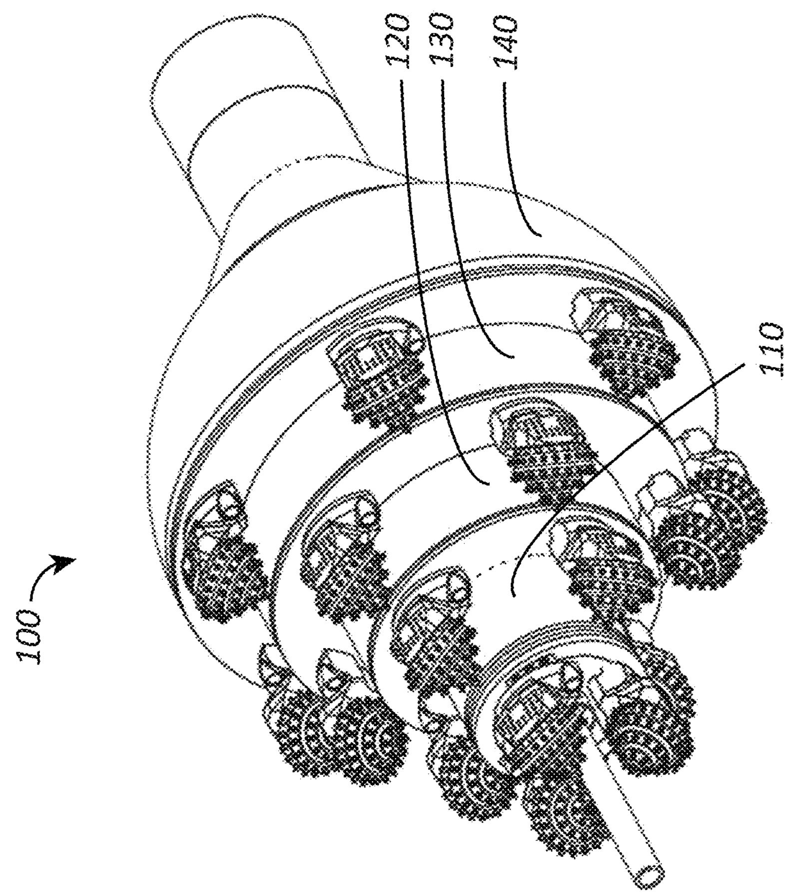



FIG. 6B

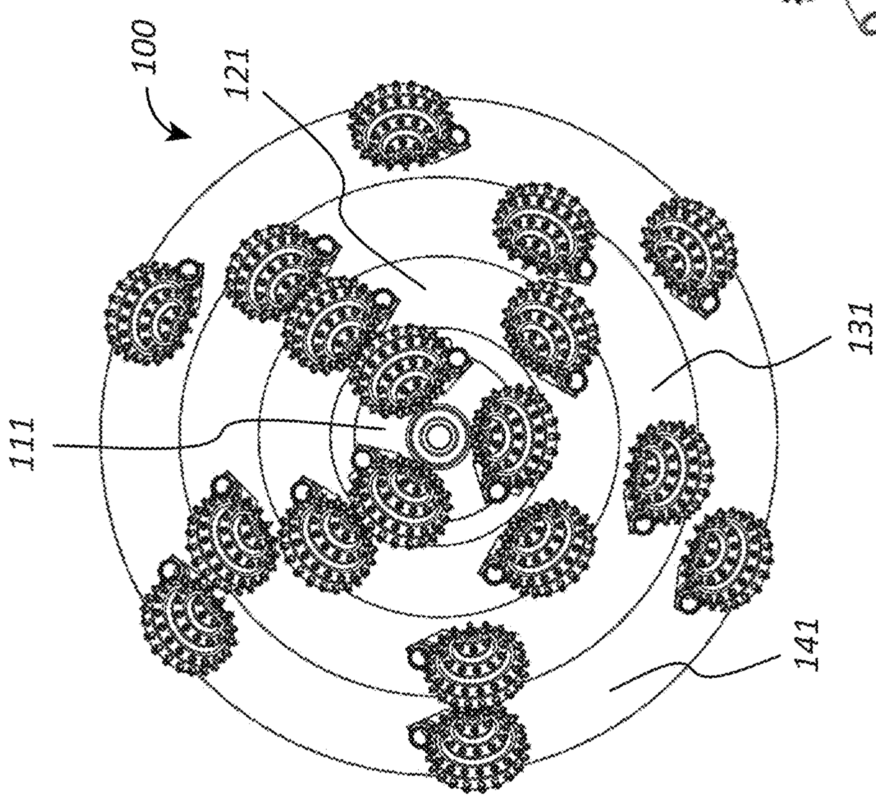



FIG. 6A


FIG. 7B

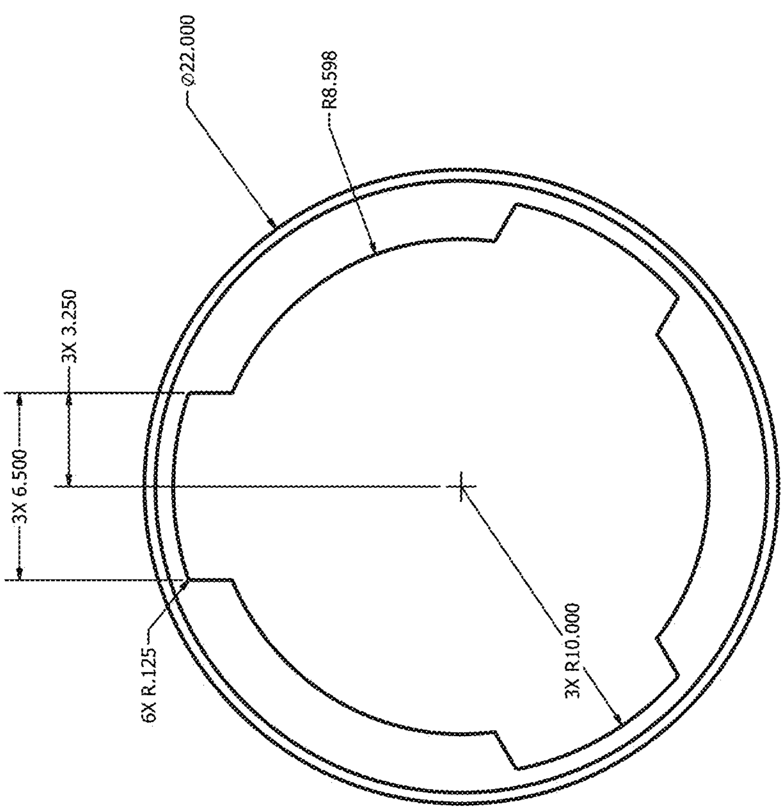



FIG. 7A

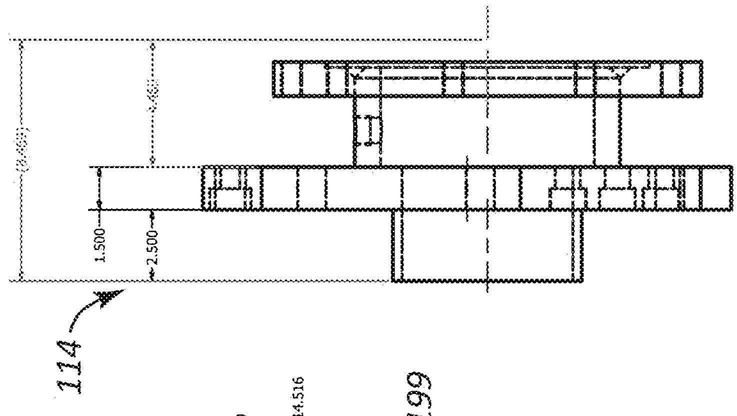



FIG. 8C

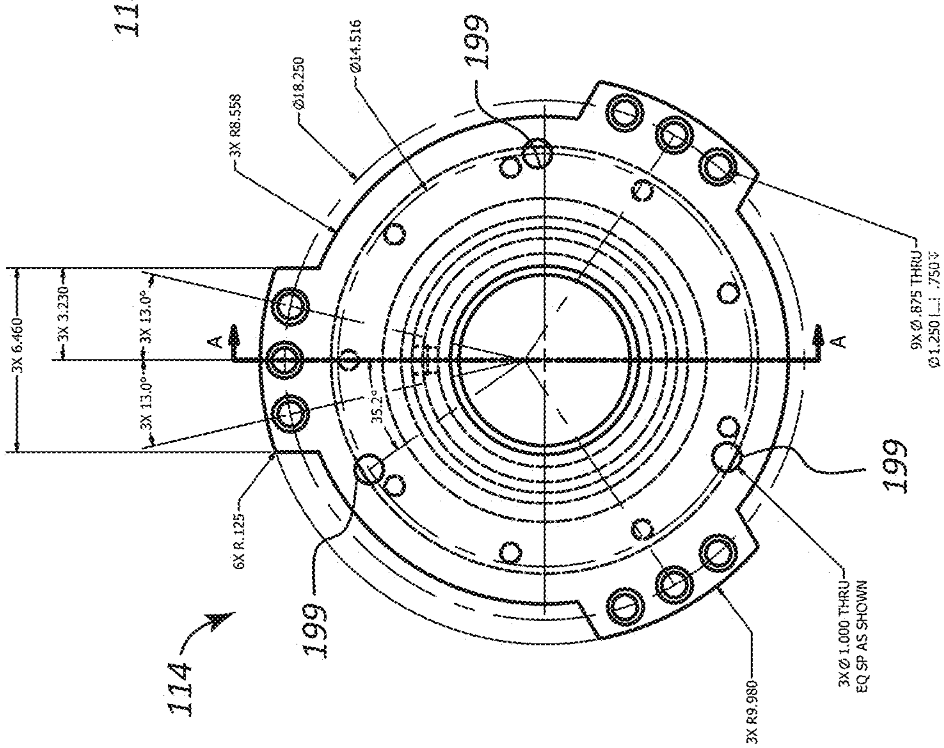
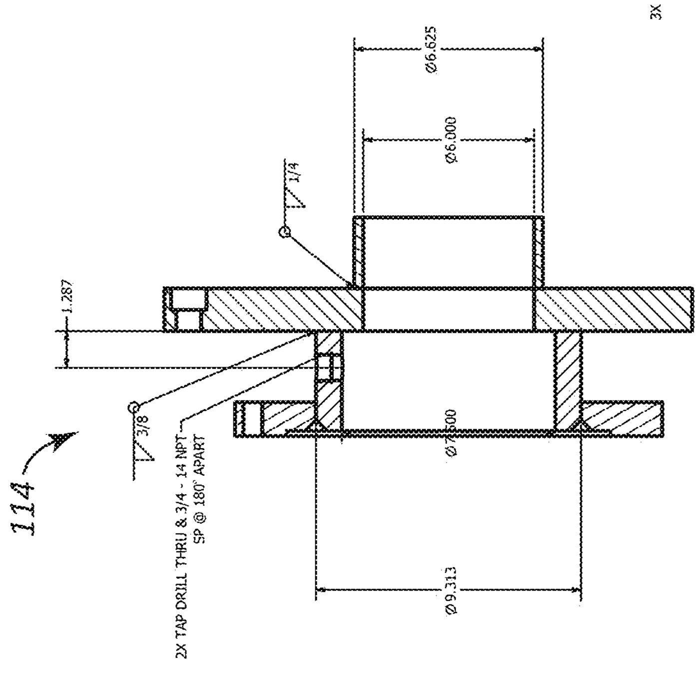
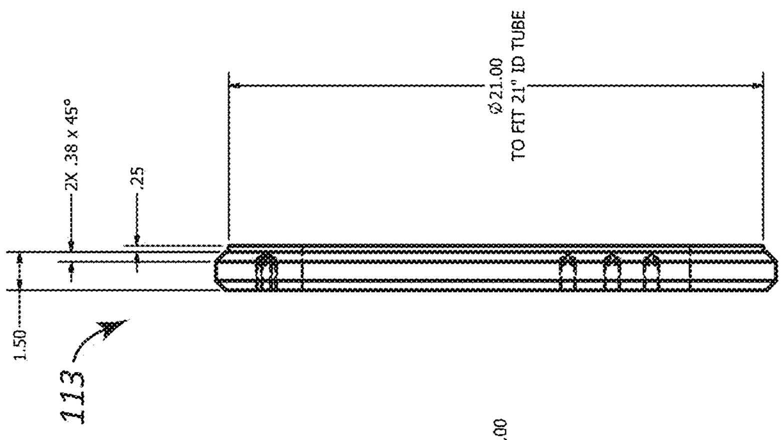



FIG. 8A




SECTION A-A
