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(54) **MILL AND STABILISER FOR AN OUTER CASING**

(57) A method of milling an outer casing in a wellbore comprises deploying a bottom hole assembly (BHA) into the wellbore through an inner casing string, the BHA comprising a first mill and a stabilizer located below the first mill, the first mill and the stabilizer each comprising a tubular housing having an upper end, a lower end, and a bore extending continuously from the upper end to the lower end. The method further comprises extending arms of the stabilizer through a window or milled section of the inner casing string and into engagement with an inner surface of an outer casing string, extending arms of the first mill through the window or milled section and radially cutting through the outer casing string, thereby forming an outer window through the outer casing string, and longitudinally advancing the BHA while longitudinally milling the outer casing string using the first mill, thereby opening the outer window. The BHA can be retrieved from the wellbore and through the inner casing.

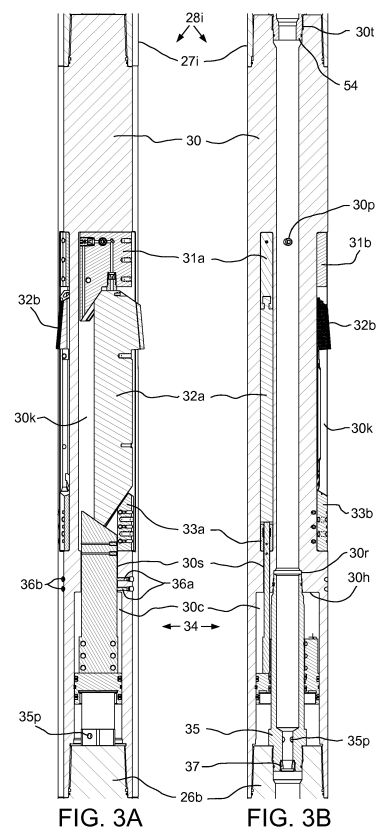


FIG. 3A

FIG. 3B

Description

BACKGROUND OF THE DISCLOSURE

Field of the Disclosure

[0001] The present disclosure generally relates to a method and BHA for milling an outer casing in a wellbore.

Description of the Related Art

[0002] A wellbore is formed to access hydrocarbon bearing formations, e.g. crude oil and/or natural gas, by the use of drilling. Drilling is accomplished by utilizing a drill bit that is mounted on the end of a tubular string, such as a drill string. To drill within the wellbore to a predetermined depth, the drill string is often rotated by a top drive or rotary table on a surface platform or rig, and/or by a downhole motor mounted towards the lower end of the drill string. After drilling to a predetermined depth, the drill string and drill bit are removed and a section of casing is lowered into the wellbore. An annulus is thus formed between the string of casing and the formation. The casing string is temporarily hung from the surface of the well. The casing string is cemented into the wellbore by circulating cement into the annulus defined between the outer wall of the casing and the borehole. The combination of cement and casing strengthens the wellbore and facilitates the isolation of certain areas of the formation behind the casing for the production of hydrocarbons.

[0003] It is common to employ more than one string of casing in a wellbore. In this respect, the well is drilled to a first designated depth with the drill string. The drill string is removed. A first string of casing is then run into the wellbore and set in the drilled out portion of the wellbore, and cement is circulated into the annulus behind the casing string. Next, the well is drilled to a second designated depth, and a second string of casing or liner, is run into the drilled out portion of the wellbore. If the second string is a liner string, the liner is set at a depth such that the upper portion of the second string of casing overlaps the lower portion of the first string of casing. The liner string may then be fixed, or "hung" off of the existing casing by the use of slips which utilize slip members and cones to frictionally affix the new string of liner in the wellbore. The second casing or liner string is then cemented. This process is typically repeated with additional casing or liner strings until the well has been drilled to total depth. In this manner, wells are typically formed with two or more strings of casing/liner of an ever-decreasing diameter.

[0004] Once the hydrocarbon formations have been depleted, the wellbore must be plugged and abandoned (P&A) using cement plugs. This P&A procedure seals the wellbore from the environment, thereby preventing wellbore fluid, such as hydrocarbons and/or salt water, from polluting the surface environment. This procedure also seals sensitive formations, such as aquifers, traversed by the wellbore from contamination by the hydro-

carbon formations. Setting of a cement plug when there are two adjacent casing strings lining the wellbore is presently done by perforating the casing strings and squeezing cement into the formation. This procedure sometimes does not give a satisfactory seal because wellbore fluid can leak to the surface through voids and cracks formed in the cement.

[0005] Applicant's own US 2011/0220357 discloses a section mill and method for abandoning a wellbore.

SUMMARY OF THE DISCLOSURE

[0006] An aspect of the present disclosure relates to a method of milling an outer casing in a wellbore according to claim 1.

[0007] A further aspect of the present disclosure relates to a bottom hole assembly (BHA) according to claim 7.

[0008] Optional features are set out in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this disclosure and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments.

Figures 1A-1C illustrates a milling system for abandoning a wellbore, according to one embodiment of the present disclosure.

Figures 2A-2F illustrate a first bottomhole assembly (BHA) of the milling system.

Figures 3A and 3B illustrate a radial cutout and window (RCW) mill of the first BHA.

Figure 4A illustrates arms of the RCW mill. Figures 4B and 4C illustrate upper blocks of the RCW mill. Figures 4D-4G illustrate an actuator of the RCW mill.

Figures 5A-5D illustrate operation of the RCW mill.

Figures 6A and 6B illustrate a section mill of the first BHA. Figure 6C illustrates arms of the section mill.

Figures 7A-7C illustrate operation of the section mill.

Figures 8A-8F illustrate a second BHA of the milling system. Figure 8G illustrates upper blocks of the second BHA.

Figures 9A-9D illustrate operation of an RCW mill of the second BHA. Figures 9E and 9F illustrate operation of a section mill of the second BHA.

Figures 10A and 10B illustrate the wellbore plugged and abandoned.

Figures 11A and 11B illustrate an optional hydraulically operated stabilizer for use with the second BHA, according to another embodiment of the present disclosure. Figure 11C illustrates arms of the hydraulically operated stabilizer.

Figures 12A-12E illustrate hydraulic operation of the stabilizer with the second BHA.

Figure 13 illustrates an alternative upper block, according to another embodiment of the present disclosure.

DETAILED DESCRIPTION

[0010] Figures 1A-1C illustrates a milling system 1 for abandoning a wellbore 2, according to one embodiment of the present disclosure. The milling system 1 may include a drilling rig 1r, a fluid handling system 1f, a pressure control assembly (PCA) 1p, and a mill string 3. The drilling rig 1r may include a derrick 4 having a rig floor 5 at its lower end. The rig floor 5 may have an opening through which the mill string 3 extends downwardly into the PCA 1p. The mill string 3 may include a bottomhole assembly (BHA) 6 and a conveyor string 7. The conveyor string 7 may include joints of drill pipe connected together, such as by threaded couplings. The BHA 6 may be connected to the conveyor string 7, such as by threaded couplings. The BHA 6 may be rotated 8r (Figure 5A) by a top drive 9 via the conveyor string 7.

[0011] An upper end of the conveyor string 7 may be connected to a quill of the top drive 9. The top drive 9 may include a motor for rotating 8r the quill. The top drive motor may be electric or hydraulic. A frame of the top drive 9 may be coupled to a rail (not shown) of the derrick 4 for preventing rotation thereof during rotation 8r of the mill string 3 and allowing for vertical movement of the top drive with a traveling block 10t. The frame of the top drive 9 may be suspended from the derrick 4 by the traveling block 10t. The traveling block 10t may be supported by wire rope 11 connected at its upper end to a crown block 10c. The wire rope 11 may be woven through sheaves of the blocks 10t,c and extend to drawworks 12 for reeling thereof, thereby raising or lowering 8a (Figure 5C) the traveling block 10t relative to the derrick 4.

[0012] The PCA 1p may include, one or more blow out preventers (BOPs) 13u,b, a flow cross 14, and one or more pressure gauges 15r,s. A housing of each BOP 13u,b and the flow cross 14 may each be interconnected and/or connected to a wellhead 16, such as by a flanged connection. The wellhead 16 may be located adjacent to

a surface 17 of the earth. The wellhead 16 may be mounted on an outer casing string 18o which has been deployed into the wellbore 2 and cemented 19o into the wellbore. An inner casing string 18i has been deployed into the wellbore 2, hung from the wellhead 16, and cemented 19i into place. Each casing string 18i,o may include a plurality of casing joints connected together, such as by threaded couplings. The outer casing string 18o may isolate an upper formation, such as aquifer 20a, from drilling and production. The inner casing string 19i may extend to a lower formation, such as hydrocarbon bearing formation 20h, and have been perforated for production therefrom.

[0013] The fluid system 1f may include a mud pump 21, a milling fluid reservoir, such as a pit 22 or tank, a solids separator, such as a shale shaker 23, and one or more flow lines, such as a return line 24r, a feed line 24f, and a supply line 24s. A first end of the return line 24r may be connected to a branch of the flow cross 14 and a second end of the return line may be connected to an inlet of the shaker 23. The returns pressure gauge 15r may be assembled as part of the return line 24r for monitoring wellhead pressure. A lower end of the supply line 24s may be connected to an outlet of the mud pump 21 and an upper end of the supply line may be connected to an inlet of the top drive 9. The supply pressure gauge 15s may be assembled as part of the supply line 24s for monitoring standpipe pressure. A lower end of the feed line 24f may be connected to an outlet of the pit 25 and an upper end of the feed line may be connected to an inlet of the mud pump 21. The mud pump 21 may have a stroke counter 15c for monitoring a flow rate thereof. The milling fluid 25f may include a base liquid. The base liquid may be refined or synthetic oil, water, brine, or a water/oil emulsion. The milling fluid 25f may further include solids dissolved or suspended in the base liquid, such as organophilic clay, lignite, and/or asphalt, thereby forming a mud.

[0014] Alternatively, a workover rig may be used instead of a drilling rig. Alternatively, the upper formation may instead be hydrocarbon bearing and may have been previously produced to depletion or ignored due to lack of adequate capacity. Alternatively, the wellbore 2 may be subsea having the wellhead 16 located adjacent to the waterline and the drilling rig 1r may be located on a platform adjacent to the wellhead. Alternatively, the wellbore 2 may be subsea having the wellhead 16 located adjacent to the seafloor, the drilling rig 1r may be located onboard an offshore drilling unit or intervention vessel, and the milling system 1 may further include a marine riser connecting the fluid handling system 1f to the wellhead or the PCA 1p may further include a rotating control device and a subsea return line connecting the fluid handling system 1f to the wellhead. Alternatively, a Kelly and rotary table (not shown) may be used instead of the top drive 9. Alternatively, the mill string 3 may further include a drilling motor (not shown) for rotating 8r the BHA 6 independently or in conjunction with the top drive 9. Al-

ternatively, the conveyor string 7 may be coiled tubing instead of drill pipe and the mill string 3 may include the drilling motor for rotating 8r the BHA 6.

[0015] Figures 2A-2F illustrate the BHA 6. The BHA 6 may include an upper adapter 26u, a section mill 27i, a radial cutout and window (RCW) mill 28i, a lower adapter 26b, and a shoe, such as a drill bit 29. The upper adapter 26u may have a threaded coupling formed at each longitudinal end thereof for connection to a bottom of the conveyor string 7 at an upper end thereof and for connection to an upper end of the section mill 27i at a lower end thereof. The lower adapter 26b may have a threaded coupling formed at each longitudinal end thereof for connection to the RCW mill 28i at an upper end thereof and for connection to the drill bit 29 at a lower end thereof.

[0016] Alternatively, the BHA 6 may further include a second (or more) section mill 28i. Alternatively, the BHA 6 may further include a disconnect sub connected between the upper adapter 26u and the conveyor string 7. Alternatively, the mills 27i, 28i may be transposed in the BHA 6. Alternatively, the shoe may be a guide shoe or reamer shoe instead of the drill bit 29.

[0017] Figures 3A and 3B illustrate the RCW mill 28i. The RCW mill 28i may include a housing 30, one or more upper blocks 31a-c (31c in Figure 4B), one or more arms 32a-c (32c in Figure 4A), one or more lower blocks 33a, b (third lower block not shown), an actuator 34, and a mandrel 35.

[0018] The housing 30 may be tubular, have a bore formed therethrough, and have threaded couplings formed at longitudinal ends thereof for connection to the section mill 27i at an upper end thereof and connection to the lower adapter 26b at a lower end thereof. The housing 30 may have a pocket 30k formed in a wall thereof for each arm 32a-c and a port 30p formed through the wall thereof for each pocket. Each port 30p may extend from the bore to an outer surface of the housing 30 and intersect each pocket 30k, thereby providing fluid communication between the housing bore and the respective pocket. The housing 30 may also have a shoulder 30h formed in an inner surface thereof. A chamber 30c may be formed radially between the housing 30 and the mandrel 35 and longitudinally between the housing shoulder 30h and a top of the upper adapter 26b. An outer surface of the mandrel 35 and an inner surface of the housing 30 adjacent to the chamber may be seal receptacles for interaction with the actuator 34. A nominal outer diameter of the housing 30 may be equal to or slightly less than a drift diameter of the inner casing 18i.

[0019] The housing 30 may have a threaded socket 30t formed in an inner surface thereof at the upper end thereof for receiving a mandrel 54 of the section mill 27i. The housing 30 may also have a seal receptacle 30r formed in an inner surface thereof adjacent to the shoulder 30h for receiving an upper end of the mandrel 35. The lower adapter 26b may have a threaded socket formed in an inner surface thereof for receiving a lower end of the mandrel 35. The mandrel 35 may carry a seal

at each longitudinal end thereof for isolating an interface between the mandrel and the housing 30 and between the mandrel and the lower adapter 26b. The mandrel 35 may have a threaded coupling formed at a lower end thereof for connection to the lower adapter 26b. The mandrel 35 may have one or more ports 35p formed through a wall thereof for providing fluid communication between a bore of the RCW mill 28i (formed by the housing bore and mandrel bore) and the actuator 34. The mandrel 35 may have a threaded socket formed in an inner surface thereof at a lower end thereof (below the ports 35p) for receiving a nozzle 37. The nozzle 37 may be made from an erosion resistant material and restrict flow of the milling fluid 25f therethrough to create a pressure differential between the mill bore and an annulus 2a formed between the mill string 3 and the inner casing 18i for operation of the actuator 34.

[0020] Each arm 32a-c may be movable relative to the housing 30 between a retracted position (Figures 2B, 2C, 2E, and 2F) and an extended position (Figures 3A and 3B). Each arm 32a-c may be disposed in the respective pocket 30k in the retracted position and at least a portion of each arm may extend outward from the respective pocket in the extended position. Each pocket 30k may be eccentrically arranged relative to the housing 30 and each arm 32a-c may have an eccentric extension path relative to the housing resulting in a far-reaching available blade sweep.

[0021] Figure 4A illustrates the arms 32a-c. Figures 4B and 4C illustrate the upper blocks 31a-c. Each upper block 31a-c may be disposed in a respective pocket 30k and connected to the body 30, such as by one or more fasteners. Each upper block 31a-c may include a body 41, a respective nozzle 42a-c, and a stop 43. Each lower block 33a-c may be disposed in a respective pocket 30k and connected to the body 30, such as by one or fasteners.

[0022] Each arm 32a-c may have an inner body portion 38y and an outer blade portion 38d. Each body portion 38y may have an upper guide 38u, such as an inclined T-shaped tongue, formed in an inner portion of an upper end thereof and the respective upper block body 41 may have a mating guide 41p, such as an inclined T-slot, formed in an inner portion of a lower end thereof. Each body portion 38y may also have a lower guide 38b, such as an inclined tongue, formed in a mid and an outer portion of a lower end thereof and the respective lower block 33a-c may have a mating guide, such as an inclined T-slot 33p (Figure 2C), formed in a mid and inner portion of an upper end thereof. Each body portion 38y may have a lower cam, such as a ramp 38r, formed in an inner portion of a lower end thereof for interaction with the actuator 34. Inclinations of the guides 33p, 38u,b, 41p may be corresponding and the cam inclination may be opposed to the guide inclinations.

[0023] The arms 32a-c may slide along the guides 33p, 38u,b, 41p to move radially outward as the arms are pushed longitudinally upward by the actuator 34. The

guides 33p, 38u,b, 41p may also serve to mechanically lock the arms 32a-c in the extended position during longitudinal milling as longitudinal reaction force from the inner casing 18i pushes each blade portion 38d against the respective upper block 31a-c, thereby reducing or eliminating any chattering of the blade portions due to pressure fluctuations in the milling fluid 25f.