SCALE 1 / 3

FIG. 8B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1.50
2X .38 x 45°
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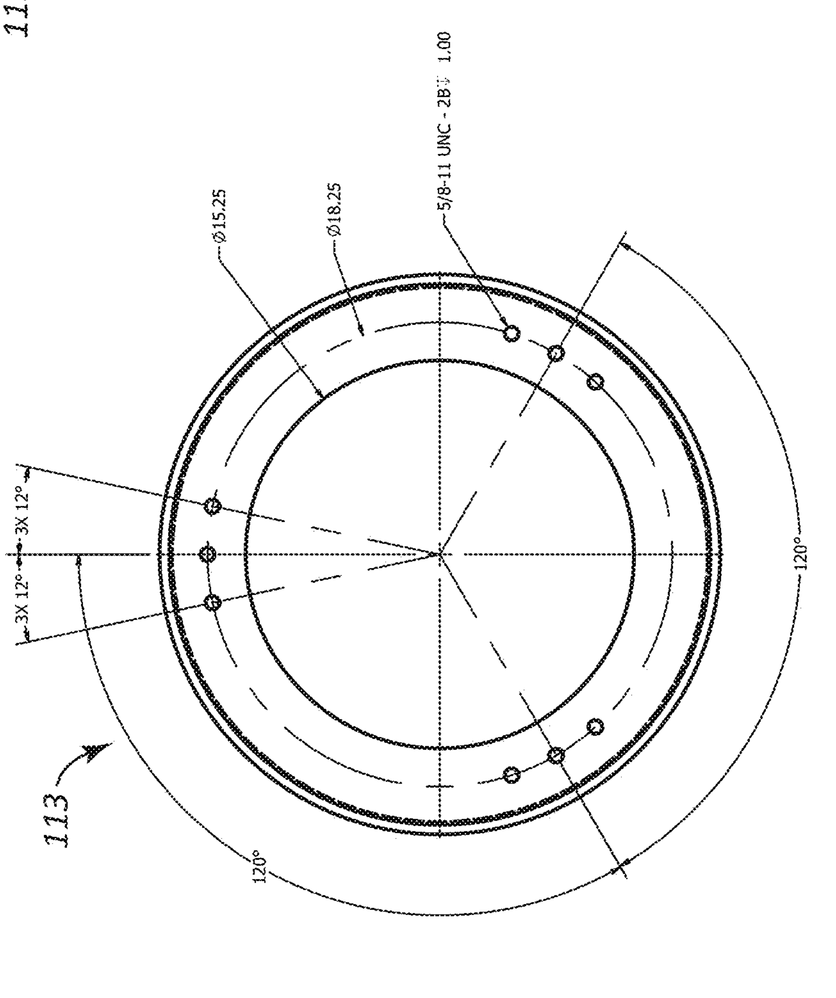
∅21.00
TO FIT 21" ID TUBE

FIG. 9B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5/8-11 UNC - 2B ↧ 1.00
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3X 12°
120°
120°

FIG. 9A

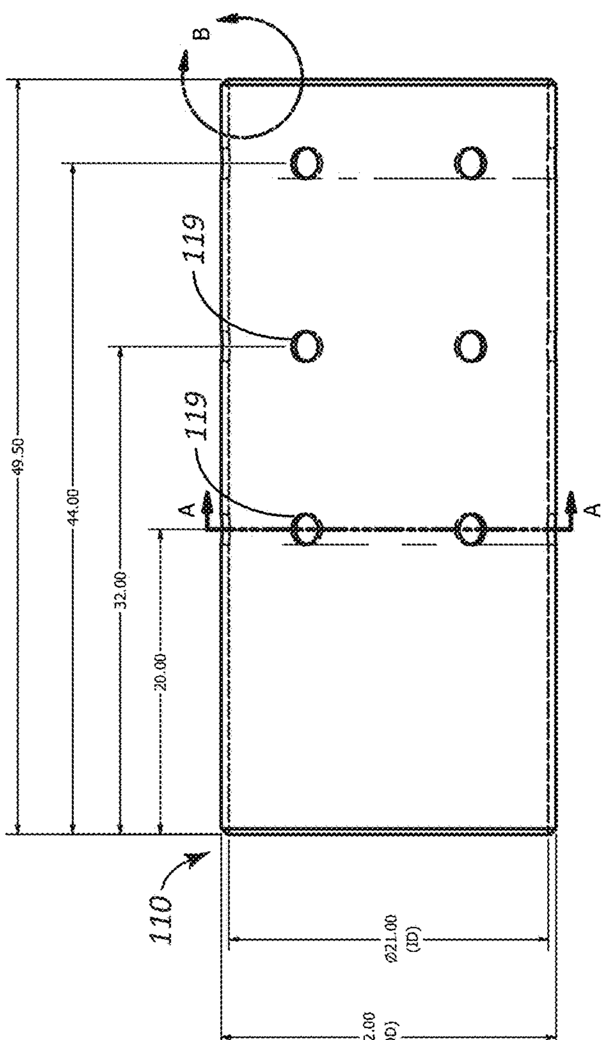



FIG. 10A

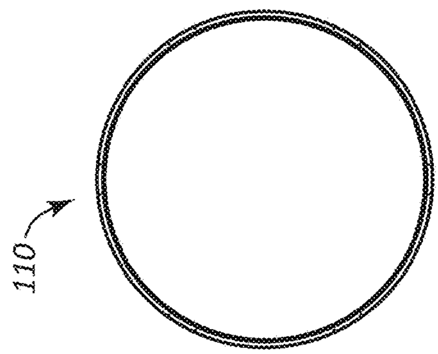



FIG. 10B

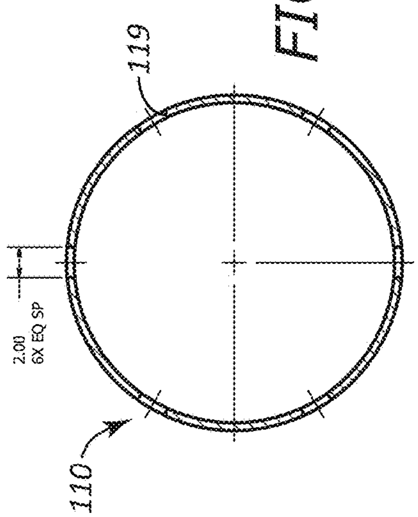



FIG. 10C

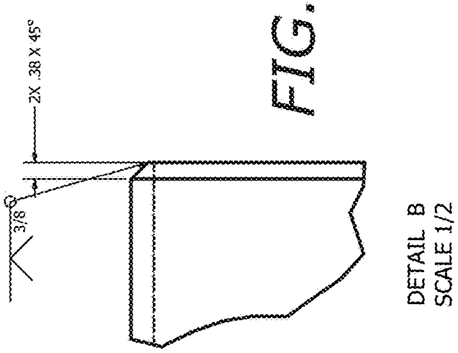



FIG. 10D

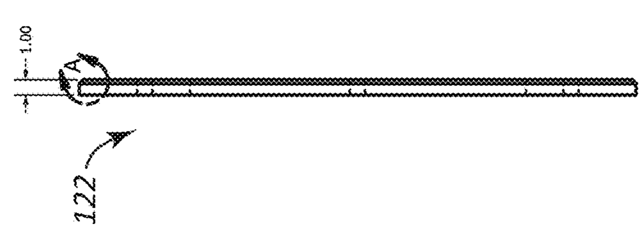



FIG. 11A

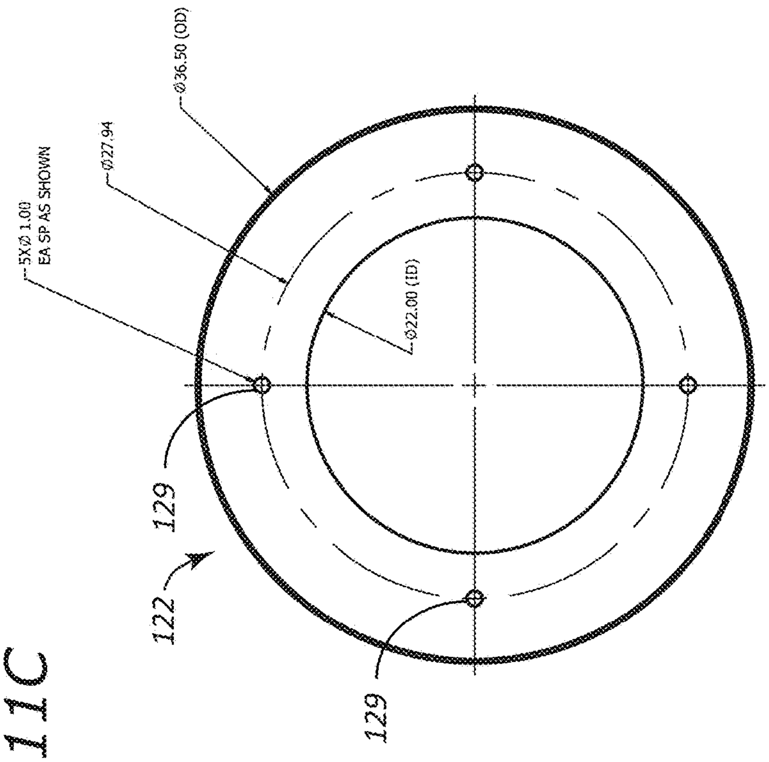



FIG. 11B

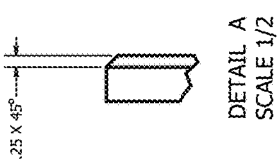



FIG. 11C

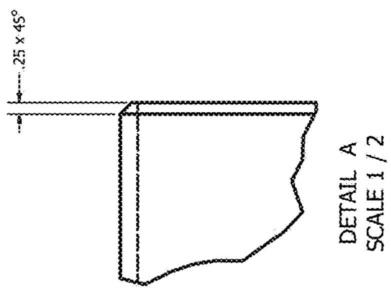



FIG. 12C

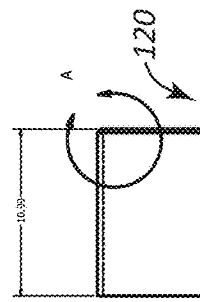



FIG. 12B

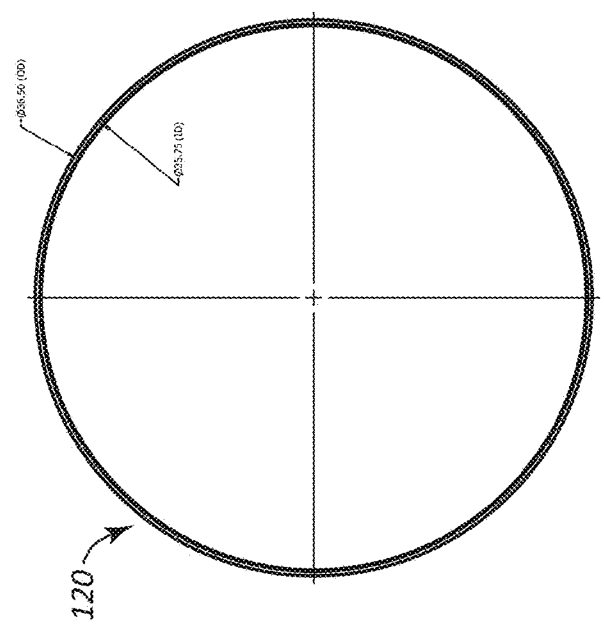



FIG. 12A

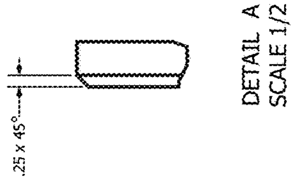



FIG. 13C

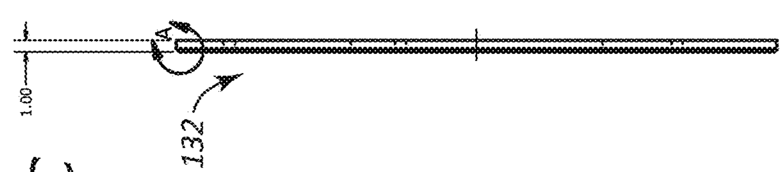



FIG. 13B

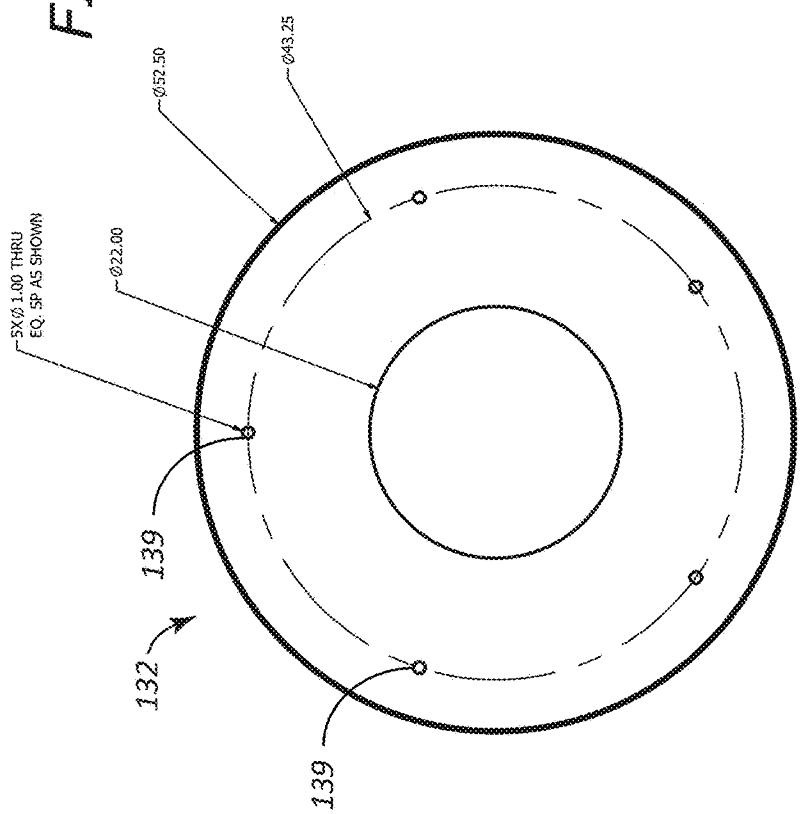



FIG. 13A

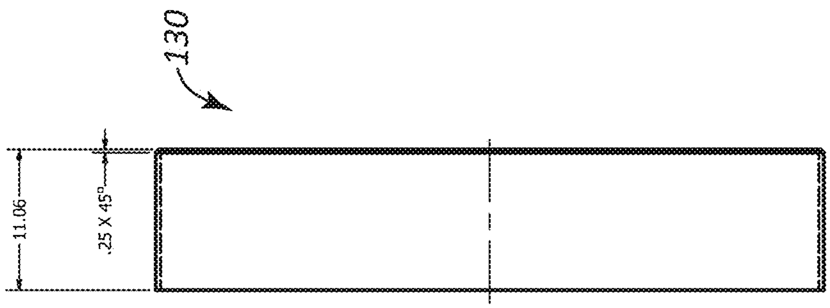



FIG. 14B

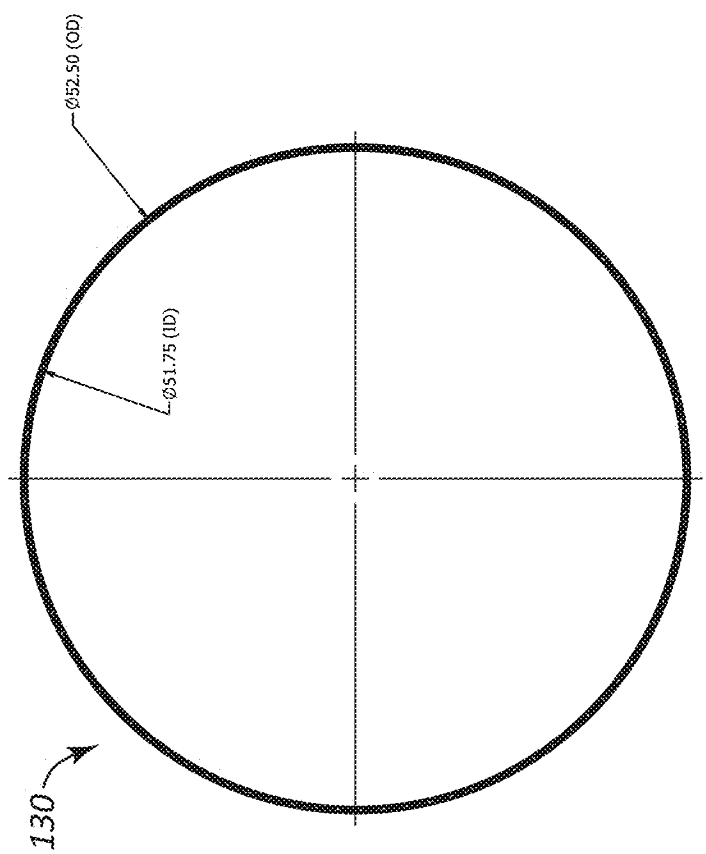
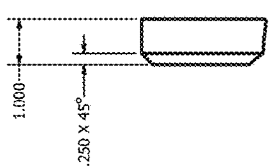