[0024] Each blade portion 38d may have one or more rows 40a-c of sockets extending along a forward face thereof. The rows 40a-c may be adjacent to each other. A cutter 39c may be disposed into each socket. Each cutter 39c may be made from a material suitable for cutting the casing material (i.e. steel), such as ceramic or cermet (i.e., tungsten carbide). The cutters 39c may be pressed or threaded into the sockets and the rows 40a-c fixed into place, such as by welding. The inner and intermediate rows 40a,b may form a lead cutting surface for the inner casing joint and the outer row 40c may be slightly offset tangentially to form a trail cutting surface for the inner casing coupling.

[0025] Alternatively, the cutters 39 may be crushed ceramic or cermet dressed onto the rows 39a-c by hard-facing.

[0026] Each upper block body 41 may have a shoulder 41s formed in an outer portion of the lower end thereof adjacent to the guide 41p. Each stop 43 may be fastened to the respective upper block body 41 at the shoulder 41s. A mid portion of the upper end of each body portion 38y may serve as a stop shoulder 38h and extension of the blades 32a-c may be complete when the stop shoulders engage the respective stops 43.

[0027] An outer portion of each body portion upper end and an upper end of each blade portion 38d may be inclined for serving as a retraction profile 38t. The retraction profile 38t may engage the inner casing string 18i (upper surface of an inner window 51i (Figure 5C)) for partially or fully retracting the arms 32a-c once milling of the inner casing string is complete. The retraction inclination may correspond to the cam inclination.

[0028] The blade portion 38d may have a length substantially shorter than a length of the body portion 38y, such as less than or equal to one-half thereof. An outer surface of each blade portion 38d may also taper 38a slightly outwardly from a top of the RCW mill 28i to a bottom of the mill. The taper 38a may be between one and ten degrees or between three and seven degrees, such as five degrees. The short blade portion 38d may provide increased cutting pressure when starting the inner window 51i through the inner casing 18i, thereby reducing or eliminating any bearing effect. The taper 38a may ensure that a bottom of the blade portion 38d engages the inner casing 18i before the rest of the blade portion, thereby further increasing cutting pressure. The short blade portion 38d may also provide a relatively short cutting lifespan to form a relatively short inner window 51i. The cutting lifespan may be less than or equal to the length of a joint of the casing (typically forty feet), such as one-third, one-half, two thirds, or three-quarters the

joint length and be greater than or equal to the length of the section mill blade portions 52a-c (Figure 6C). When extended, a sweep of the RCW mill 28i may be equal to or slightly greater than a coupling diameter of the inner casing 18i and the RCW mill may be capable of cutting the inner window through the inner casing joint or coupling.

[0029] Each body portion 38y may have a groove 38g formed along an exposed portion (not having the blade portion 38d) of an outer surface thereof. A pad 39p may be pressed into each groove 38g and fixed into place, such as by welding. Each pad 39p may be made from a material harder than the casing material, such as tool steel, ceramic, or cermet. A sweep of the pads 39p may be slightly greater than the drift diameter of the inner casing 18i for engaging the inner surface thereof after the blade portions 38d have cut through the inner casing. Engagement of the pads 39p with the inner casing 18i may stabilize the RCW mill 28i and prevent damage to the outer casing 18o. Once the blade portions 38d have worn off, the pads 39p may continue to serve as a stabilizer for the section mill 27i. The worn blade portions may also serve as a scraper.

[0030] Alternatively, each groove 38g and/or the pad 39p may extend along only a portion of the body portion outer surface. Alternatively, each pad 39p may be the exposed outer surface of the body portion 38y instead of an insert and the exposed outer surface may be surface hardened or coated.

[0031] Each upper block body 41 may have one or more passages 41i,o formed therein and a port 41t formed therethrough. Each passage 41i,o may intersect the port 41t. The inner passage 41i may extend from the port 41t to the guide 41p for pressurizing the pocket 30k with milling fluid 25f from the housing bore to discourage infiltration of cuttings. The outer passage 41o may extend from the port 41t to the stop 43. Each body 41 may also have an inner threaded socket formed at a bend of the inner passage 41i for receiving the respective nozzle 42a-c and a second threaded socket formed at the respective shoulder 41s for receiving the respective stop 43. Each nozzle 42a-c may include a threaded plug and a jet fastened thereto. Each threaded plug may have a bore formed therein and one or more crossover ports in fluid communication with the bore and may carry a seal to isolate an interface between the respective nozzle 42a-c and the housing 30. Due to a pressure drop across the nozzles 42a-c, the respective pocket 30k may be maintained at an intermediate pressure greater than pressure in the annulus 2a and less than pressure in the mill bore.

[0032] Each stop 43 may include a threaded plug and a jet fastened thereto. Each threaded plug may have a bore formed therethrough and may carry a seal to isolate an interface between the respective stop 43 and the housing 30. Engagement of each stop shoulder 38h with the respective stop 43 may close the respective outer passage 41o, thereby causing an increase in standpipe pressure detectable by monitoring the supply pressure

gauge 15s and confirming extension of the arms 32a-c.

[0033] The RCW mill 28i may further include a flow diverter 44a-c for each housing port 30p. Each housing port 30p may be a threaded socket for receiving a respective diverter 44a-c and each upper block port 41t may be a seal receptacle for receiving the diverter. Each diverter 44a-c may include a threaded plug having a bore formed therein and one or more crossover ports in fluid communication with the bore. Each diverter plug may carry a pair of seals straddling the crossover ports to isolate an interface between the respective diverter 44a-c and the upper block 31a-c and a seal to isolate an interface between the respective diverter and the housing 30.

[0034] Figures 4D-4G illustrate the actuator 34. The actuator 34 may be hydraulic and longitudinally movable relative to the housing 30 between an upper position (Figures 3A and 3B) and a lower position (Figures 2B, 2C, 2E, and 2F). The actuator 34 may include a body 45 and a pusher 46a-c for each arm 32a-c.

[0035] The body 45 may be disposed in the chamber 30c. The body 45 may have a lower piston portion 45p, an upper mount portion 45m, and a shoulder 45h formed between the two portions. The piston portion 45p may carry an outer seal for sealing an interface between the body 45 and the housing 30 and an inner seal for sealing an interface between the body and the mandrel 35. The piston portion 45p may also carry one or more (two shown) outer linear bearings 49o for facilitating sliding of the body 45 relative to the housing 30 and one or more (two shown) inner linear bearings 49i for facilitating sliding of the body 45 relative to the mandrel 35. Each linear bearing 49i,o may be a plain bearing made from an abrasion resistant material, such as bronze, graphite alloy composite, Babbitt metal, ceramic, cermet, bi-metal, or lubricant infused alloy composite.

[0036] The mount 45m may be n-polygonal (n equaling the number of arms 32a-c), such as triangular, for receiving the pushers 46a-c. Each pusher 46a-c may be a rectangular plate. A lower portion 47f of each pusher 46a-c may be disposed against the shoulder 45h and connected to the mount portion 45m, such as by a respective set 48a-c of one or more (six shown) fasteners. Each pusher 46a-c may extend from the mount 45m through a respective slot 30s formed in the housing wall and bridging the chamber 30c and the respective pocket 30k. Each lower block 33a,b may have slot formed therethrough aligned with the respective housing slot 30s and the respective pusher 46a-c may also extend through the respective lower block slot into the respective pocket 30k. Each pusher 46a-c may have a cam, such as a ramp 47r, formed in an upper end thereof for mating with the respective ramp 38r, thereby extending the respective arm 32a-c when the pusher is pressed against the arm by the piston portion 45p.

[0037] The piston portion 45p may divide the chamber 30c into an upper portion and a lower portion. The chamber upper portion may be in fluid communication with the

pockets 30k via leakage through the slots 30s. The chamber lower portion may be in fluid communication with the mill bore via the mandrel ports 35p. Pressure differential between the mill bore pressure and the intermediate pocket pressure may exert a net upward actuation force on the piston portion 45p when the milling fluid 25f is pumped down the mill string 3.

[0038] The RCW mill 28i may initially be restrained in the retracted position by one or more sets 36a,b (third set not shown) of one or more (two shown) shearable fasteners, such as pins. The housing 30 may have a socket formed through the wall thereof for receiving an outer portion of each shear pin and each pusher 46a-c may have a socket formed in an outer face thereof for receiving an inner portion of each pin of a respective set 36a, b. Each housing socket may be threaded for receiving a retention plug to keep the respective shear pin in place. Collectively, the shear pins may fasten the actuator 34 to the housing 30 until the actuation force reaches a shear force necessary to fracture the shear pins and release the actuator from the housing. The actuation force may increase as an injection rate of milling fluid 25f through the mill string 3 is increased until the injection rate reaches an activation threshold.

[0039] Figures 5A-5D illustrate operation of the RCW mill 28i. Once hydrocarbon bearing formation 20h is depleted, it may be desirable to plug and abandon (P&A) the wellbore 2. To begin the P&A operation, production equipment (not shown), such as a production tubing string and a production tree may be removed from the wellbore 2 and wellhead 16 and a lower cement plug 50b set to isolate the hydrocarbon formation 20h.

[0040] The BHA 6 may be assembled and deployed into the wellbore 2 using the conveyor string 7 through the inner casing 18i and to the lower cement plug 50b. During deployment of the mill string 3, the milling fluid 25f may be circulated by the mud pump 21 at a flow rate less than the activation threshold. The mill string 3 may then be rotated 8r and the drill bit 29 may be engaged with a top of the plug 50b to verify integrity thereof. Rotation 8r may be halted and the BHA 6 may be raised to the aquifer 20a. The BHA 6 may be raised so that the RCW mill 28i is slightly above a top of the aquifer 20a and between couplings of the inner casing 18i. Rotation 8r of the mill string 3 may resume and injection of the milling fluid 25f may be increased to at least the activation threshold, thereby releasing the actuator 34 from the housing 30. The piston portion 45p may then move the pushers 46a-c upward and the arms 32a-c outward until cutters 39c of the outer row 40c engage the inner surface of the inner casing string 18i. During extension of the RCW mill 28i, the section mill 27i may be restrained from extension.

[0041] The blade portions 38d may engage the inner casing 18i and begin to radially cut through the inner casing wall. The milling fluid 25f may be circulated through the mill string 3 and up the annulus 2a and a portion of the milling fluid 25f may be diverted into the upper blocks

31a-c. The BHA 6 may be held longitudinally in place during the radial cut through operation. The supply pressure gauge 15s may be monitored to determine when the RCW mill 28i has radially cut through the inner casing 18i and started the window 51i as indicated by an increase in pressure caused by engagement of the arms 32a-c with the respective stops 43. Each window 51i may extend entirely around and through the inner casing 18i. Weight may then be set down on the BHA 6. The RCW mill 28i may then longitudinally open the window 51i while the pads 39p engage the inner surface of the inner casing 18i, thereby stabilizing the RCW mill. Longitudinal advancement of the RCW mill 28i may continue until the blade portions 38d are exhausted. Torque exerted by the top drive 9 may be monitored to determine when the blade portions 38d have become exhausted.

[0042] Figures 6A and 6B illustrate the section mill 27i. The section mill 27i may include the housing 30, the upper blocks 31a-c, one or more arms 52a-c (52c in Figure 6C), the lower blocks 33a,b (third lower block not shown), the actuator 34, and a mandrel 54.

[0043] The mandrel 54 may carry a seal at each longitudinal end thereof for isolating an interface between the mandrel and the housing 30 and between the mandrel and the RCW housing 30. The mandrel 54 may have a threaded coupling formed at a lower end thereof for connection to the RCW housing. The mandrel 54 may have one or more ports 54p formed through a wall thereof for providing fluid communication between a bore of the section mill 27i (formed by the housing bore and mandrel bore) and the actuator 34. The mandrel 54 may have a receiver 54r formed in an inner surface thereof at a lower end thereof (below the ports 54p) for receiving a pump down plug, such as a dart 55. The receiver 54r may include a landing shoulder and a seal receptacle. The dart 55 may include a body having a threaded socket formed in an inner surface thereof at a lower end thereof for receiving a nozzle. The dart nozzle may be made from an erosion resistant material and restrict flow of the milling fluid 25f therethrough to create a pressure differential between the mill bore and the annulus 2a. The dart body may carry a seal for sealing an interface between the dart 55 and the mandrel and have a landing shoulder formed in an outer surface thereof for seating against the mandrel landing shoulder.

[0044] Each arm 52a-c may be movable relative to the housing 30 between a retracted position (Figures 2A, 2B, 2D, and 2E) and an extended position (Figures 6A and 6B). Each arm 52a-c may be disposed in the respective pocket 30k in the retracted position and at least a portion of each arm may extend outward from the respective pocket in the extended position. Each pocket 30k may be eccentrically arranged relative to the housing 30 and each arm 52a-c may have an eccentric extension path relative to the housing resulting in a far-reaching available blade sweep.

[0045] Figure 6C illustrates arms 52a-c of the section mill. Each arm 52a-c may have an inner body portion 56y

and an outer blade portion 56d. Each body portion 56y may have the upper guide 38u and the lower guide 38b for interaction with the respective blocks 31a-c, 33a,b and the ramp 38r for interaction with the actuator 34. Each blade portion 56d may have one or more rows 58a-c of sockets extending along a forward face thereof. The rows 58a-c may be adjacent to each other. The cutter 39c may be disposed into each socket. The inner and intermediate rows 58a,b may form a lead cutting surface for the inner casing joint and the outer row 58c may be slightly offset tangentially to form a trail cutting surface for the inner casing coupling.

[0046] An outer portion of each body portion upper end and an upper end of each blade portion 56d may be inclined for serving as a retraction profile 56t. The retraction profile 56t may engage the inner casing string 18i (upper surface of the inner window 51i) for partially or fully retracting the arms 52a-c once milling of the inner casing string is complete. The retraction inclination may correspond to the cam inclination.

[0047] Each blade portion 56d may have a length substantially greater than the RCW blade portions 38d and corresponding to, such as slightly less than, a length of the body portion 56y to ensure a long cutting lifespan. The lifespan may be greater than or equal to a length of one or more casing joints, such as greater than or equal to one hundred feet of casing (including couplings). An outer surface of each blade portion 56d may be straight. When extended, a sweep of the section mill 27i may be equal to or slightly greater than a coupling diameter of the inner casing 18i and the section mill 27i may be capable of milling an inner section 59i (Figure 7C) through the inner casing joint or coupling.

[0048] Each body portion 56y may have a groove 56g formed along an exposed portion (not having the blade portion 56d) of an outer surface thereof. A pad 57 may be pressed into each groove 56g and fixed into place, such as by welding. Each pad 57 may be made from any of the materials for the pad 39p. A sweep of the pads 57 may be slightly greater than the drift diameter of the inner casing 18i for engaging the inner surface thereof after the blade portions 56d have been extended through the inner window 51i. Engagement of the pads 57 with the inner casing 18i may stabilize the section mill 27i and prevent damage to the outer casing 18o.

[0049] The section mill 27i may initially be restrained in the retracted position by one or more sets 53a,b (third set not shown) of one or more (two shown) shearable fasteners, such as pins. Collectively, the shear pins may fasten the actuator 34 to the housing 30 until the actuation force reaches a second shear force necessary to fracture the shear pins and release the actuator from the housing. The actuation force may increase as an injection rate of milling fluid 25f through the mill string 3 is increased until the injection rate reaches a second activation threshold. The second shear force and second activation threshold may be greater than those of the RCW mill 28i such that the section mill 27i remains locked in the retracted posi-

tion during milling of the inner window 51i.

[0050] Figures 7A-7C illustrate operation of the section mill 27i. Once the inner window 51i has been formed, rotation of the mill string 3 may be halted. The section mill 27i may then be aligned with the inner window 51i or may already be aligned with the inner window. An upper portion of the conveyor string 7 may be disconnected and the dart 55 inserted into the mill string 3. The conveyor string 7 may then be reconnected and the mud pump 21 operated to pump the dart 55 downward through the conveyor string 7 and into the BHA 6 until the dart engages the receiver 54r. An injection rate of the milling fluid 25f into the mill string 3 may be increased until the second threshold is reached, thereby releasing the actuator 34.

[0051] The blade portions 56d may be extended through the inner window 51i by the actuator 34. The BHA 6 may be rotated 8r and held longitudinally in place during extension of the arms 52a-c. The supply pressure gauge 15s may be monitored to confirm extension as indicated by an increase in pressure caused by engagement of the arms 52a-c with the respective stops 43. Weight may then be set down on the BHA 6. The section mill 27i may then be advanced to longitudinally mill the inner section 59i while the pads 57 engage the inner surface of the inner casing 18i, thereby stabilizing the section mill. Longitudinal advancement of the section mill 27i may continue until the inner section 59i adjacent to the aquifer 20a is complete and may or may not further continue until the blade portions 56d are exhausted. The mill string 3 may then be retrieved to the drilling rig 1r.