FIG. 14A



DETAIL A
SCALE 1/2

FIG. 15C

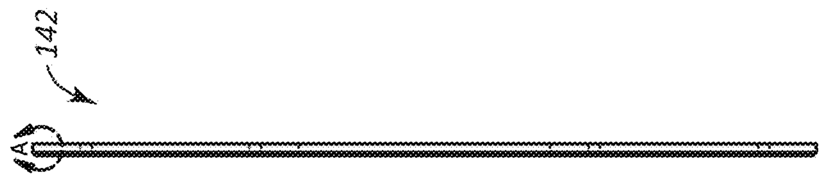


FIG. 15B

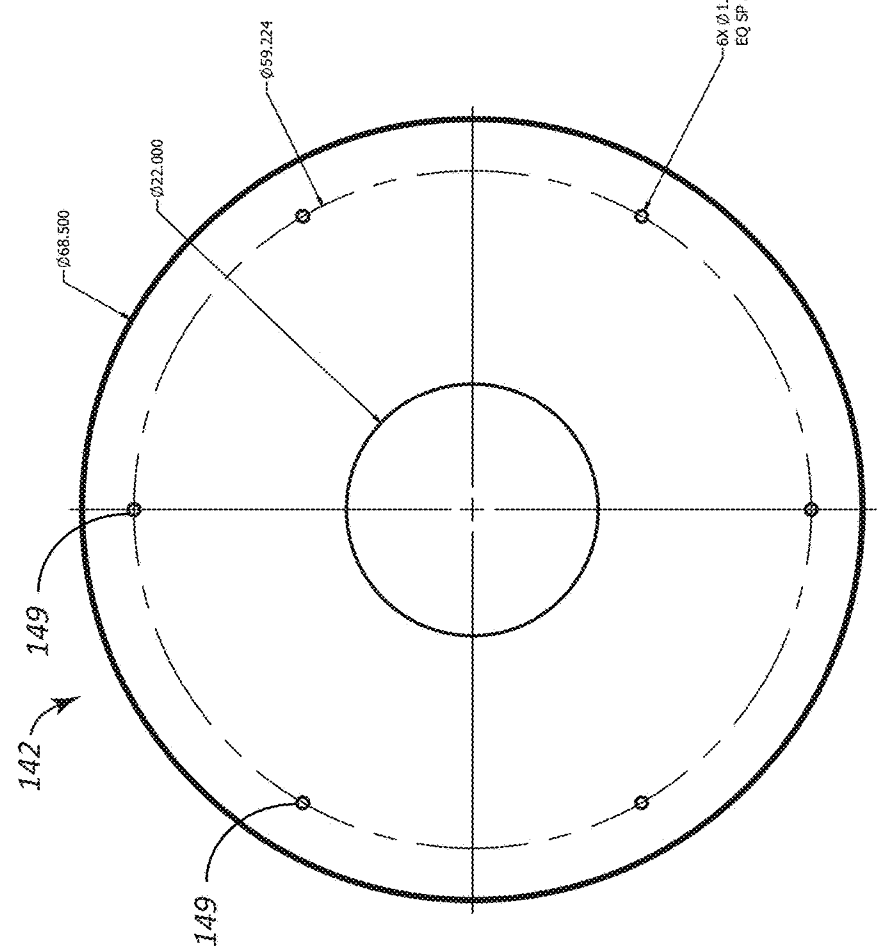


FIG. 15A

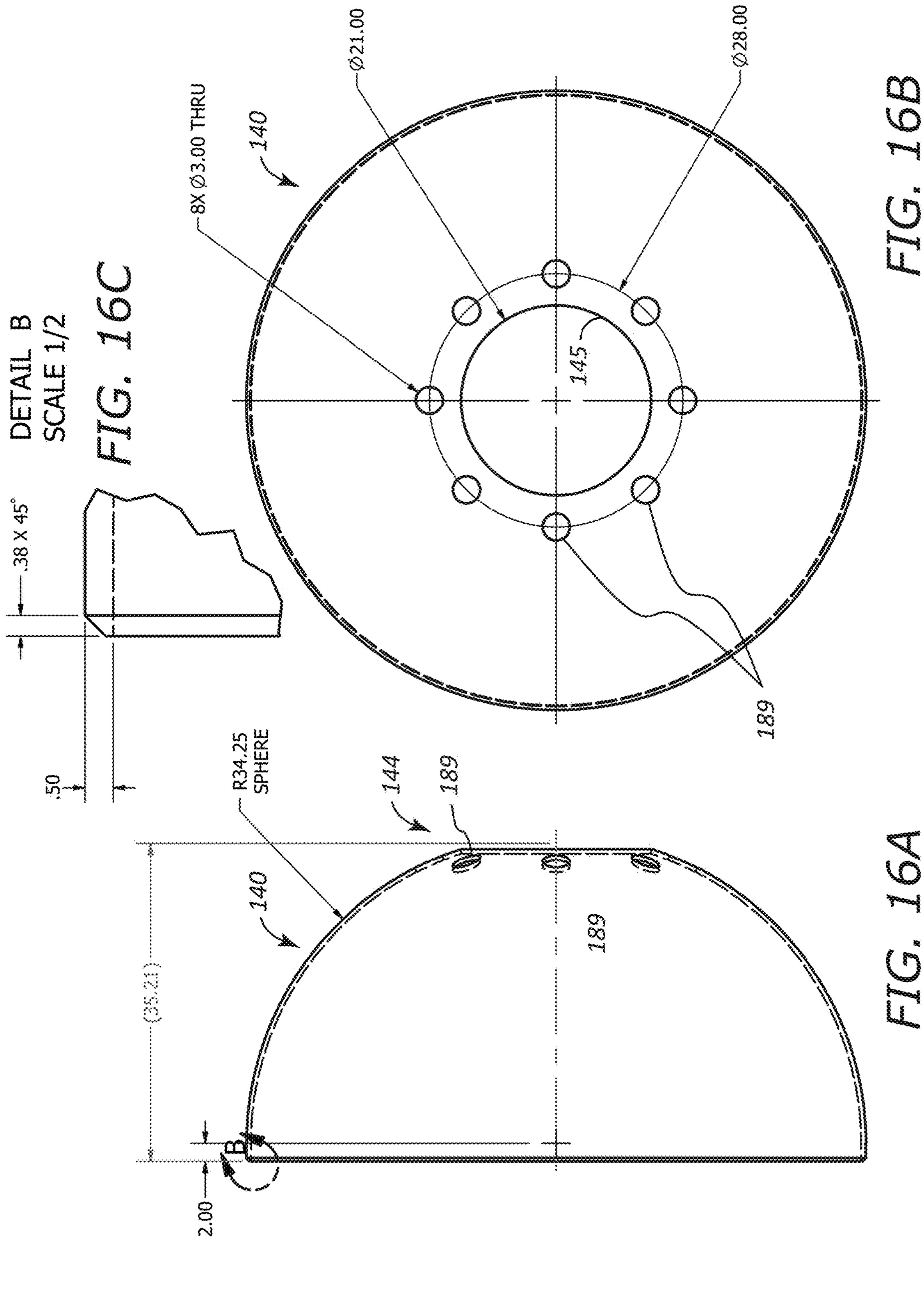



FIG. 16A

FIG. 16B

FIG. 16C

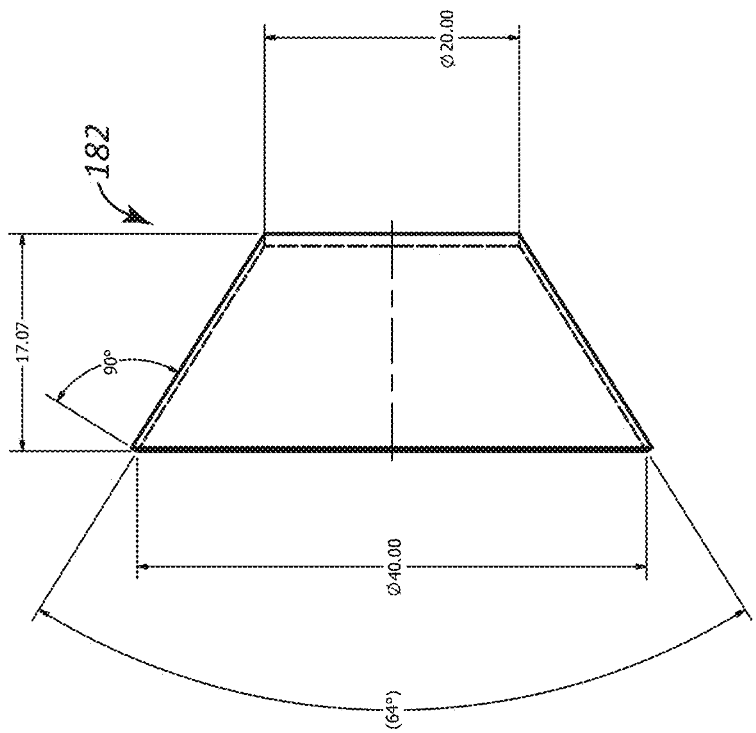



FIG. 17B

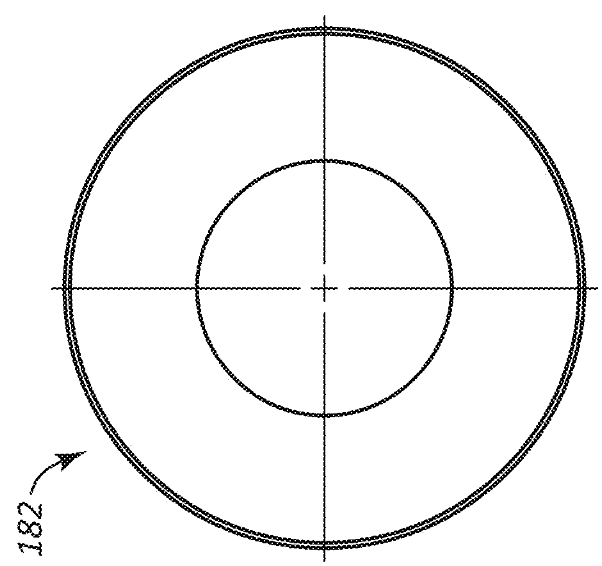



FIG. 17A

1800

1802 — *Advancing a pilot pipe from an exit side to an entry side in relation to respective ends of a bore hole to be drilled, and then securing the pilot pipe at the entrance side (and/or at the exit side/pilot drill)*

1804 — *Utilizing a drill pipe and a reamer to drill the bore hole (in a single pass) advancing along (a drill path defined by) the pilot drill pipe (the reamer and drill pipe riding over the pilot pipe) while directing a flow of fresh mud through the reamer to exit via cutter jets of the reamer and toward the entry side of the bore hole being drilled*

1806 — *Once the reamer reaches the exit side, removing the reamer from the drill pipe*

1808 — *Performing a swab pass to clean the bore hole while leaving the pilot pipe in the bore hole*

1810 — *Using the pilot pipe to pull a product pipe in the bore hole, or replacing the pilot pipe with the larger drill pipe and using the drill pipe to pull the product pipe through the bore hole to the entry side*

1812 — *(While performing the step of utilizing a drill pipe and a reamer to drill the bore hole) collecting mudflow, that is spoils mud, exiting from the bore hole (being drilled) at the entry side; and cleaning solids from the spoils mud to provide (recycled) fresh mud and adjusting properties of the fresh mud (and storing the fresh mud in holding tanks) (wherein the step of adjusting properties of the fresh mud is performed based on a priori knowledge of geological characteristics at the present location (and/or soon/next to be drilled locations) in respect to the reamer (rather than determined on-the-fly*

(A)

FIG. 18A

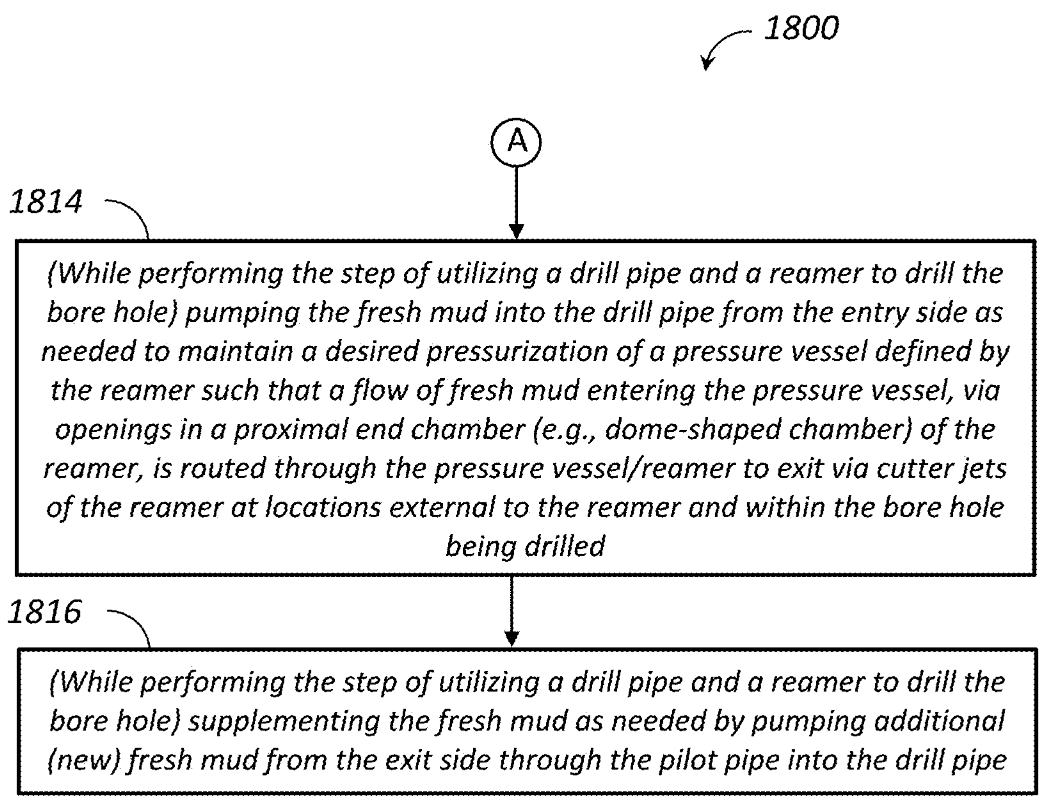

1800
A
1814
(While performing the step of utilizing a drill pipe and a reamer to drill the bore hole) pumping the fresh mud into the drill pipe from the entry side as needed to maintain a desired pressurization of a pressure vessel defined by the reamer such that a flow of fresh mud entering the pressure vessel, via openings in a proximal end chamber (e.g., dome-shaped chamber) of the reamer, is routed through the pressure vessel/reamer to exit via cutter jets of the reamer at locations external to the reamer and within the bore hole being drilled
1816
(While performing the step of utilizing a drill pipe and a reamer to drill the bore hole) supplementing the fresh mud as needed by pumping additional (new) fresh mud from the exit side through the pilot pipe into the drill pipe

FIG. 18B

# DIRECTIONAL BORING SYSTEMS AND METHODS

## TECHNICAL FIELD

**[0001]** Various embodiments described herein generally relate to trenchless construction technologies and techniques and, in particular, to directional drilling technologies and methodologies involving/utilizing a reamer embodying a pressure vessel configured for directing flows of fresh mud through the reamer/pressure vessel and toward an entry side of a bore hole being drilled by the reamer and facilitating single pass ream directional drilling of bore holes after a pilot hole is drilled.

## INTRODUCTION

**[0002]** Horizontal Directional Drilling (HDD) is a form of trenchless installation of utilities. HDD allows the installation of pipelines and other utilities in environmentally sensitive areas as well as avoiding other infrastructure by going under all obstacles.

**[0003]** HDD begins with a bore plan identifying the entry and exit of the bore as well as the path to be followed between them. The Drill rig begins the pilot hole (small diameter hole drilled along the bore path with a steerable drill head) from the Entry side of the bore and continues to the Exit side of the bore. In some instances a contractor will set a drill rig on both entry and exit sides and drill in both directions meeting along the bore path for what is referred to as an intersect. The drill on entry side will then follow the pilot hole drilled by the exit side drill rig to the exit side. This will allow the drill on exit side to handle the Tail String (drill pipe added behind the reamer as the reamer advances).

**[0004]** Once the pilot hole has been drilled, the reaming passes begin. This involves pulling drilling tools that are larger than the pilot hole to enlarge the bore path until it is large enough to install the utility. Depending on the size of the utility this is done in several steps or ream passes to get to the desired diameter. As an example for a finished diameter of 42 inches it would typically require after drilling the pilot hole to make ream passes of 16 inches, 24 inches, 36 inches and then 42 inches. While making these ream passes, drilling mud problematically may be exiting the bore on both the Entry and Exit sides of the project.