[0052] Figures 8A-8F illustrate a second BHA 60 of the milling system 1. The second BHA 60 may be similar or identical to the BHA 6 except for the substitution of an outer section mill 27o and outer RCW mill 28o for the respective inner section mill 27i and inner RCW mill 28i.

[0053] Figure 8G illustrates upper blocks of the second BHA 60. The outer section mill 27o may be similar or identical to the inner section mill 27i except for the substitution of upper blocks 61a-c for the respective upper blocks 31a-c. The outer RCW mill 28o may be similar or identical to the inner RCW mill 28i except for the substitution of the upper blocks 61a-c for the respective upper blocks 31a-c. Each upper block 61a-c may be disposed in a respective pocket 30k and connected to the body 30, such as by one or fasteners. Each upper block 61a-c may include a body 62, the respective nozzle 42a-c, and the stop 43.

[0054] Each upper block body 62 may have a guide 62p, such as an inclined T-slot, formed in an inner and mid portion of a lower end thereof. Each guide 62p may be extended relative to the respective guide 41p for increasing a blade sweep 63b (Figure 9D) and integral stabilizer sweep 63s to correspond to the outer casing string 18o. Each upper block body 62 may have a shoulder 62s formed in an outer portion of the lower end thereof adjacent to the guide 62p. Each stop 43 may be fastened to the respective upper block body 62 at the shoulder 62s. When extended, the blade sweep 63b of the outer mills

27o, 28o may be equal to or slightly greater than a coupling diameter 64o of the outer casing 18o. The sweep 63s of the pads 39p, 57 may be slightly greater than the drift diameter 64d of the outer casing 18o for engaging the inner surface thereof after the respective blade portions 38d, 56d have cut/extended through the outer casing.

[0055] Each upper block body 62 may have the inner passage 41i and an outer passage 62o formed therein and the port 41t formed therethrough. Each passage 41i, 62o may intersect the port 41t. The inner passage 41i may extend from the port 41t to the guide 41p for pressurizing the pocket 30k with milling fluid 25f from the housing bore to discourage infiltration of cuttings. The outer passage 62o may extend from the port 41t to the stop 43. Each body 62 may also have an inner threaded socket formed at a bend of the inner passage 41i for receiving the respective nozzle 42a-c and a second threaded socket formed at the respective shoulder 62s for receiving the respective stop 43. Due to a pressure drop across the nozzles 42a-c, the respective pocket 30k may be maintained at an intermediate pressure greater than pressure in the annulus 2a and less than pressure in the mill bore. Engagement of each stop shoulder 38h with the respective stop 43 may close the respective outer passage 62o, thereby causing an increase in standpipe pressure detectable by monitoring the supply pressure gauge 15s and confirming extension of the respective arms 32a-c, 52a-c.

[0056] Each outer mill 27o, 28o may further include the flow diverter 44a-c for each housing port 30p. Each housing port 30p may be a threaded socket for receiving a respective diverter 44a-c and each upper block port 41t may be a seal receptacle for receiving the diverter. Each diverter 44a-c may include a threaded plug having a bore formed therein and one or more crossover ports in fluid communication with the bore. Each diverter plug may carry a pair of seals straddling the crossover ports to isolate an interface between the respective diverter 44a-c and the upper block 61a-c and a seal to isolate an interface between the respective diverter and the housing 30.

[0057] Figures 9A-9D illustrate operation of the outer RCW mill 28o. The second BHA 60 may be assembled and deployed into the wellbore 2 using the conveyor string 7 through the inner casing 18i to the inner window 51i. The second BHA 60 is positioned in the wellbore 2 at a predetermined location near the top end of the inner window 51i. During deployment of the mill string, the milling fluid 25f may be circulated by the mud pump 21 at a flow rate less than the activation threshold. The second BHA 60 may be rotated 8r and injection of the milling fluid 25f may be increased to at least the activation threshold, thereby releasing the actuator 34 from the housing 30. The piston portion 45p may then move the pushers 46a-c upward and the arms 32a-c outward through the inner window 51i until cutters 39c of the outer row 40c engage the inner surface of the outer casing string 18o. During

extension of the outer RCW mill 28o, the outer section mill 27o may be restrained from extension.

[0058] The blade portions 38d may engage the outer casing 18o and begin to radially cut through the outer casing wall. The milling fluid 25f may be circulated through the mill string and up the annulus 2a and a portion of the milling fluid 25f may be diverted into the upper blocks 61a-c. The second BHA 60 may be held longitudinally in place during the radial cut through operation. The supply pressure gauge 15s may be monitored to determine when the outer RCW mill 28o has radially cut through the outer casing 18o and started the outer window 51o as indicated by an increase in pressure caused by engagement of the arms 32a-c with the respective stops 43. The outer window 51o may extend entirely around and through the outer casing 18o. Weight may then be set down on the second BHA 60. The outer RCW mill 28o may then longitudinally open the outer window 51o while the pads 39p engage the inner surface of the outer casing 18o, thereby stabilizing the outer RCW mill. Longitudinal advancement of the outer RCW mill 28o may continue until the blade portions 38d are exhausted. Torque exerted by the top drive 9 may be monitored to determine when the blade portions 38d have become exhausted.

[0059] Figures 9E and 9F illustrate operation of the outer section mill 27o. Once the outer window 51o has been formed, rotation of the mill string may be halted. The outer section mill 27o may then be aligned with the outer window 51o or may already be aligned with the outer window. An upper portion of the conveyor string 7 may be disconnected and the dart 55 inserted into the mill string. The conveyor string 7 may then be reconnected and the mud pump 21 operated to pump the dart 55 downward through the conveyor string 7 and into the second BHA 60 until the dart engages the receiver 54r. An injection rate of the milling fluid 25f into the mill string may be increased until the second threshold is reached, thereby releasing the actuator 34.

[0060] The blade portions 56d may be extended through the inner and outer windows 51i,o by the actuator 34. The second BHA 60 may be rotated 8r and held longitudinally in place during extension of the arms 52a-c. The supply pressure gauge 15s may be monitored to confirm extension as indicated by an increase in pressure caused by engagement of the arms 52a-c with the respective stops 43. Weight may then be set down on the second BHA 60. The outer section mill 27o may then be advanced to longitudinally mill the outer section 59o while the pads 57 engage the inner surface of the outer casing 18o, thereby stabilizing the outer section mill. Longitudinal advancement of the outer section mill 27o may continue until the outer section 59o adjacent to the aquifer 20a is complete. The mill string may then be retrieved to the drilling rig 1r.

[0061] Figures 10A and 10B illustrate the wellbore plugged and abandoned. Once the sections 59i,o of the casings 18i,o have been milled, a BHA (not shown) may

be connected to the conveyor string 7. The BHA may include the bridge plug 65b, a setting tool, and a cementing shoe/collar. The BHA may be run into the wellbore 2 using the conveyor string 7 to a depth proximately below a bottom of the aquifer 20a. The bridge plug 65b may be set using the setting tool by pressurizing the workstring. The setting tool may be released from the bridge plug 65b. Cement slurry may then be pumped through the workstring to displace wellbore fluid from the aquifer 20a. The workstring may then be removed from the wellbore 2 and the cement slurry allowed to cure, thereby forming the cement plug 50m. A casing cutter (not shown) may then be connected to the conveyor 7. The casing cutter may then be deployed a predetermined depth, such as one hundred feet, in the wellbore 2. The inner and outer casings 18i,o may be cut at the predetermined depth and removed from the wellbore 2. The bridge plug 65u may be set proximately below the cut depth and the cement slurry may be pumped and allowed to cure, thereby forming an upper cement plug 50u. The wellbore 2 may then be abandoned.

[0062] Figures 11A and 11B illustrate an optional hydraulically operated stabilizer 70 for use with the second BHA 60, according to another embodiment of the present disclosure. The stabilizer 70 may include the housing 30, the upper blocks 61a-c, one or more arms 72a-c (72c in Figure 11C), the lower blocks 33a,b (third lower block not shown), the actuator 34, and the mandrel 35.

[0063] The nozzle 77 may be screwed into the mandrel 35 instead of the nozzle 37. The nozzle 77 may be made from an erosion resistant material and restrict flow of the milling fluid 25f therethrough to create a pressure differential between the mill bore and an annulus 2a formed between the mill string 3 and the inner casing 18i for operation of the actuator 34. The nozzle 77 may have an inner diameter less than the nozzle 37.

[0064] Each arm 72a-c may be movable relative to the housing 30 between a retracted position (not shown) and an extended position (Figures 11A and 11B). Each arm 72a-c may be disposed in the respective pocket 30k in the retracted position and at least a portion of each arm may extend outward from the respective pocket in the extended position. Each pocket 30k may be eccentrically arranged relative to the housing 30 and each arm 72a-c may have an eccentric extension path relative to the housing resulting in a far-reaching available sweep.

[0065] Figure 11C illustrates arms 72a-c of the stabilizer 70. Each arm 72a-c may have an inner body portion 78y. Each body portion 78y may have the upper guide 38u and the lower guide 38b for interaction with the respective blocks 61a-c, 33a,b and the ramp 38r for interaction with the actuator 34. An outer portion of each body portion upper end may be inclined for serving as the retraction profile 38t. The retraction profile 38t may engage the inner casing string 18i (upper surface of the inner window 51i) for partially or fully retracting the arms 72a-c once milling of the outer casing string 18o is complete. Each body portion 78y may have the groove 38g formed

along an outer surface thereof. The pad 39p may be pressed into each groove 38g and fixed into place, such as by welding. A sweep of the pads 39p may be slightly greater than the drift diameter of the outer casing 18o for engaging the inner surface thereof. Engagement of the pads 39p with the outer casing 18o may stabilize the mills 27o, 28o.

[0066] The stabilizer 70 may initially be restrained in the retracted position by one or more sets 71a,b (third set not shown) of one or more (two shown) shearable fasteners, such as pins. Collectively, the shear pins may fasten the actuator 34 to the housing 30 until the actuation force reaches a shear force necessary to fracture the shear pins and release the actuator from the housing. The actuation force may increase as an injection rate of milling fluid 25f through the mill string 3 is increased until the injection rate reaches a third activation threshold. The third shear force and third activation threshold may be less than those of the RCW mill 28o such that the stabilizer 70 extends before the mills 27o, 28o.

[0067] Figures 12A-12E illustrate hydraulic operation of the stabilizer 70 with the second BHA 60. The stabilizer 70 may be added to the second BHA 60 to form a third BHA 76. The stabilizer 70 may be located between the outer RCW mill 28o and the lower adapter 26b. The third BHA 76 may be assembled and deployed into the wellbore 2 using the conveyor string 7 through the inner casing 18i to the inner window 51i. The third BHA 76 is positioned in the wellbore 2 at a predetermined location near the top end of the inner window 51i. During deployment of the mill string, the milling fluid 25f may be circulated by the mud pump 21 at a flow rate less than the third activation threshold. The third BHA 76 may be rotated 8r and injection of the milling fluid 25f may be increased to at least the third activation threshold, thereby releasing and extending the stabilizer 70 into engagement with the inner surface of the outer casing string 18o.

[0068] The injection of the milling fluid 25f may be increased to at least the activation threshold, thereby releasing and extending the outer RCW mill 28o into engagement with the inner surface of the outer casing string 18o. The outer window 51o may then be opened and extended until the outer RCW mill 28o is exhausted. The stabilizer 70 may be engaged with the outer casing string 18o while the outer window 51o is opened and extended. Engagement of the stabilizer 70 with the outer casing string 18o may: center the third BHA 76 within the outer casing string, minimize or eliminate excess movement or play while allowing the third BHA to rotate freely within the outer casing string, and allow rotation of the third BHA within the outer casing string while limiting radial movement therein.

[0069] Once the outer window 51o has been formed, rotation of the mill string may be halted. The dart 55 may then be pumped to the outer section mill 27o and the milling fluid pumped to the third BHA 76 at the second threshold to release and extend the section mill through the inner and outer windows 51i,o. The outer section 59o

may then be milled and the mill string retrieved to the drilling rig 1r. The stabilizer 70 may be engaged with the outer casing string 18o while the outer section 59o is milled.

[0070] Alternatively, the third activation threshold may be greater than or equal to the activation threshold or greater than or equal to the second activation threshold such that the stabilizer 70 may be released and extended simultaneously or after release and extension of the outer RCW mill 28o and/or the outer section mill 27o.

[0071] Figure 13 illustrates an alternative upper block 81, according to another embodiment of the present disclosure. An upper block 81 may be disposed in each respective pocket 30k and connected to the body 30 instead of the respective upper blocks 61a-c for the outer RCW mill 28o, outer section mill 27o, and the stabilizer 70. The upper block 81 may include a body 82, a nozzle similar to the nozzles 42a-c, and a stop 83.

[0072] The upper block body 82 may have a guide similar to the guide 62p formed in an inner and mid portion of a lower end thereof. The upper block body 82 may have the shoulder 62s formed in an outer portion of the lower end thereof adjacent to the guide. The stop 83 may be fastened to the upper block body 82 at the shoulder 82s. The upper block body 82 may have an inner passage similar to the inner passage 41i and an outer passage 82o formed therein and the port 41t formed therethrough. Each passage 82o may intersect the port 41t. The outer passage 82o may extend from the port 41t to the stop 83. The body 82 may also have a (second) threaded socket formed at the shoulder 62s for receiving the stop 83.

[0073] The stop 83 may include a housing 83h, a flow tube 83t, and a biasing member, such as a compression spring 83s. An interface between the housing 83 and the block body 82 may be isolated, such as by a seal 83b. The flow tube 83t may have an upper valve portion, a lower stinger portion, and a shoulder portion connecting the valve and stinger portions. The flow tube 83t may be longitudinally movable relative to the housing 83h and block body 82 between an open position (shown) and a closed position (not shown). The flow tube 83t may be biased toward the open position by the spring 83s disposed between the shouldered portion of the flow tube and the block body 82.

[0074] The housing 82b may have seal bore 82b formed as part of the outer passage 82o at a bend thereof. The valve portion of the flow tube 83t may carry a pair of straddle seals 83u,m on an outer surface thereof for closing the outer passage 82o. In the open position, the valve portion may be clear of the bend in the outer passage 82o, thereby allowing the flow of the milling fluid 25f there-through. In the closed position, the seals 83u,m of the valve portion may engage the seal bore 82b and straddle a radial portion of the outer passage 82o while the valve portion extends across the radial portion, thereby closing the outer passage 82o. In the open position, the stinger portion of the flow tube 83t may protrude downward past

a lower end of the housing 83h for receipt of the stop shoulder 38h. Engagement of the stop shoulder 38h with the stinger portion may overcome the bias of the spring 83s and push the flow tube 83t to the closed position, thereby causing an increase in standpipe pressure detectable by monitoring the supply pressure gauge 15s and confirming extension of the respective arms 32a-c, 52a-c, 72a-c.

[0075] Additionally, the upper blocks 31a-c of the inner mills 27i, 28i may be modified in a similar fashion.

[0076] Alternatively, either or both of the mandrel nozzles 37, 77 and/or the dart 55 may be omitted and nozzles of the drill bit 29 may be relied upon to create any of the activation thresholds instead. Alternatively, the guide shoe or reamer shoe alternatives for the drill bit 29, discussed above, may have nozzles for creating any of the activation thresholds.

[0077] Alternatively, the inner and outer mills may be deployed in the same trip or the inner or outer mills may be run for a single casing milling operation. Alternatively, instead of a plug and abandon operation, any of the BHAs may be used to form a window for a sidetrack or directional drilling operation. Alternatively, instead of casing strings, any of the BHAs may be used to mill one or more liner strings. Alternatively, instead of milling sections of the casing strings for plugs and leaving portions of the casing strings in the wellbore, the RCW mills may be used to remove the casing strings from the wellbore. Alternatively, instead of milling the entire casing string sections, a plurality of mini-sections may be milled in the casing strings.

[0078] Alternatively, each of the mills may include a control module for receiving instruction signals from the surface, thereby obviating the shear screws. Each control module may include a hydraulic or mechanical lock for restraining movement of the flow tube until the control module receives the instruction signal for releasing the flow tube from surface. The instruction signal may sent by modulating rotation of the workstring, modulating injection rate of the milling fluid, modulating pressure of the milling fluid (mud pulse), electromagnetic telemetry, transverse electromagnetic telemetry, radio frequency identification (RFID) tag, or conductors extending along the conveyor string. The control module may further include a transmitter for transmitting acknowledgment of the instruction signal, such as a mud pulser, electromagnetic or transverse electromagnetic transmitter, or RFID tag launcher. Each control module may further include a position sensor operable to monitor movement of the flow tube and the control module may transmit measurements of the position sensor to the telemetry sub for relay to the surface.

[0079] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope of the invention is determined by the claims that follow.

[0080] The following numbered clauses set out some

features of the present disclosure.

[0081] Clause 1. A mill for use in a wellbore, comprising:

5 a tubular housing having a bore therethrough and a plurality of eccentrically arranged pockets formed in a wall thereof;
an arm disposed in each pocket, each arm:

10 having a body portion and a blade portion extending from an outer surface of the body portion, and
movable between an extended position and a retracted position;

15 cutters disposed along each blade portion;
a block disposed in each pocket and connected to the housing, each block having:

20 a guide engaged with a mating guide of the respective body portion; and
an inner passage for providing fluid communication between the housing bore and the respective pocket; and

25 an actuator for extending the arms.

[0082] Clause 2. The mill of clause 1, wherein:

30 each block comprises a body and a stop connected thereto for receiving the respective arm in the extended position,
each block further has an outer passage for providing fluid communication between the housing bore and the respective stop, and
35 each arm is operable to close the respective outer passage in the extended position.

[0083] Clause 3. The mill of clause 2, wherein each block further comprises a jet disposed in each passage.

[0084] Clause 4. The mill of clause 1, wherein:

45 each block comprises a body and a stop connected thereto for receiving the respective arm in the extended position,
each block further has an outer passage for providing fluid communication between the housing bore and the respective stop, and
each stop has a valve operable to close the respective outer passage response to extension of the respective arm.

[0085] Clause 5. The mill of clause 1, wherein:

55 each block has a port formed therethrough for providing fluid communication with the respective inner passage,
the housing has a port for each pocket, each port

extending from the bore thereof to an outer surface thereof and intersecting the respective pocket, and the mill further comprises a plug disposed in each housing port for diverting flow from the respective housing port to the respective block port.

[0086] Clause 6. The mill of clause 1, wherein the actuator comprises:

a piston disposed in a chamber formed in the housing,
a pusher for each pocket, each pusher connected to the piston and extending through a respective slot formed in the housing and into the respective pocket.

[0087] Clause 7. The mill of clause 6, further comprising a plurality of shearable fasteners, each shearable fastener connecting the respective pusher to the housing with the arms in the retracted position.

[0088] Clause 8. The mill of clause 6, further comprising a mandrel in sealing engagement with the housing and having one or more ports formed through a wall thereof for providing fluid communication between the bore thereof and the chamber.

[0089] Clause 9. The mill of clause 8, further comprising a nozzle connected to the mandrel below the mandrel ports.

[0090] Clause 10. The mill of clause 8, wherein the mandrel has a receiver formed in an inner surface thereof below the mandrel ports for receiving a pump down plug.

[0091] Clause 11. The mill of clause 1, further comprising a pad formed or disposed on an exposed portion of the outer surface of each body portion.

[0092] Clause 12. The mill of clause 1, wherein:

an outer surface of each blade portion tapers outwardly, and
each blade portion has a length substantially less than a length of the body portion.

[0093] Clause 13. The mill of clause 1, wherein:

each blade portion has a length corresponding to a length of the body portion, and
an outer surface of each blade portion is straight.

[0094] Clause 14. The mill of clause 1, wherein:

the cutters are a first row of cutters,
the mill further comprises a second row of cutters, and
the cutter rows are offset.

[0095] Clause 15. The mill of clause 1, wherein:

an outer diameter of the housing corresponds to a drift diameter of an inner casing string,
each block comprises a stop for receiving the re-

spective arm in the extended position, and
a sweep of the extended blade portions corresponds to a coupling diameter of the inner casing string.

[0096] Clause 16. A bottomhole assembly (BHA) for use in a wellbore, comprising:

a window mill of clause 15, wherein each blade portion has a length substantially less than a length of the body portion; and
a section mill of clause 15, wherein each blade portion has a length corresponding to a length of the body portion.

[0097] Clause 17. A method of using the BHA of clause 16, comprising:

deploying the BHA into the wellbore through the inner casing string,
extending arms of the window mill and radially cutting through the inner casing string, thereby forming a window through the inner casing string;
longitudinally advancing the BHA while longitudinally milling the inner casing string using the extended window mill, thereby opening the window; and
extending arms of the section mill through the window and longitudinally milling a section of the inner casing string.

[0098] Clause 18. The mill of clause 1, wherein:

an outer diameter of the housing corresponds to a drift diameter of an inner casing string;
each block comprises a stop for receiving the respective arm in the extended position,
a sweep of the extended blade portions corresponds to a coupling diameter of an outer casing string.

[0099] Clause 19. A bottomhole assembly (BHA) for use in a wellbore, comprising:

a window mill of clause 18, wherein each blade portion has a length substantially less than a length of the body portion; and
a section mill of clause 18, wherein each blade portion has a length corresponding to a length of the body portion.

[0100] Clause 20. The BHA of clause 19, further comprising a stabilizer, comprising:

a tubular housing having a bore therethrough and a plurality of eccentrically arranged pockets formed in a wall thereof;
an arm disposed in each pocket, each arm movable between an extended position and a retracted position;
a pad formed or disposed on an outer surface of

each arm;
a block disposed in each pocket and connected to the housing, each block having:

a guide engaged with a mating guide of the respective body portion; and
an inner passage for providing fluid communication between the housing bore and the respective pocket; and

a hydraulic actuator for extending the arms.

[0101] Clause 21. A method of using the BHA of clause 19, comprising:

deploying the BHA into the wellbore through the inner casing string,
extending arms of the window mill through a previously milled window or section of the inner casing string and radially cutting through the outer casing string, thereby forming a window through the outer casing string;
longitudinally advancing the BHA while longitudinally milling the outer casing string using the extended window mill, thereby opening the outer window; and
extending arms of the section mill through the outer window and longitudinally milling a section of the outer casing string.

[0102] Clause 22. A milling system for use in a wellbore, comprising:

a first BHA, comprising:

a window mill of clause 1; and
a section mill of clause 1,

a second BHA, comprising:

a window mill of clause 1; and
a section mill of clause 1,

wherein:

an outer diameter of each housing corresponds to a drift diameter of an inner casing string, each block comprises a stop for receiving the respective arm in the extended position, and a sweep of the extended first mill blade portions corresponds to a coupling diameter of the inner casing string,
a sweep of the extended second mill blade portions corresponds to a coupling diameter of an outer casing string,
each blade portion of the window mills has a length substantially less than a length of the body portion, and
each blade portion of the section mills has a

length corresponding to a length of the body portion.

[0103] Clause 23. A method of using the milling system of clause 22, comprising:

deploying the first BHA into the wellbore through the inner casing string;
extending arms of the first window mill and radially cutting through the inner casing string, thereby forming an inner window through the inner casing string;
longitudinally advancing the first BHA while longitudinally milling the inner casing string using the extended first window mill, thereby opening the inner window; and
extending arms of the first section mill through the inner window and longitudinally milling a section of the inner casing string; and
retrieving the first BHA from the wellbore through the inner casing string; and
deploying the second BHA into the wellbore through the inner casing string,
extending arms of the second window mill through the inner window or milled section of the inner casing string and radially cutting through the outer casing string, thereby forming an outer window through the outer casing string;
longitudinally advancing the second BHA while longitudinally milling the outer casing string using the extended second window mill, thereby opening the outer window; and
extending arms of the second section mill through the outer window and longitudinally milling a section of the outer casing string; and
retrieving the second BHA from the wellbore through the inner casing string.

[0104] Clause 24. A bottomhole assembly (BHA) for use in a wellbore, comprising:

an inner window mill of clause 1;
an inner section mill of clause 1;
an outer window mill of clause 1; and
an outer section mill of clause 1,
wherein:

an outer diameter of each housing corresponds to a drift diameter of an inner casing string, each block comprises a stop for receiving the respective arm in the extended position, and a sweep of the extended inner mill blade portions corresponds to a coupling diameter of the inner casing string,
a sweep of the extended outer mill blade portions corresponds to a coupling diameter of an outer casing string,
each blade portion of the window mills has a length substantially less than a length of the

body portion, and
each blade portion of the section mills has a
length corresponding to a length of the body por-
tion.

[0105] Clause 25. A method of using the BHA of clause 24, comprising:

deploying the BHA into the wellbore through the inner casing string,
extending arms of the inner window mill and radially cutting through the inner casing string, thereby forming an inner window through the inner casing string;
longitudinally advancing the BHA while longitudinally milling the inner casing string using the extended inner window mill, thereby opening the inner window;
and
extending arms of the section mill through the inner window and longitudinally milling a section of the inner casing string;
extending arms of the outer window mill through the inner window or milled section of the inner casing string and radially cutting through the outer casing string, thereby forming an outer window through the outer casing string;
longitudinally advancing the BHA while longitudinally milling the outer casing string using the extended outer window mill, thereby opening the outer window;
and
extending arms of the outer section mill through the outer window and longitudinally milling a section of the outer casing string; and
retrieving the BHA from the wellbore through the inner casing string.

[0106] Clause 26. A bottomhole assembly (BHA) for use in a wellbore, comprising:

a window mill;
a section mill; and
a stabilizer,
wherein:

the mills and the stabilizer each comprise:

a tubular housing having a bore there-
through and a plurality of pockets formed in
a wall thereof;
an arm disposed in each pocket and mov-
able between an extended position and a
retracted position; and
a hydraulic actuator for extending the arms;

an outer diameter of each housing corresponds
to a drift diameter of an inner casing string,
the mills further comprise cutters disposed along
an outer blade portion of each arm,
a sweep of the extended blade portions corre-

sponds to a coupling diameter of an outer casing
string,
the stabilizer further comprises a pad disposed
along an outer surface of each arm,
a sweep of the extended pads corresponds to a
drift diameter of the outer casing string,
the mills and the stabilizer are connected togeth-
er, and
the stabilizer is located below the mills.

[0107] Clause 27. A method of abandoning a wellbore, comprising:

deploying a bottomhole assembly (BHA) into the
wellbore through an inner casing string the BHA, the
BHA comprising a window mill, a section mill, and a
stabilizer located below the mills;
extending arms of the stabilizer through a window or
milled section of the inner casing string and into en-
gagement with an inner surface of an outer casing
string;
extending arms of the window mill through the win-
dow or milled section and radially cutting through the
outer casing string, thereby forming an outer window
through the outer casing string;
longitudinally advancing the BHA while longitudinally
milling the outer casing string using the window mill,
thereby opening the outer window;
extending arms of the section mill through the outer
window and longitudinally milling a section of the out-
er casing string; and
retrieving the BHA from the wellbore through the in-
ner casing string.

[0108] Clause 28. The method of clause 27, wherein
the stabilizer is engaged with the outer casing string dur-
ing extension of the window mill arms, advancement of
the BHA, and extension of the section mill arms.

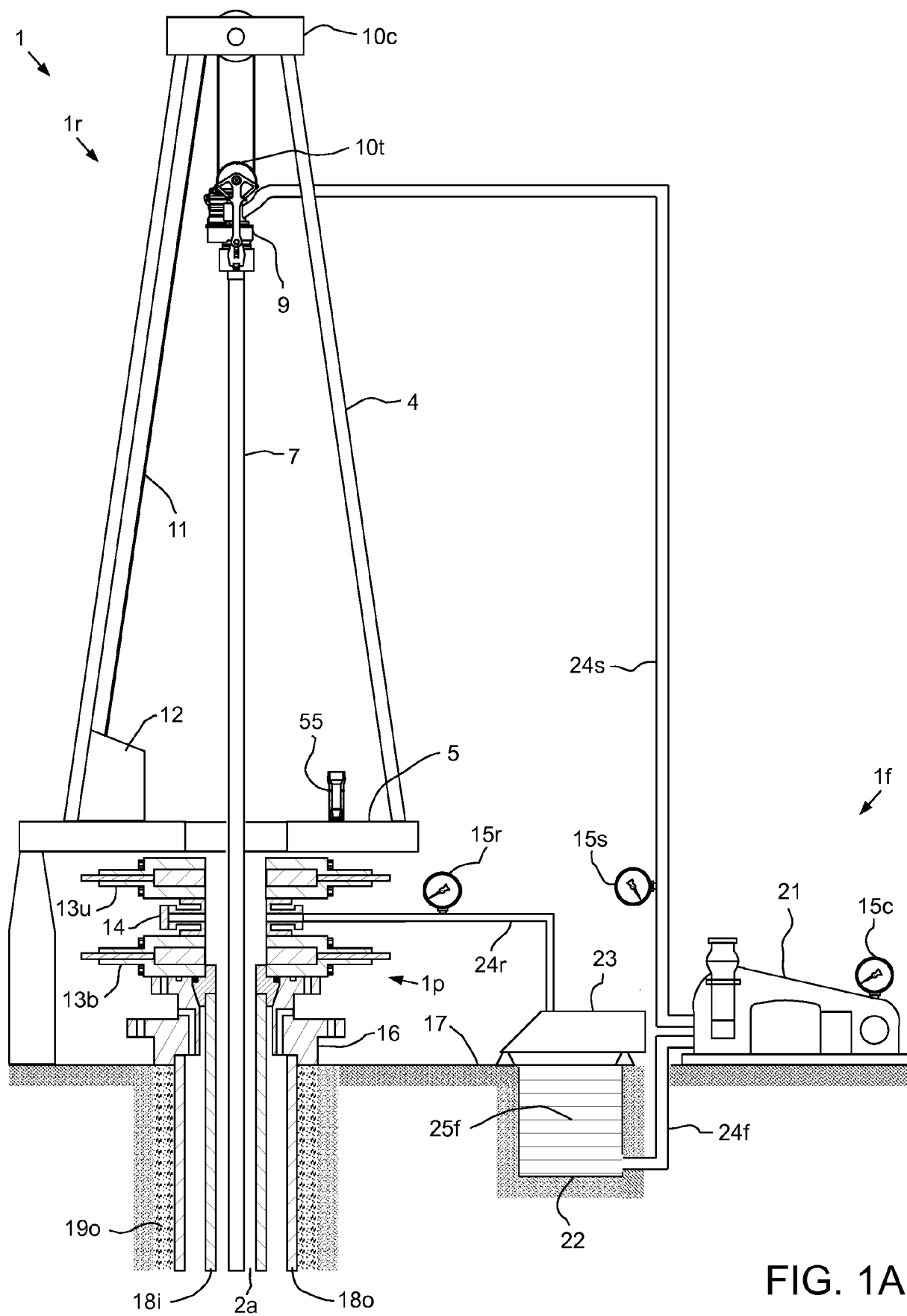
Claims

1. A method of milling an outer casing in a wellbore, comprising:

deploying a bottom hole assembly (BHA) into
the wellbore through an inner casing string, the
BHA comprising a first mill and a stabilizer lo-
cated below the first mill, the first mill and the
stabilizer each comprising a tubular housing
having an upper end, a lower end, and a bore
extending continuously from the upper end to
the lower end;
extending arms of the stabilizer through a win-
dow or milled section of the inner casing string
and into engagement with an inner surface of
an outer casing string;
extending arms of the first mill through the win-

- dow or milled section and radially cutting through the outer casing string, thereby forming an outer window through the outer casing string; longitudinally advancing the BHA while longitudinally milling the outer casing string using the first mill, thereby opening the outer window; and retrieving the BHA from the wellbore and through the inner casing. 5
2. The method according to claim 1, wherein the first mill and stabilizer each comprise a plurality of pockets, wherein each arm: 10
is located within one of the plurality of pockets:
includes an arm length oriented substantially parallel to the longitudinal axis; and 15
is moveable with respect to the corresponding pocket between retracted and extended positions while the arm length is maintained substantially parallel to the longitudinal axis. 20
3. The method according to any preceding claim, wherein extending the arms of the first mill occurs after engaging the outer casing string with the arms of the stabilizer. 25
4. The method according to any preceding claim, further comprising providing fluid pressure in the BHA at a first threshold to extend the arms of the stabilizer. 30
5. The method according to claim 4, further comprising providing fluid pressure in the BHA at a second threshold to extend the arms of the first mill, optionally wherein the second threshold is greater than or equal to the first threshold. 35
6. The method according to any preceding claim, wherein the BHA further comprise a second mill with the stabilizer located below both the first and second mills, the method comprising extending arms of the second mill through the outer window and longitudinally milling a section of the outer casing string. 40
7. A bottomhole assembly (BHA) for use milling an outer casing in a wellbore, the BHA comprising: 45
a mill and a stabilizer located below the mill, wherein the mill and stabilizer each comprise:
a tubular housing having an upper end, a lower end, and a bore extending continuously from the upper end to the lower end; and 50
a plurality of arms moveable between retracted and extended positions, 55
wherein the arms of the stabilizer are extendable through a window or milled section of an inner casing string and into engagement with an inner surface of an outer casing string; and wherein the arms of the mill are extendable through the window or milled section for radially cutting through the outer casing string, thereby forming an outer window through the outer casing string.
8. The BHA according to claim 7, wherein the mill and stabilizer each comprise a plurality of pockets, wherein each arm: 10
is located within one of the plurality of pockets:
includes an arm length oriented substantially parallel to the longitudinal axis; and 15
is moveable with respect to the corresponding pocket between retracted and extended positions while the arm length is maintained substantially parallel to the longitudinal axis.
9. The BHA according to claim 7 or 8, wherein each arm of the mill and stabilizer includes first and second axially spaced guides, and each pocket of the mill and stabilizer includes first and second axially spaced mating guides configured to engage with the first and second axially spaced guides, respectively, of each arm, wherein, in use, longitudinal movement of the arms causes sliding engagement between the respective first and second guides and mating guides to cause the arms to move radially outward. 30
10. The BHA according to claim 7 or 8, wherein each arm of the mill and stabilizer includes upper and lower axially spaced guides, and each of the mill and stabilizer includes: 35
an upper block disposed in each pocket and connected to the housing, the upper block having an upper mating guide for engaging with the upper guide of a corresponding arm;
a lower block disposed in each pocket and connected to the housing, the lower block having a lower mating guide for engaging with the lower guide of a corresponding arm, 40
wherein longitudinal movement the arms to cause sliding engagement between the respective upper and lower guides and mating guides to cause the arms to move radially outward.
11. The BHA according to any one of claims 7 to 10, wherein the arms of the mill and the arms of the stabilizer each have an outer surface including an engagement material, the engagement material being harder than a material of the outer casing. 45
12. The BHA according to claim 11, wherein the engagement material is in the form of a pad. 50