**[0005]** Conventionally, when pull reaming the reamer is attached to the drill pipe on the Exit side and pulled toward the rig (Entry side). As the reamer is pulled drill pipe is added as a tail string to keep pipe throughout the length of the bore. As these ream passes are made the returns will normally alternate between entry and exit side pits and may be dealt with in different ways depending on available work space, equipment, and access to exit side. Some companies will put a cleaning system and mud pump on both sides so they can pump both ways and others may truck or pump any returns (drilling returns) from exit side back to the entry side.

**[0006]** It would be helpful to be able to provide directional drilling technologies and methodologies that eliminate the inefficiencies and logistical (and other) issues resulting from creating a utility or product pipe hole utilizing multiple ream passes.

**[0007]** It would be helpful to be able to provide directional drilling technologies and methodologies that eliminate the need in some conventional HDD drilling projects for use and processing of tail string.

**[0008]** It would be helpful to be able to provide directional drilling technologies and methodologies that eliminate or substantially eliminate the flow of drilling fluid returns to the Exit side.

**[0009]** It would be helpful to be able to provide directional drilling technologies and methodologies that facilitate directional drilling of bore holes in a single pass of a reamer.

**[0010]** It would be helpful to be able to provide directional drilling technologies and methodologies that prevent the reamer from deviating from the path of the pilot hole.

**[0011]** It would be helpful to be able to provide directional drilling technologies and methodologies that prevent dog legs in the bore (which are undesirable and pose issues installing the product pipe) when penetrating varying geology.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** FIG. **1**A is a diagram conceptually representing pilot drilling as described herein.

**[0013]** FIG. **1**B is a diagram conceptually representing reaming a bore hole utilizing a reamer and a pilot pipe as described herein.

**[0014]** FIG. **2** shows DETAIL A of FIG. **1**B.

**[0015]** FIG. **3** is a cross-sectional side view of an example reamer and (reamer) drill pipe shown with a pilot pipe received within a channel of the reamer.

**[0016]** FIG. **4** is a diagram conceptually representing an example Horizontal Directional Drilling (HDD) site plan.

**[0017]** FIG. **5** is a cross-sectional side perspective view of an example reamer and (reamer) drill pipe shown with a pilot pipe received within a channel of the reamer.

**[0018]** FIG. **6**A is a distal end view of the reamer and (reamer) drill pipe of FIG. **5**.

**[0019]** FIG. **6**B is another perspective view of the reamer and (reamer) drill pipe of FIG. **5**.

**[0020]** FIGS. **7**A and **7**B are rear and side views respectively of an internal gear structural component of the reamer of FIG. **5**.

**[0021]** FIG. **8**A is a rear view of an external gear and seal mount component of the reamer of FIG. **5**.

**[0022]** FIG. **8**B is a cross-sectional left side view of the external gear and seal mount along A-A of FIG. **8**A.

**[0023]** FIG. **8**C is a right side view of the external gear and seal mount of FIG. **8**A showing hidden surfaces (inclusive of openings therethrough) in dashed lines.

**[0024]** FIGS. **9**A and **9**B are distal end and side views respectively of a faceplate structural component of the reamer of FIG. **5**.

**[0025]** FIGS. **10**A and **10**B are side and proximal end views respectively of a first housing structural component of the reamer of FIG. **5**.

**[0026]** FIG. **10**C is a cross-sectional distal end view of the first housing along A-A of FIG. **10**A.

**[0027]** FIG. **10**D shows DETAIL B of FIG. **10**A.

**[0028]** FIGS. **11**A and **11**B are side and proximal end views respectively of a second housing mounting ring structural component of the reamer of FIG. **5**.

**[0029]** FIG. **11**C shows DETAIL A of FIG. **11**A.

**[0030]** FIGS. **12**A and **12**B are distal end and side views respectively of a second housing structural component of the reamer of FIG. **5**.

**[0031]** FIG. **12**C shows DETAIL A of FIG. **12**B.

**[0032]** FIGS. **13**A and **13**B are proximal end and side views respectively of a third housing mounting ring structural component of the reamer of FIG. **5**.

**[0033]** FIG. **13**C shows DETAIL A of FIG. **13**B.

**[0034]** FIGS. **14**A and **14**B are distal end and side views respectively of a third housing structural component of the reamer of FIG. **5**.

**[0035]** FIGS. **15**A and **15**B are proximal end and side views respectively of a fourth housing mounting ring structural component of the reamer of FIG. **5**.

**[0036]** FIG. **15**C shows DETAIL A of FIG. **15**B.

**[0037]** FIGS. **16**A and **16**B are side and proximal end views respectively of a fourth housing structural component of the reamer of FIG. **5**.

**[0038]** FIG. **16**C shows DETAIL B of FIG. **16**A.

**[0039]** FIGS. **17**A and **17**B are distal end and side views respectively of a conical periphery structure of the reamer of FIG. **5**.

**[0040]** FIGS. **18**A and **18**B are a flow chart showing an example method for directional drilling a bore hole in a single pass.

## DESCRIPTION

**[0041]** Technologies and methodologies described herein variously relate to apparatuses, devices and operating environments depicted in FIGS. **1**A-**4**, which (as numerically denoted therein) include: pilot drill rig **1**, pilot drill **2**, reamer **3**, pilot drill pipe **4**, pilot drill spoils pit **5**, reamer drill spoils pit **6**, reamer drill pipe **7**, fresh mud flow (through reamer) **8**, spoils mud flow **9**, fresh mud flow (through pilot drill pipe) **10**, fresh mud flow (through reamer drill pipe) **11**, reamer drill rig **12**, pilot drill pipe staging **13**, mud pre-mix **14**, object to clear **15**, reamer drill pipe staging **16**, and mud processing unit **17**.

**[0042]** Technologies and methodologies described herein involve utilizing a guide mechanism for accurately steering a reamer along a path defined by a pilot hole. In example embodiments, the aforementioned guide mechanism is the pilot drill pipe (or pilot pipe) which is left in the pilot hole after drilling of the pilot hole is completed. The pilot hole can be drilling from entry to exit with a smaller diameter drill pipe and thereafter securing the drill pipe to an anchor point on exit side. Alternatively, a smaller drill rig on exit side is used to drill toward entry side to the entry side pit, and the small drill is thereafter used to hold the smaller drill pipe in place. In either case, a reamer and (reamer) drill pipe as described herein is used to drill (push ream) a finish size bore hole by swallowing over the pilot drill pipe left in the pilot hole. Once the reamer is on exit side it (the reamer) may be replaced with the swab and the rig can then pull the swab to the rig leaving the pilot pipe in the finished bore hole. Now the rig may reattach to the drill pipe and connect (at the Exit side) to the product pipe to be pulled in.

**[0043]** By push reaming in a single pass the need for additional equipment on the exit side is all but eliminated. By utilizing the reamer technologies and methodologies described herein, drilling mud returns are directed to the entry side for the majority of the ream pass and only a minimal amount of returns to the exit side near the end of the ream (upon the exiting of the reamer) and partial returns during the swab pass and pipe pull.

**[0044]** Technologies and methodologies described herein involve/utilize a reamer embodying a pressure vessel configured for directing flows of fresh mud through the reamer/pressure vessel and toward an entry side of a bore hole being drilled by the reamer. As further described herein, the reamer as a whole is a pressure vessel for the fresh mud.

**[0045]** With reference to FIGS. **5**-**17**B, an example embodiment of a reamer **100** is now described. Referring in particular to FIG. **5**, the reamer **100** and a (reamer) drill pipe **101** are coupled together and configured, e.g., as described herein, to facilitate drilling a bore hole in a single pass. The reamer **100** includes an assembly of chambers (or housings) **102**, a channel **104** (extending longitudinally through the reamer and configured to receive a pilot pipe **105** therethrough) and cutting bits **106** with cutter jets **107** (e.g., cone shaped cutters with pedestal/commercially available cutting wheels). In this example embodiment, the assembly of chambers (or housings) **102** includes a first housing **110** (FIGS. **5** and **10**A-**10**D) (e.g., an inner and/or distal-most housing) (e.g., 22 inch diameter), with a distal facing exterior surface **111** (FIG. **6**A), an internal gear **112** (FIGS. **5** and **7**A and **7**B), a faceplate **113** (FIGS. **5**, **9**A and **9**B), an external gear and seal mount **114** (FIGS. **5**, **8**A, **8**B and **8**C), a seal **115**, a seal mount bolt-on **116** (for securing a periphery flange portion of the seal **115** against the seal mount **114**, e.g., with bolts, screws or the like), a rigside seal mount **117**, an end cap **118** and openings **119** (in the housing **110**). At the distal end of housing **110**, the external gear (FIG. **8**A) includes three openings **199** which are fluidically connected to the cutter jets **107** of the three cutting bits **106** secured to the exterior surface **111** (FIG. **6**A).

**[0046]** The reamer **100** also includes a second housing **120** (FIGS. **5** and **12**A-**12**C) (e.g., circumferentially positioned about and secured to the first housing **110** as shown), with a distal facing exterior surface **121** (FIG. **6**A) of a second housing mounting ring **122** (FIGS. **5** and **11**A-**11**C) (which is secured, e.g., welded, to the distal end of the second housing **120**). At the distal end of housing **120**, the second housing mounting ring **122** (e.g., 40 inch diameter) includes four openings **129** (FIGS. **5** and **11**B) which are fluidically connected to the cutter jets **107** of the four cutting bits **106** secured to the exterior surface **121** (FIG. **6**A).