13. The BHA according to claim 11 or 12, wherein the engagement material on the outer surface of the arms of the first mill extends along a portion of the arm lengths of each arm of the mill, and the engagement material on the outer surface of the arms of the stabilizer extends along a portion of the arm lengths of each arm of the stabilizer. 5
14. The BHA according to any one of claims 7 to 13, wherein the mill is movable between a deployment configuration and a casing cutting configuration, and wherein when the mill is in the casing cutting configuration, a lateral blade sweep dimension is at least equal to a coupling diameter of the casing. 10 15
15. The BHA according to any one of claims 7 to 14, wherein the stabilizer is movable between a deployment configuration and a stabilizing configuration, and wherein when the stabilizer is in the stabilizing configuration, a lateral sweep dimension is at least equal to a drift diameter of the outer casing. 20 25 30 35 40 45 50 55



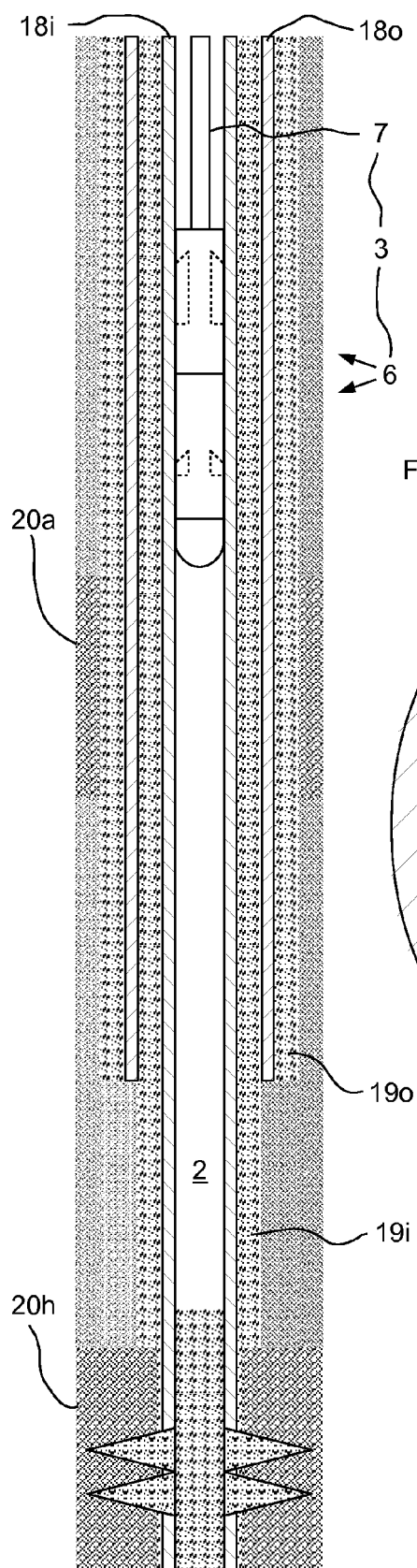


FIG. 1B

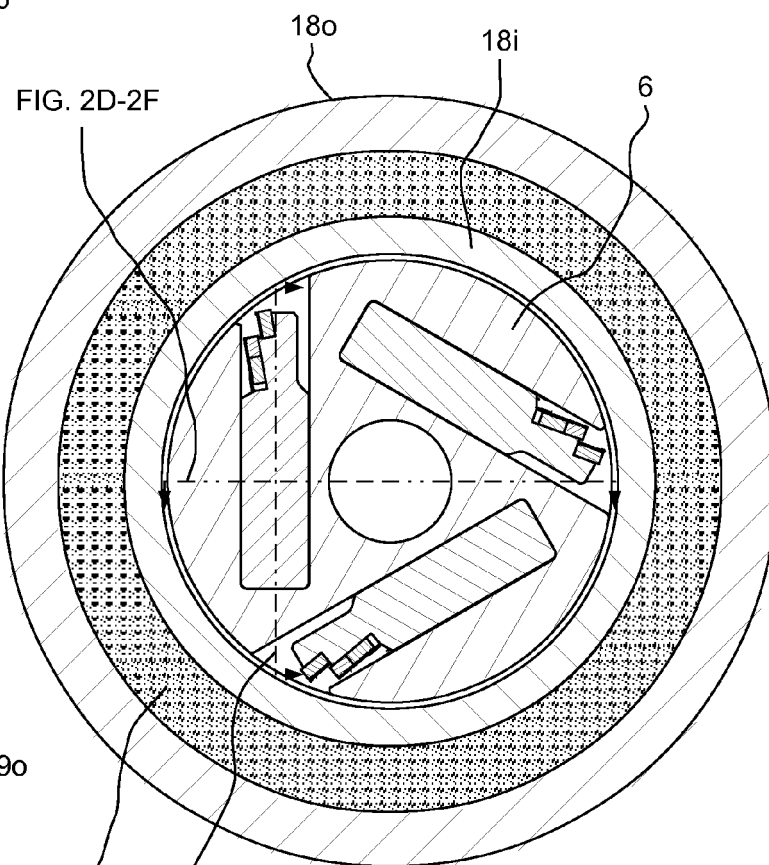


FIG. 1C

FIG. 2A-2C

FIG. 2D-2F

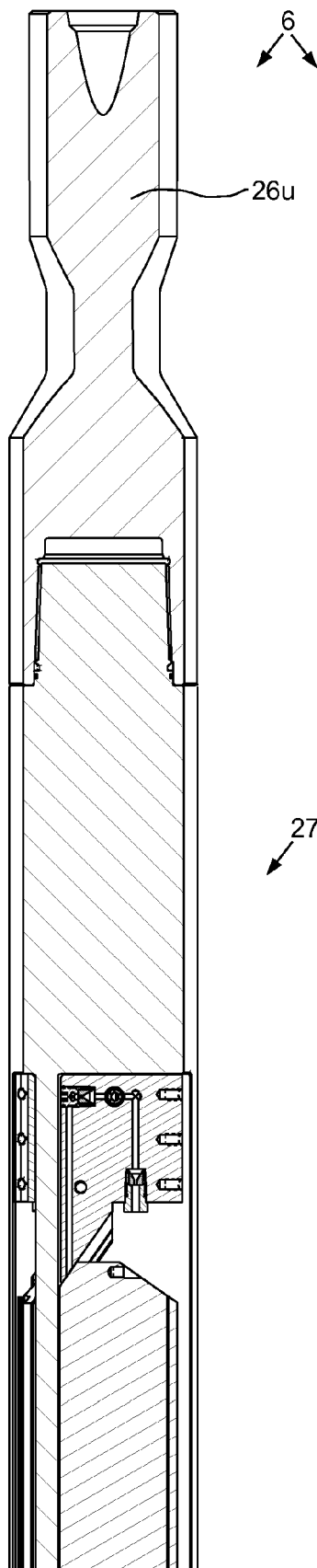


FIG. 2A

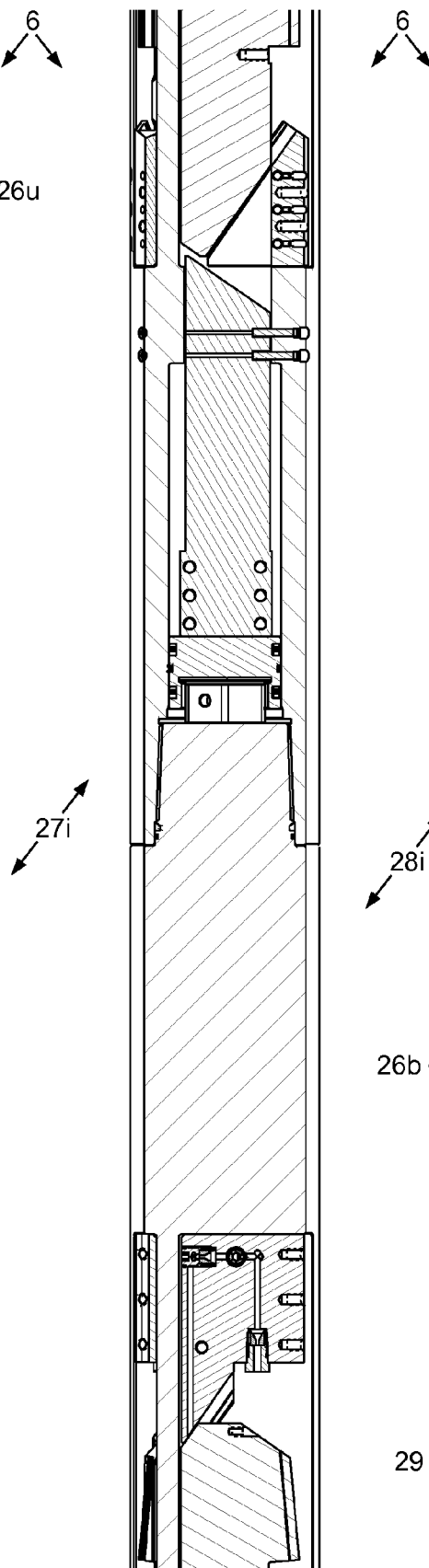


FIG. 2B

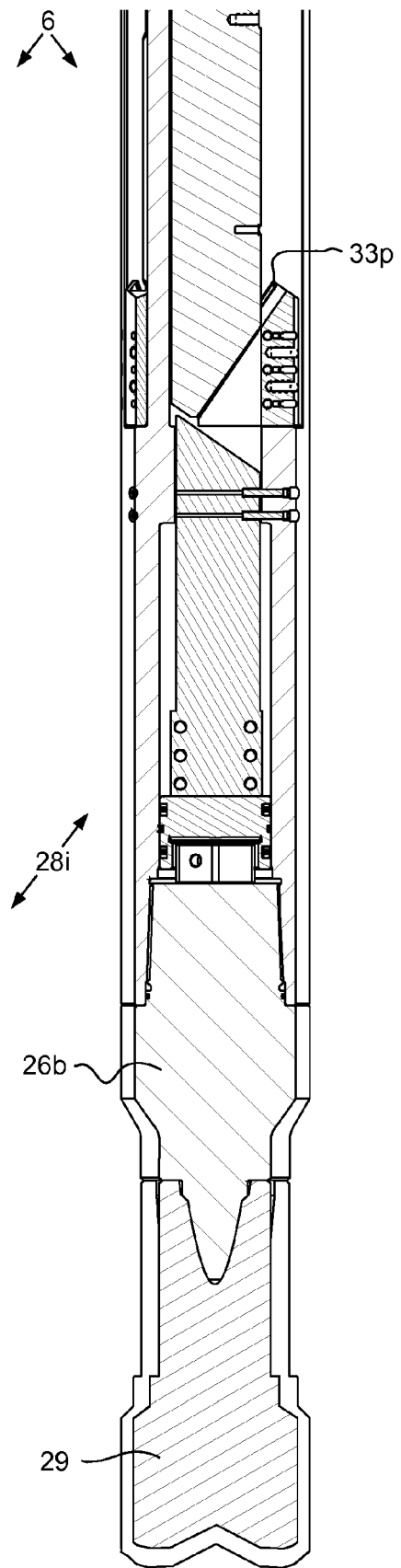
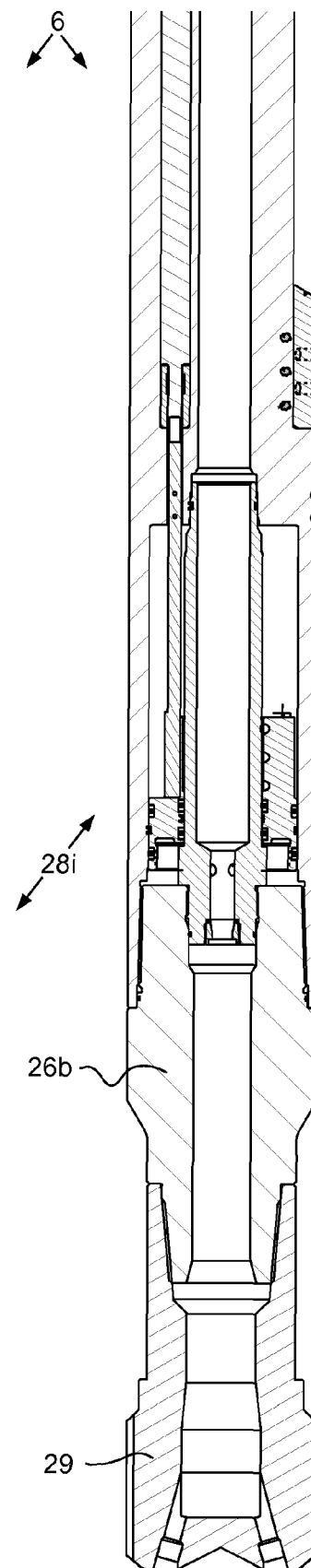
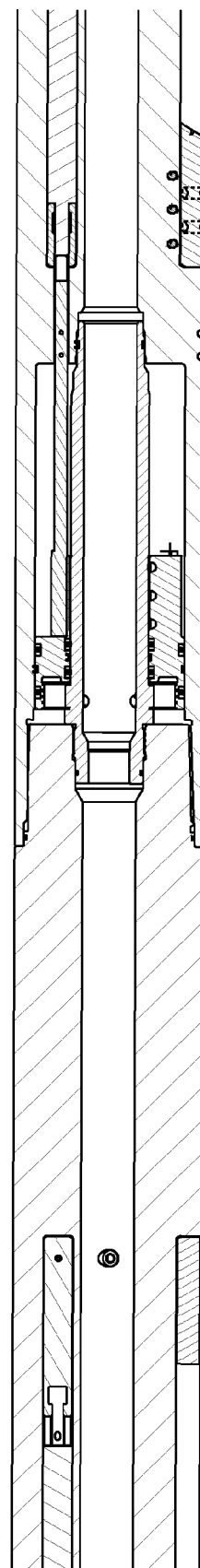
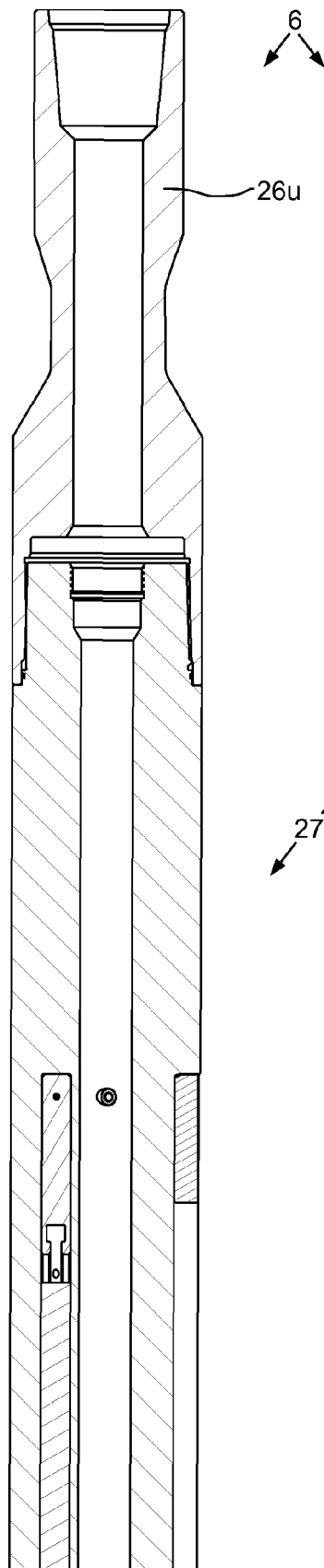
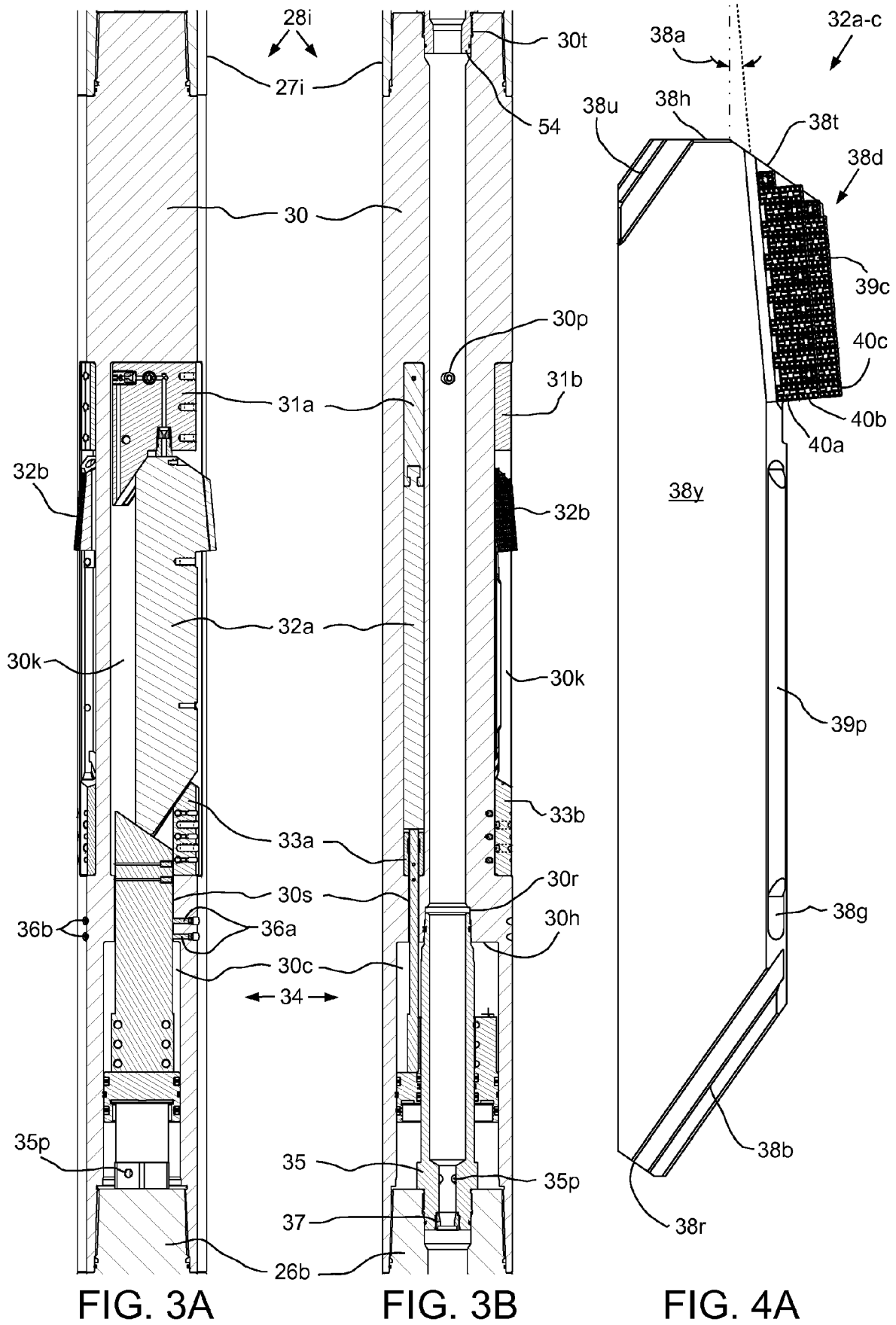


FIG. 2C





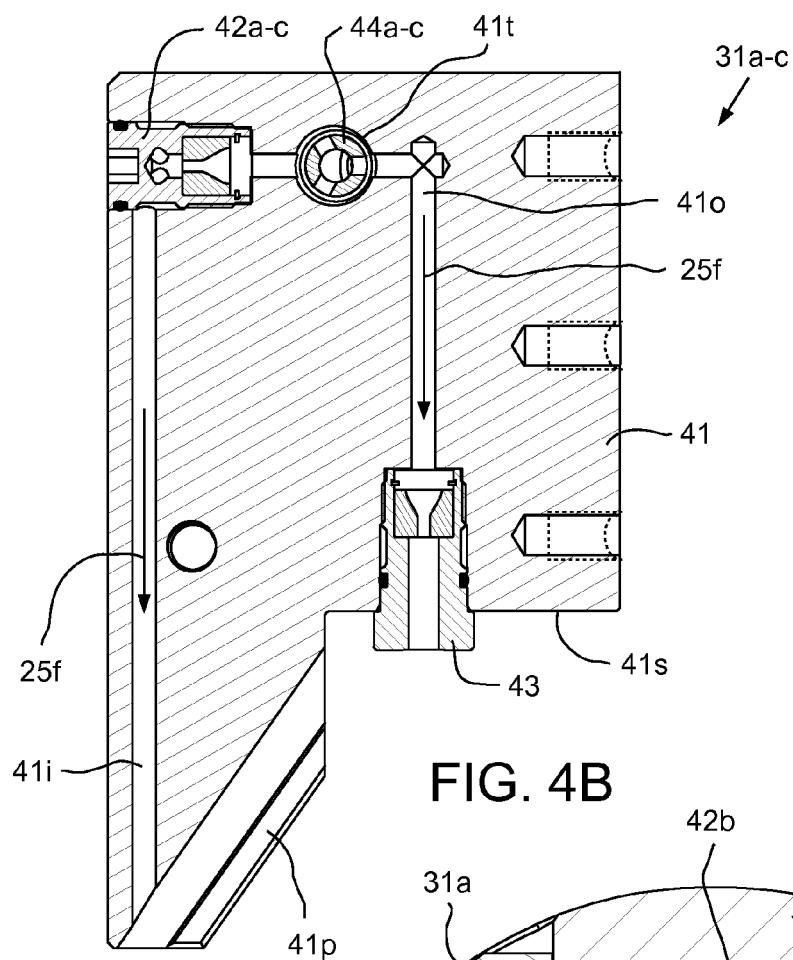


FIG. 4B

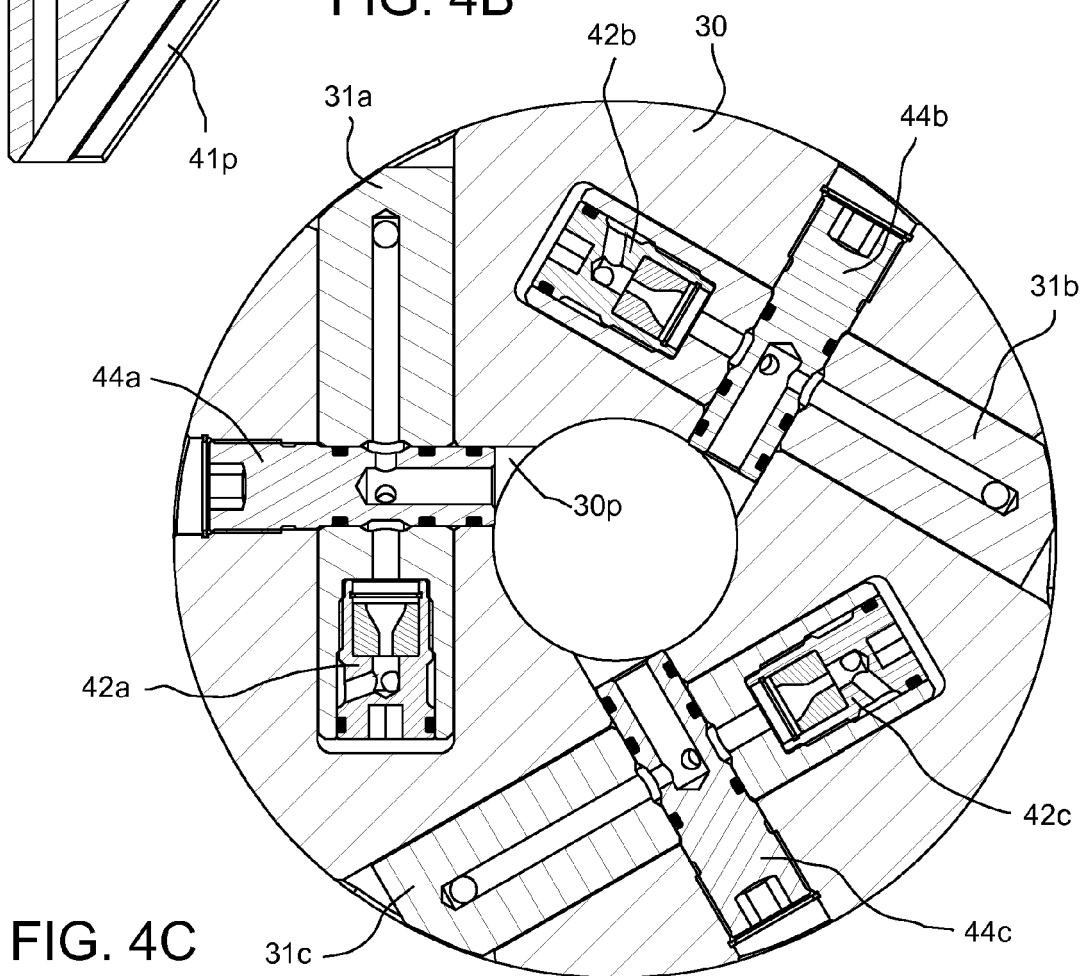


FIG. 4C

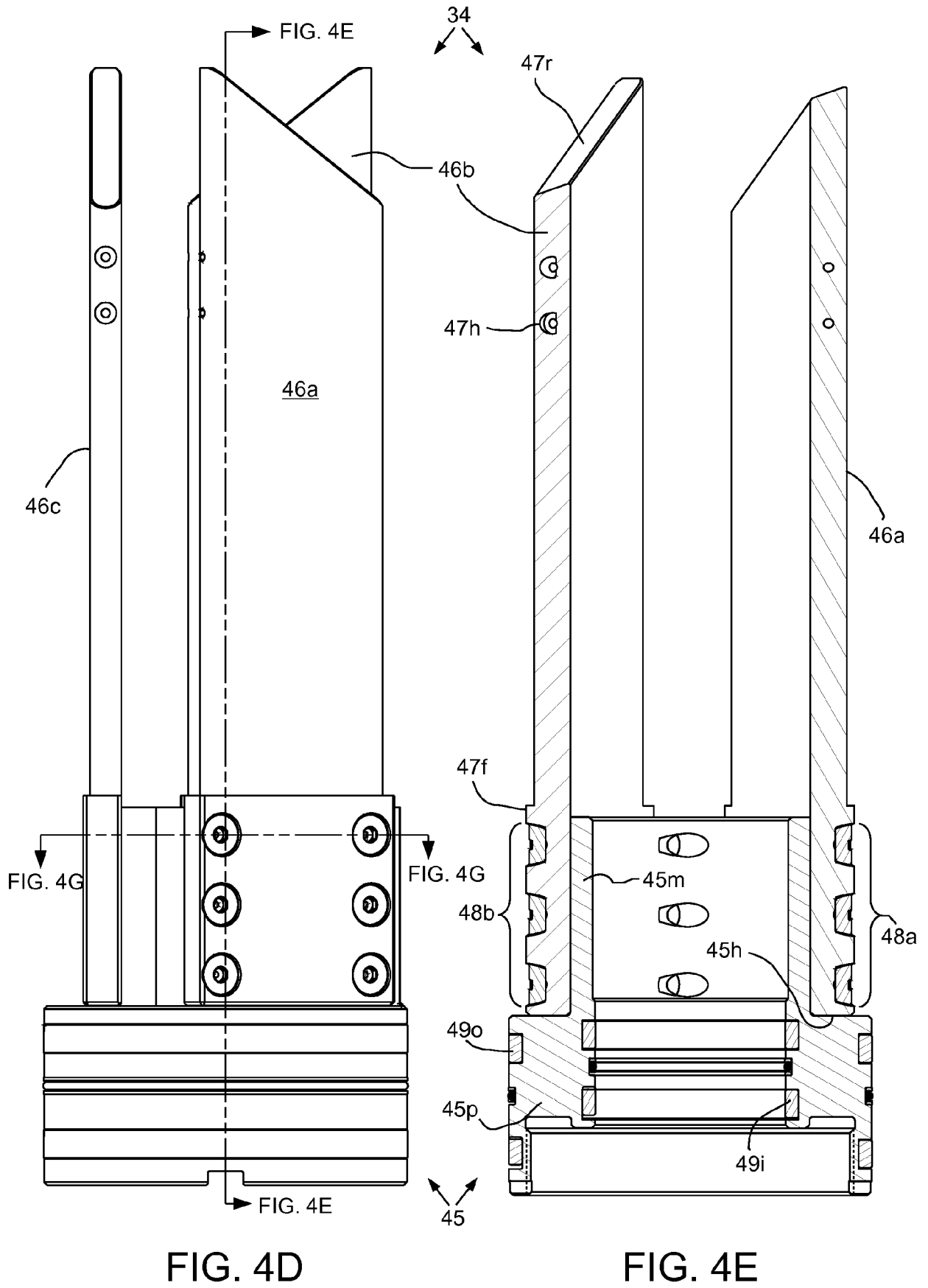


FIG. 4F

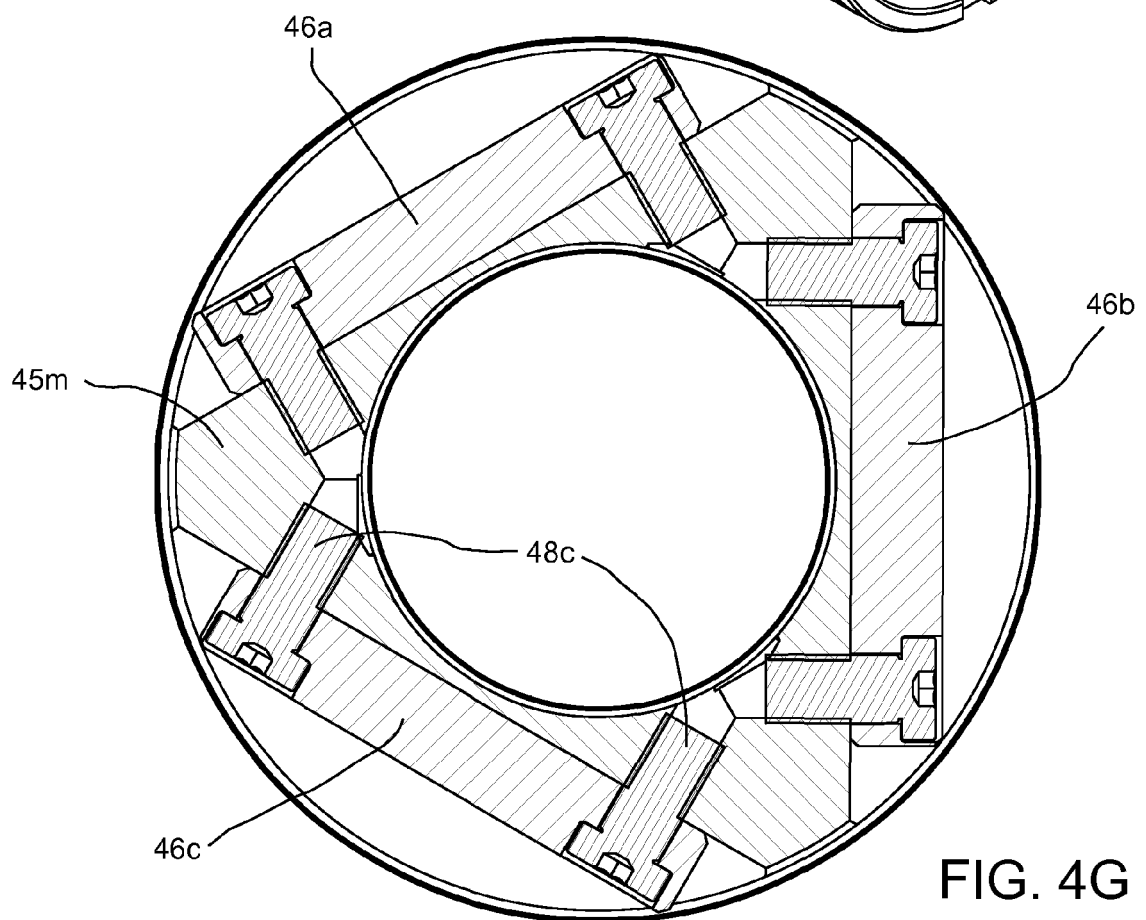
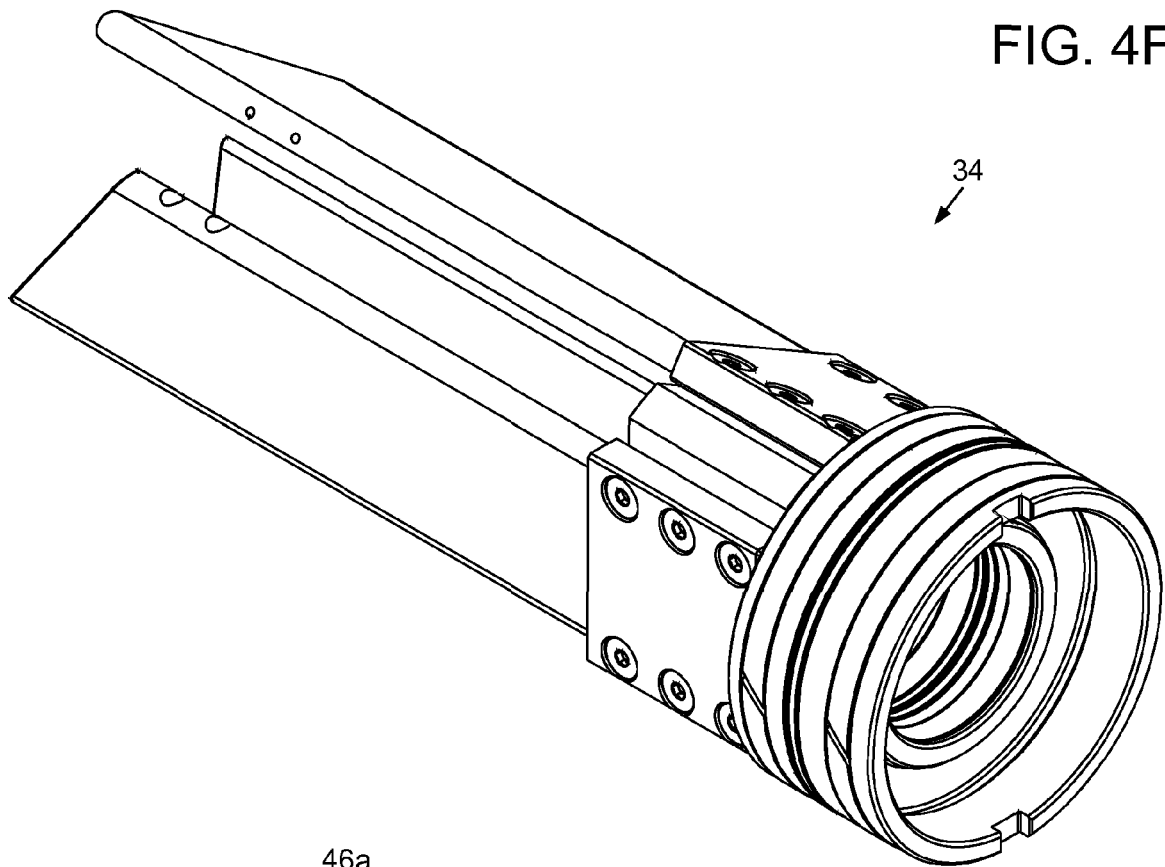