**[0047]** The reamer **100** also includes a third housing **130** (FIGS. **5**, **14**A and **14**B) (e.g., circumferentially positioned about and secured to the first housing **110** as shown), with a distal facing exterior surface **131** (FIG. **6**A) of a third housing mounting ring **132** (FIGS. **5** and **13**A-**13**C) (which is secured, e.g., welded, to the distal end of the third housing **130**). At the distal end of housing **130**, the mounting ring **132** (e.g., 56 inch diameter) includes five openings **139** (FIGS. **5** and **13**A) which are fluidically connected to the cutter jets **107** of the five cutting bits **106** secured to the exterior surface **131** (FIG. **6**A).

**[0048]** The reamer **100** also includes a fourth housing **140** (FIGS. **5** and **16**A-**16**C) (e.g., dome shaped as shown), with a distal facing exterior surface **141** (FIG. **6**A) of a mounting ring **142** (FIGS. **5** and **15**A-**15**C) (which is secured/welded to the distal end of fourth housing **140**). At the distal end of housing **140**, the mounting ring **142** (e.g., 72 inch diameter) includes six openings **149** (FIGS. **5** and **15**A) which are fluidically connected to the cutter jets **107** of the six cutting bits **106** secured to the exterior surface **141** (FIG. **6**A). A proximal end portion **144** (FIG. **16**A) of the fourth housing **140** has an opening **145** (FIG. **16**B) within which is secured an outer seal flange **146** (FIG. **5**) which peripherally supports an outer seal **148**.

**[0049]** In this example embodiment and with reference to FIG. **5**, the reamer **100** includes a rigside seal (or center seal) **150** which is secured (e.g., oriented as shown in relation) to the rigside seal mount **117** which includes openings **159** (e.g., six openings equidistantly spaced about the periphery of the seal mount **117**). The rigside seal (or center seal) **150** can be installed in either direction depending on the size and length of the reamer. The end cap **118** (of the housing **110**) includes an opening **198** adjoining an additional chamber **160** peripherally defined by a connecting pipe **162** which spans between the end cap **118** and the opening **145** (in the proximal end portion **144** of the fourth housing **140**).

**[0050]** The outer seal flange **146** is supported at opposite faces thereof by a proximal end of the connecting pipe **162** and a connection/adapter member **172** which includes an adapter portion **174** that couples to a distal end portion **176** of the (reamer) drill pipe **101**. The adapter portion **174** can include a threaded connection interface (e.g., as shown) thereby providing seal/bushing access. The outer seal flange **146** includes flange periphery openings **169** (e.g., nine openings equidistantly spaced about the periphery of the outer seal flange **146**), and the connection/adapter member **172** includes connection member openings **179**. A flow intake chamber (or rather interface) **170** is defined by the outer seal flange **146** (and the outer seal **148**) and the connection/adapter member **172**.

**[0051]** The reamer **100** also includes a conical periphery structure **182** (e.g., configured as shown; FIGS. **5** and **17**A-**17**B) at a proximal end of the assembly. A conic chamber **180** is defined by exterior portions of the fourth housing **140** and the connection member **172** and by the interior surface of the conical periphery structure **182**.

**[0052]** Pressurized fresh mud enters the reamer **100** at the flow intake chamber/interface **170**, that is, centrally via the flange periphery openings **169** and into the fourth housing **140** peripherally via the connection member openings **179** (into the conic chamber **180**) and then entering the housing **140** via openings **189** (FIGS. **5**, **16**A and **16**B) located at the proximal end portion **144** of the housing **140** (e.g., eight openings **189** equidistantly spaced about the opening **145** as shown in FIG. **16**B).

**[0053]** The first housing **110** acts as a manifold for mud flow and also transmits torque to outer components, namely, the second housing **120**, the third housing **130** and the fourth housing **140**. In this example embodiment and referring to FIG. **5**, the external gear and seal mount **114** is bolted to the faceplate **113** facilitating disassembly of the distal (or leading) end of the reamer to install and replace the rubber seals/bushings. The seal **115** forms a seal between the smaller pilot pipe **105** and the larger drill pipe **101** so the mud will flow through the jets in the reamer body at the cones.

**[0054]** In respect to materials, the external gear and seal mount **114**, the first housing **110**, the second housing **120**, the third housing **130**, the fourth housing **140** (and their respective mounting plates) and the connection/adapter member **172** can be fabricated (e.g., as shown herein) from A36 steel plate, low carbon steel tube.

**[0055]** Referring to FIGS. **18**A and **18**B, an example method **1800** for directional drilling a bore hole in a single pass includes: at **1802**, advancing a pilot pipe from an exit side to an entry side in relation to respective ends of a bore hole to be drilled, and then securing the pilot pipe at the entrance side (and/or at the exit side/pilot drill); and, at **1804**, utilizing a drill pipe and a reamer to drill the bore hole (in a single pass) advancing along (a drill path defined by) the pilot drill pipe (the reamer and drill pipe riding over the pilot pipe) while directing a flow of fresh mud through the reamer to exit via cutter jets of the reamer and toward the entry side of the bore hole being drilled.

**[0056]** In this regard, for example, the reamer is placed over the pilot drill pipe and connected to the larger entrance drill via a large diameter drill pipe. The larger diameter drill pipe can have a diameter of around 12 inches. The pilot drill pipe is slipped inside the reamer through the rubber seals and then exits the back side of the reamer staying inside the larger drill pipe. The pilot drill pipe is held firm with the small exit drill while the larger drill rotates and pushes the reamer back toward the smaller exit drill. The smaller drill pipe acts as a guide to steer the reamer back to the small drill. The large entrance drill also has mud pumping capability. The large entrance drill rotates and pushes the reamer as it rotates and cuts the soil to form a larger bore. Fresh clean mud is pumped from the large entrance drill toward the reamer to carry the cut soil back to the entrance side where the mud is picked up and cleaned so it can return back down the pipe to carry more soil to the entrance side. The entrance drill is usually located in a remote area that is difficult to get resources to. The small exit drill is normally located where utilities have easier access. Once the reamer is attached, fresh mud (captured cleaned mud preferably, if available) is pumped down the large diameter pipe and supplemented as needed by extra mud provided through the pilot drill pipe. Referring also to FIG. **3**, the mud flows from the exit drill through the pilot drill pipe exit inside the larger entrance drill pipe where the mud then travels towards the reamer and exit through the cutter jets into the bore hole. The mud then travels toward the entrance drill where it is picked up, cleaned and stored in large holding tanks ready to be pumped by the entrance drill towards the reamer. The pilot drill pipe does not move or rotate during the reaming process.

**[0057]** The method **1800** further includes, at **1806**, once the reamer reaches the exit side, removing the reamer from the drill pipe. The method **1800** can further include, at **1808**, performing a swab pass to clean the bore hole while leaving the pilot pipe in the bore hole. The method **1800** further includes, at **1810**, using the pilot pipe to pull a product pipe in the bore hole, or replacing the pilot pipe with the larger drill pipe and using the drill pipe to pull the product pipe through the bore hole to the entry side.

**[0058]** The method **1800** can further include, at **1812**, (while performing the step of utilizing a drill pipe and a reamer to drill the bore hole) collecting mudflow, that is spoils mud, exiting from the bore hole (being drilled) at the entry side; and cleaning solids from the spoils mud to provide (recycled) fresh mud and adjusting properties of the fresh mud (and storing the fresh mud in holding tanks). In example embodiments, the step of adjusting properties of the fresh mud is performed based on a priori knowledge of geological characteristics at the present location (and/or soon/next to be drilled locations) in respect to the reamer (rather than determined on-the-fly).

**[0059]** In example embodiments, drilling fluid is formulated to match the geology to be encountered and optimized for cuttings removal. The drilling rate is strictly controlled to maintain a clean bore and efficient solids control. In preparation for the process, after reviewing the geologic data and dimensions of the bore, the drilling fluid design and drilling rates may be determined. The drilling fluid is formulated to give maximum control of the geology and provide cuttings removal. Determination of the drilling rates takes into consideration additional information regarding the drill pipe and tooling for the pilot hole as well as the capabilities of the rig and pump equipment. The efficiency of the solids control system is a key factor. Also, at this time, the cutter design for the reamer may be determined.

**[0060]** To control the consistency of the drilling fluid, it can be either mixed in a pre-mix tank or the mud system can be ran down to a known level then stop drilling and batch mix in known volume. This will keep the mix consistent and allow for close monitoring of drilling fluid and cutting volumes to determine hole cleaning efficiency and/or fluid loss.

**[0061]** The method **1800** can further include, at **1814**, (while performing the step of utilizing a drill pipe and a reamer to drill the bore hole) pumping the fresh mud into the drill pipe from the entry side as needed to maintain a desired pressurization of a pressure vessel defined by the reamer such that a flow of fresh mud entering the pressure vessel, via openings in a proximal end chamber (e.g., dome-shaped chamber) of the reamer, is routed through the pressure vessel/reamer to exit via cutter jets of the reamer at locations external to the reamer and within the bore hole being drilled.

**[0062]** The method **1800** can further include, at **1816**, (while performing the step of utilizing a drill pipe and a reamer to drill the bore hole) supplementing the fresh mud as needed by pumping additional (new) fresh mud from the exit side through the pilot pipe into the drill pipe.