FIG. 4G

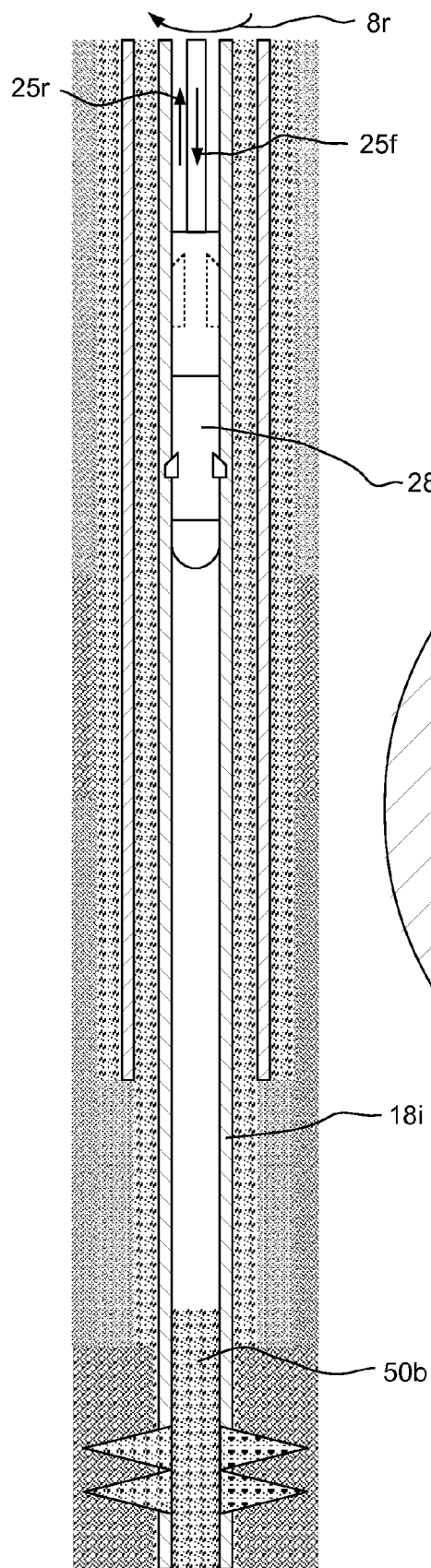


FIG. 5A

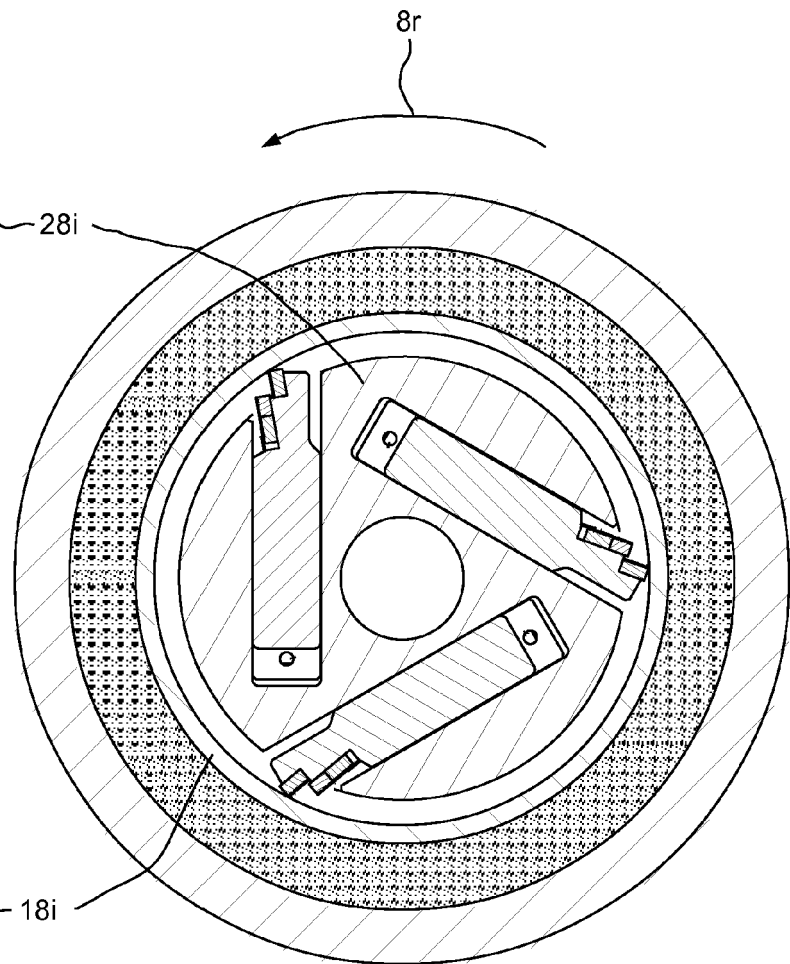


FIG. 5B

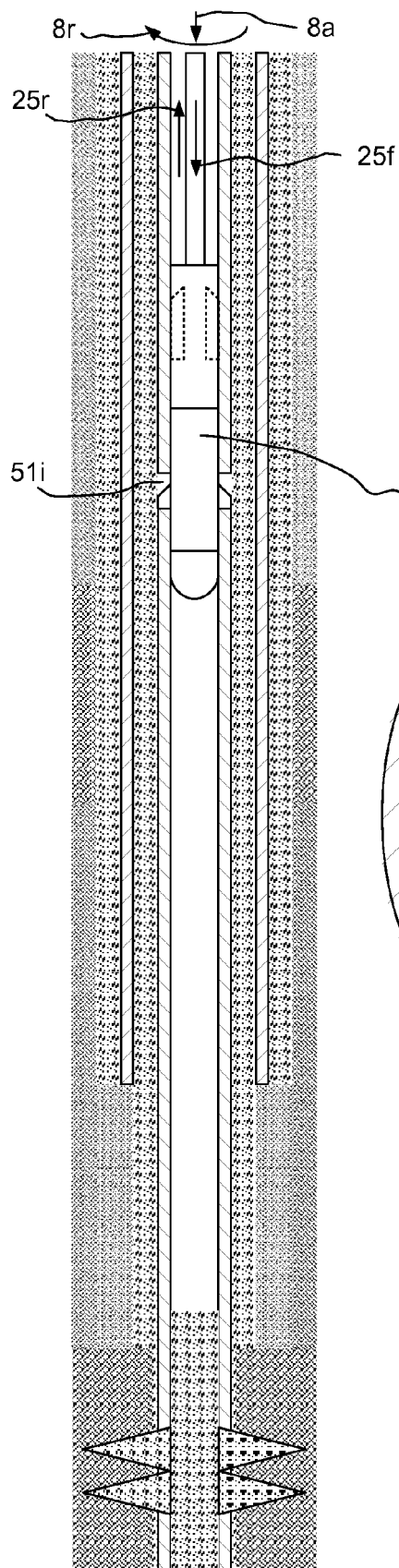


FIG. 5C

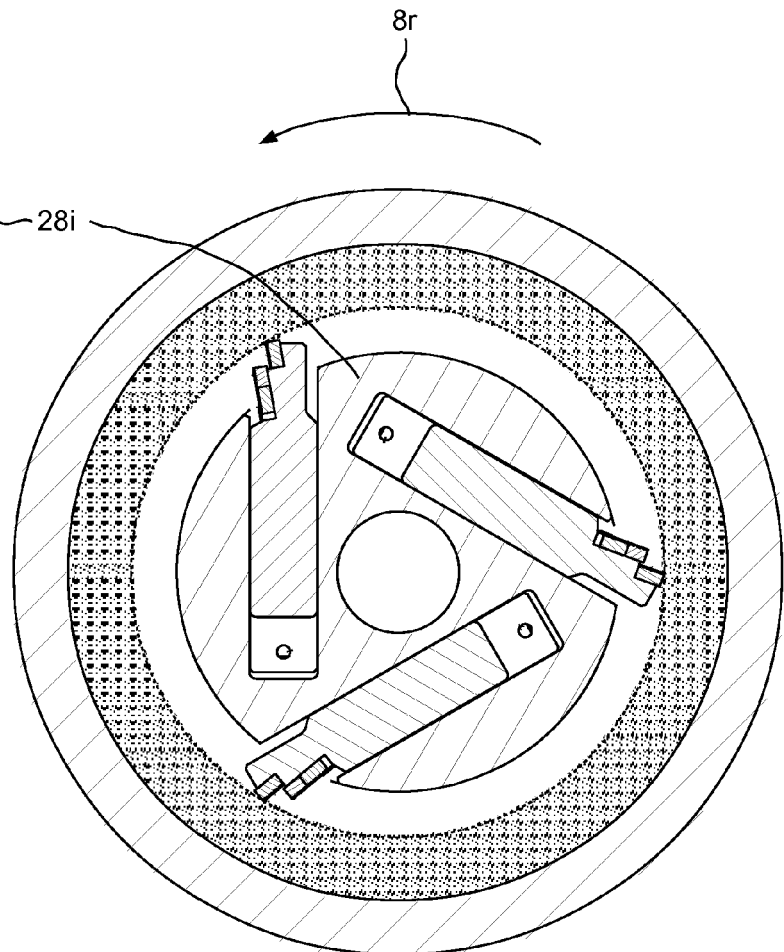


FIG. 5D

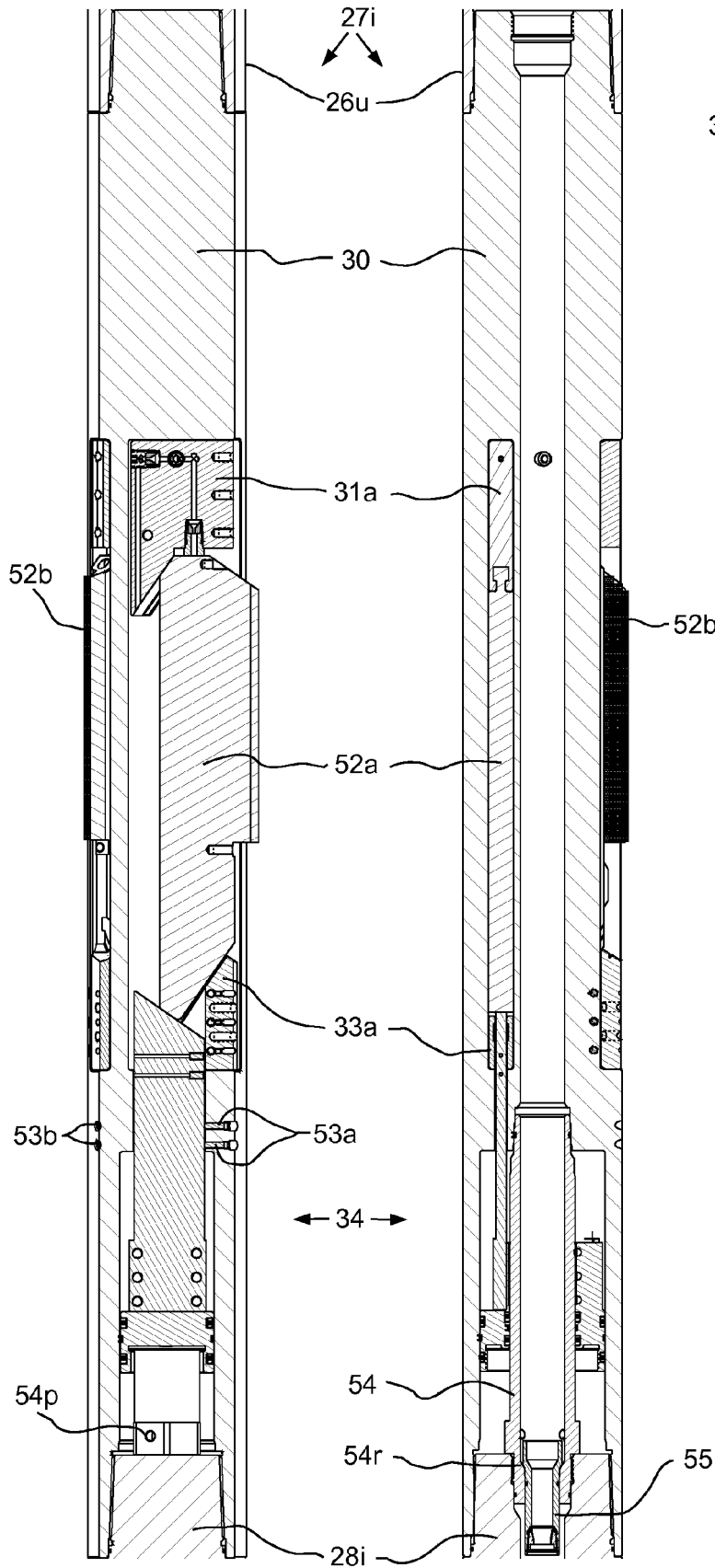


FIG. 6A

FIG. 6B