**[0063]** Thus, in an example embodiment, a reamer (or reamer apparatus/device) for (directionally) drilling a bore hole (e.g., suitable for receiving a product pipe) includes: an assembly of fluidically interconnected chambers with a channel therethrough including seals, the channel being configured to receive a pilot drill pipe and to allow the reamer to advance along a drill path defined by the pilot drill pipe (extending between an exit side to an entry side, in relation to respective ends of a bore hole to be drilled) (the pilot drill pipe being anchored at the entry side and/or secured at the exit side—while the reamer advances toward the exit side), the assembly of chambers and at least one of the seals being configured such that a flow of fresh mud entering the assembly, via openings in a proximal end chamber (e.g., dome-shaped chamber) of the assembly, is routed through the assembly to exit via cutter jets of the reamer at locations external to the chambers and within the bore hole being drilled (rather than toward the exit side). The seals are configured to fit about the pilot drill pipe (and serve as rotary bearings supporting the reamer) as the reamer is advanced along the pilot drill pipe. Portions of the assembly include openings that fluidically interconnect the chambers; and said at least one seal is secured within a distal portion of an innermost chamber of the assembly. In example embodiments, the openings are located in housings (inclusive of mounting rings) of the chambers (and in one or more of the seals and/or in one or more seal mounts peripherally supporting the seals). In example embodiments, the at least one seal spans between the channel and the pilot drill pipe when the pilot drill pipe is received within the channel. In example embodiments, the innermost chamber includes a housing having openings fluidically interconnecting the innermost chamber to three (or more) other chambers of the assembly.

**[0064]** Portions of the assembly include exit ports fluidically interconnecting the chambers (e.g., at distal-facing structures thereof) with the cutter jets. In example embodiments, the proximal end chamber is an outermost chamber of the assembly in respect to (radial distance from) the channel. In example embodiments, the proximal end chamber is dome-shaped. The assembly can include a conical periphery structure at a proximal end of the assembly.

**[0065]** Thus, in an example embodiment, a horizontal directional drilling apparatus includes a reamer (or reaming apparatus) having: a plurality of fluidically interconnected chambers providing a housing exterior having a sequence of (circumferentially expanding) (distal-facing) surfaces supporting cutting bits (e.g., rotary cone bits), the surfaces increasing in circumference along the sequence toward a proximal end portion of the reamer; a channel (e.g., centrally located) that extends longitudinally through the reamer between a distal end portion and the proximal end portion thereof, the channel being defined at the distal end portion (of the reamer) by an inner-most (and distal-most) chamber of the plurality of chambers, the channel being configured to receive a pilot drill pipe and to allow the reamer to advance along a drill path defined by the pilot drill pipe; and a sealing device within, couple to and peripherally supported by the inner-most (and distal-most) chamber, the sealing device including an annular inner portion sized to receive and closely fit about the pilot drill pipe, the sealing device spanning between the channel and the pilot drill pipe when the pilot drill pipe is received within the channel; wherein the fluidically interconnected chambers and the sealing device are configured to provide a pressure vessel that directs a flow of fresh mud entering the reamer at the proximal end portion thereof through (openings in) the chambers to exit via cutter jets of the cutting bits at locations external to the chambers and within a bore hole being drilled by the reamer and toward an entry side of the bore hole. In example embodiments, the plurality of fluidically interconnected chambers includes four or more chambers (e.g., three cylindrical chambers and one dome-shaped chamber). In example embodiments, the (distal-facing) surfaces of the housing exterior—from the distal end of the reamer—are circumferentially nested and sequentially increase in radial distance from the channel moving along the reamer toward the proximal end portion of the reamer. In example embodiments, the reamer includes a coupler (e.g., interiorally threaded) configured for connecting the plurality of nested fluidically interconnected chambers (at the proximal end portion of the reamer) to a drill pipe (e.g., exteriorally threaded and sized to fit within and engage with the coupler) that rotates and drives the reamer.

**[0066]** While example embodiments have been described herein, it should be apparent, however, that various modifications, alterations and adaptations to those embodiments may occur to persons skilled in the art with the attainment of some or all of the advantages of the subject matter described herein. The disclosed embodiments are therefore intended to include all such modifications, alterations and adaptations without departing from the scope and spirit of the technologies and methodologies as described herein.

What is claimed is:

**1**. A reamer for drilling a bore hole, comprising:

an assembly of fluidically interconnected chambers with a channel therethrough including seals, the channel being configured to receive a pilot drill pipe and to allow the reamer to advance along a drill path defined by the pilot drill pipe, the assembly of chambers and at least one of the seals being configured such that a flow of fresh mud entering the assembly, via openings in a proximal end chamber of the assembly, is routed through the assembly to exit via cutter jets of the reamer at locations external to the chambers and within the bore hole being drilled.

**2**. The reamer of claim **1**, wherein the seals are configured to fit about the pilot drill pipe and serve as rotary bearings supporting the reamer as the reamer is advanced along the pilot drill pipe.

**3**. The reamer of claim **1**, wherein portions of the assembly include openings that fluidically interconnect the chambers; and said at least one seal is secured within a distal portion of an innermost chamber of the assembly.

**4**. The reamer of claim **3**, wherein the openings are located in housings of the chambers and in one or more of the seals and/or in one or more seal mounts peripherally supporting the seals.

**5**. The reamer of claim **3**, wherein said at least one seal spans between the channel and the pilot drill pipe when the pilot drill pipe is received within the channel.

**6**. The reamer of claim **3**, wherein the innermost chamber includes a housing having openings fluidically interconnecting the innermost chamber to three or more other chambers of the assembly.

**7**. The reamer of claim **1**, wherein portions of the assembly include exit ports fluidically interconnecting the chambers with the cutter jets.

**8**. The reamer of claim **1**, wherein the proximal end chamber is an outermost chamber of the assembly in respect to the channel.

**9**. The reamer of claim **1**, wherein the proximal end chamber is dome-shaped.

**10**. The reamer of claim **1**, wherein the assembly includes a conical periphery structure at a proximal end of the assembly.

**11**. A method for directional drilling a bore hole with a single ream pass, comprising the steps of:

advancing a pilot pipe from an exit side to an entry side in relation to respective ends of a bore hole to be drilled, and then securing the pilot pipe at the entrance side and/or at the exit side; and

utilizing a drill pipe and a reamer to ream the bore hole advancing along the pilot drill pipe while directing a flow of fresh mud through the reamer to exit via cutter jets of the reamer and toward the entry side of the bore hole being drilled.

**12**. The method of claim **11**, further comprising:

once the reamer reaches the exit side, removing the reamer from the drill pipe.

**13**. The method of claim **12**, further comprising:

performing a swab pass to clean the bore hole while leaving the pilot pipe in the bore hole.

**14**. The method of claim **12**, further comprising:

using the pilot pipe to pull a product pipe in the bore hole, or replacing the pilot pipe with the drill pipe and using the drill pipe to pull the product pipe through the bore hole to the entry side.

**15**. The method of claim **11**, further comprising:

collecting mudflow, that is spoils mud, exiting from the bore hole at the entry side; and

cleaning solids from the spoils mud to provide fresh mud and adjusting properties of the fresh mud.

**16**. The method of claim **15**, wherein the step of adjusting properties of the fresh mud is performed based on a priori knowledge of geological characteristics at the present location and/or soon/next to be drilled locations in respect to the reamer.

**17**. The method of claim **15**, further comprising:

pumping the fresh mud into the drill pipe from the entry side as needed to maintain a desired pressurization of a pressure vessel defined by the reamer such that a flow of fresh mud entering the pressure vessel, via openings in a proximal end chamber of the reamer, is routed through the pressure vessel/reamer to exit via cutter jets of the reamer at locations external to the reamer and within the bore hole being drilled.

**18**. The method of claim **17**, further comprising:

supplementing the fresh mud as needed by pumping additional fresh mud from the exit side through the pilot pipe into the drill pipe.

**19**. A horizontal directional drilling apparatus comprising:

a reamer including

a plurality of fluidically interconnected chambers providing a housing exterior having a sequence of surfaces supporting cutting bits, the surfaces increasing in circumference along the sequence toward a proximal end portion of the reamer,

a channel that extends longitudinally through the reamer between a distal end portion and the proximal end portion thereof, the channel being defined at the distal end portion by an inner-most chamber of the plurality of chambers, the channel being configured to receive a pilot drill pipe and to allow the reamer to advance along a drill path defined by the pilot drill pipe, and

a sealing device within, couple to and peripherally supported by the inner-most chamber, the sealing device including an annular inner portion sized to receive and closely fit about the pilot drill pipe, the sealing device spanning between the channel and the pilot drill pipe when the pilot drill pipe is received within the channel,

wherein the fluidically interconnected chambers and the sealing device are configured to provide a pressure vessel that directs a flow of fresh mud entering the reamer at the proximal end portion thereof through the chambers to exit via cutter jets of the cutting bits at locations external to the chambers and within a bore hole being drilled by the reamer and toward an entry side of the bore hole.

**20**. The horizontal directional drilling apparatus of claim **19**, wherein the plurality of fluidically interconnected chambers includes four or more chambers.

**21**. The horizontal directional drilling apparatus of claim **19**, wherein the surfaces of the housing exterior—from the distal end of the reamer—are circumferentially nested and sequentially increase in radial distance from the channel moving along the reamer toward the proximal end portion of the reamer.

**22**. The horizontal directional drilling apparatus of claim **19**, wherein the reamer includes a coupler configured for connecting the plurality of nested fluidically interconnected chambers to a drill pipe that rotates and drives the reamer.

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