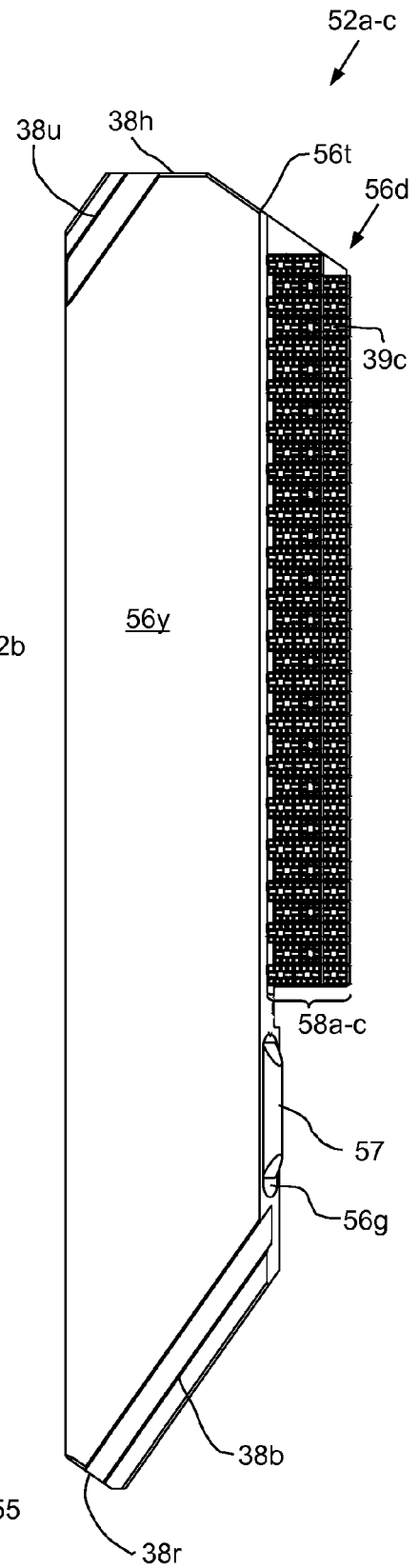


FIG. 6C

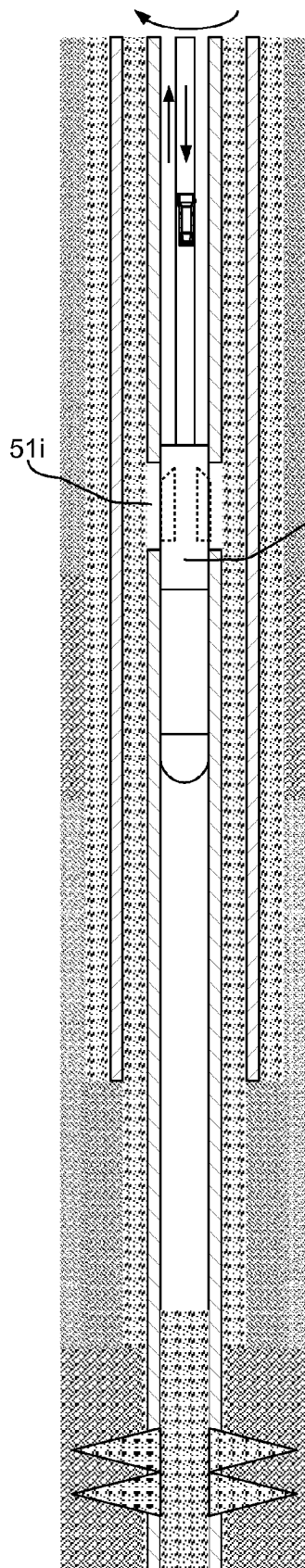


FIG. 7A

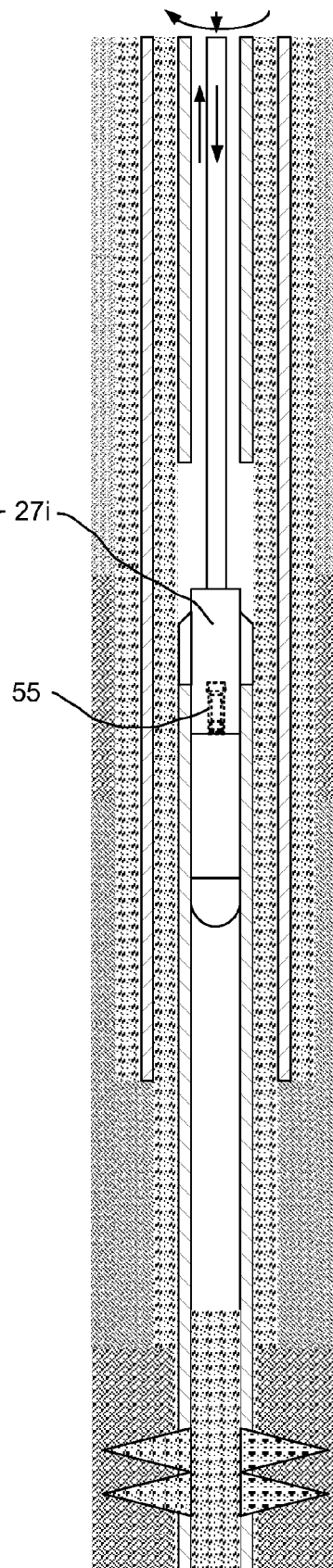


FIG. 7B

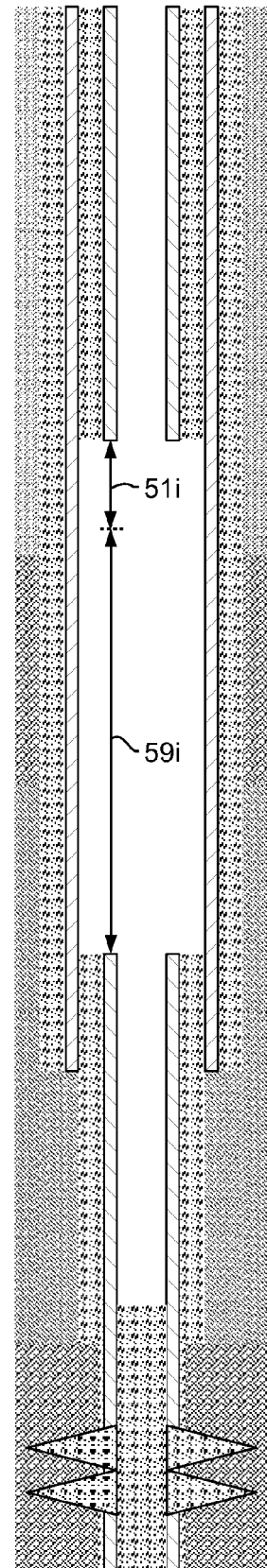
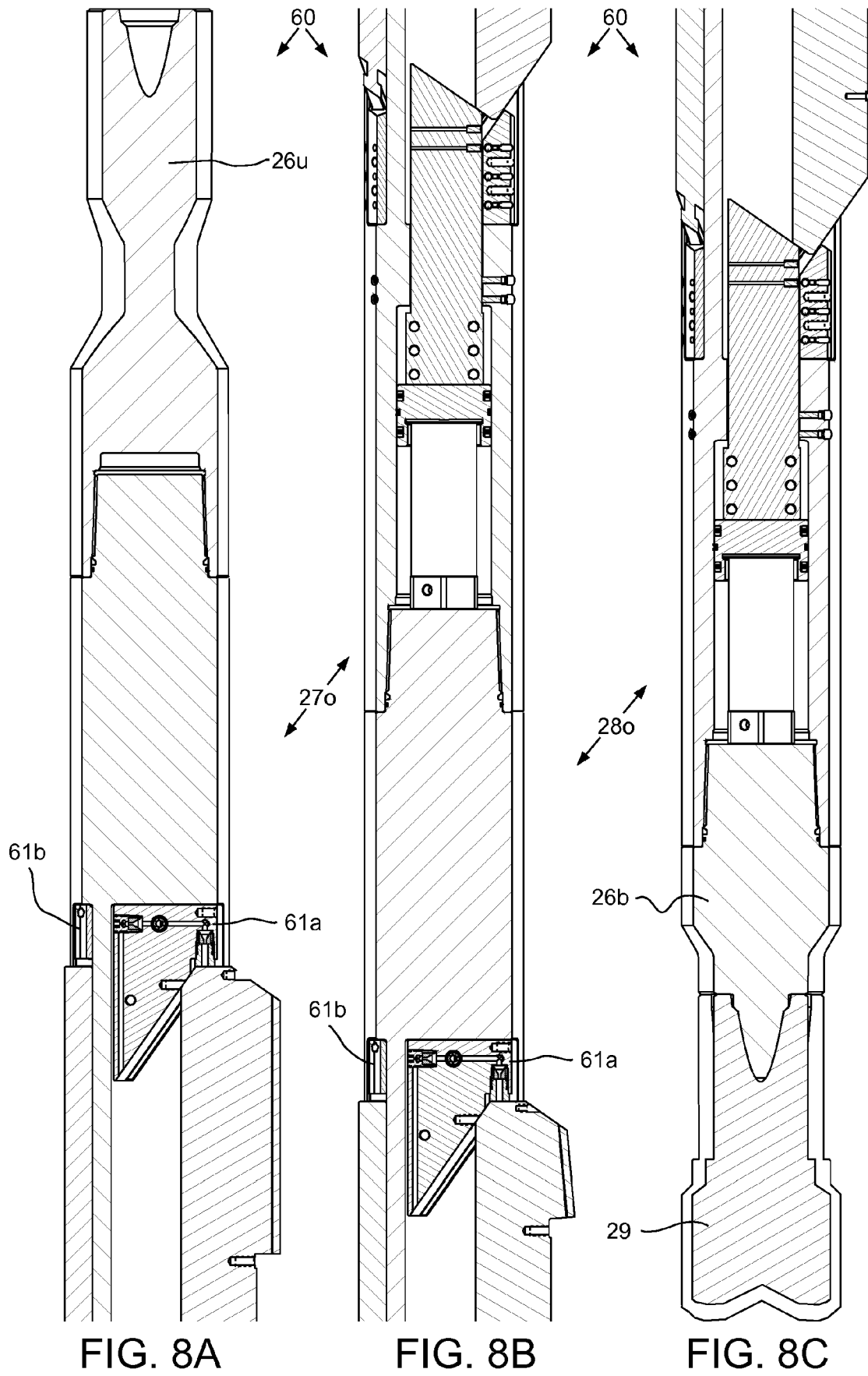
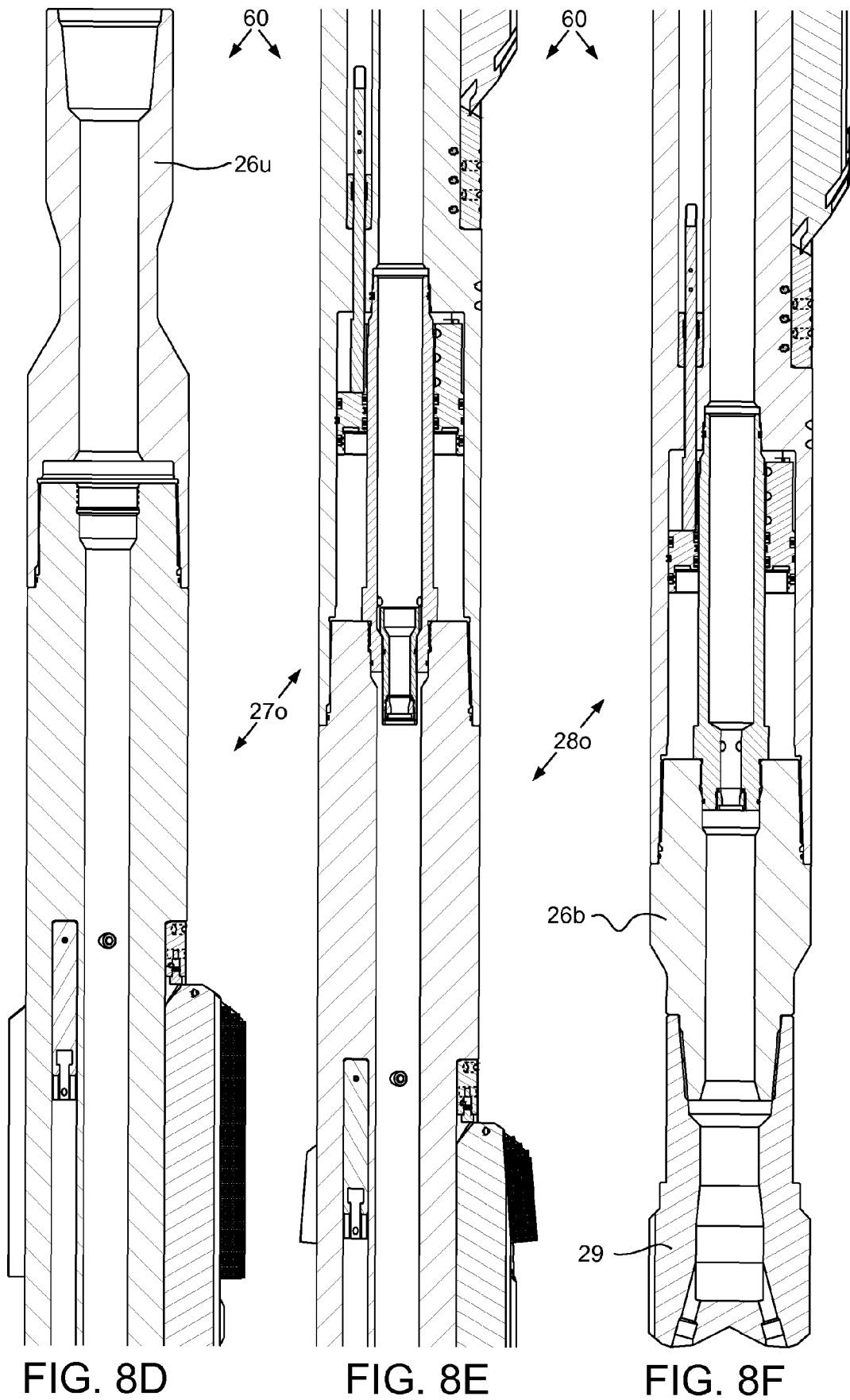
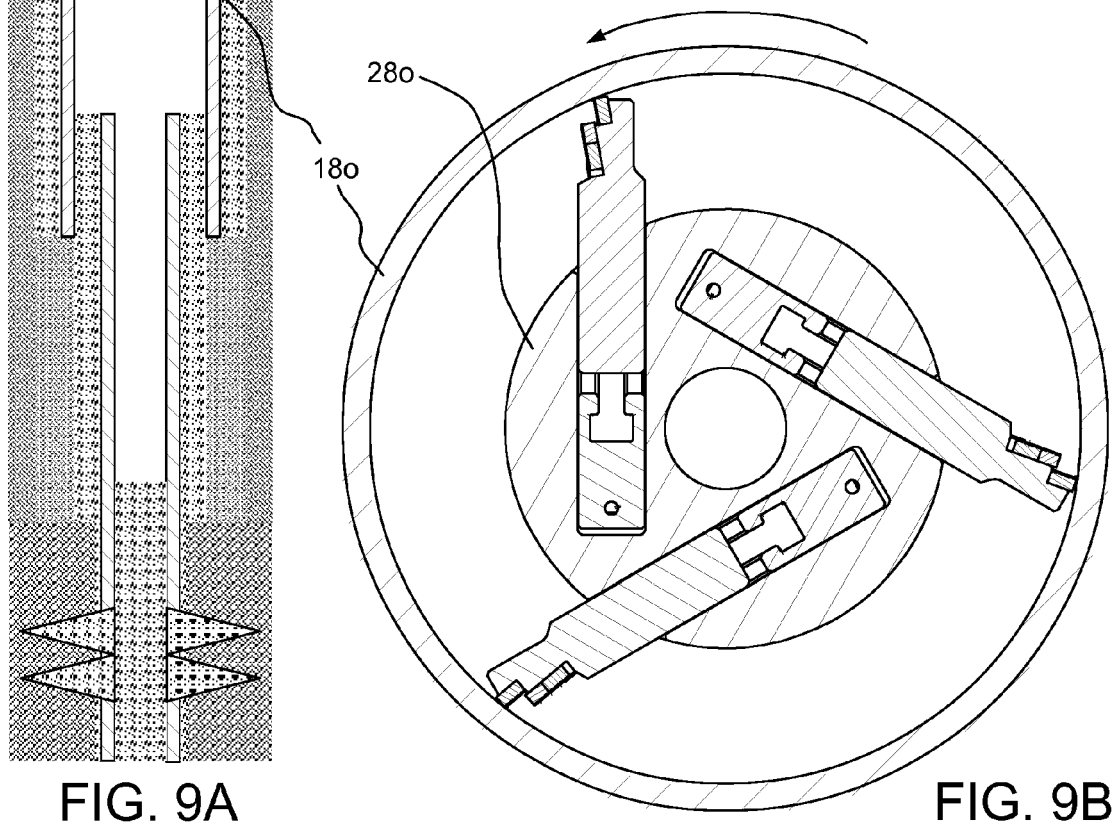
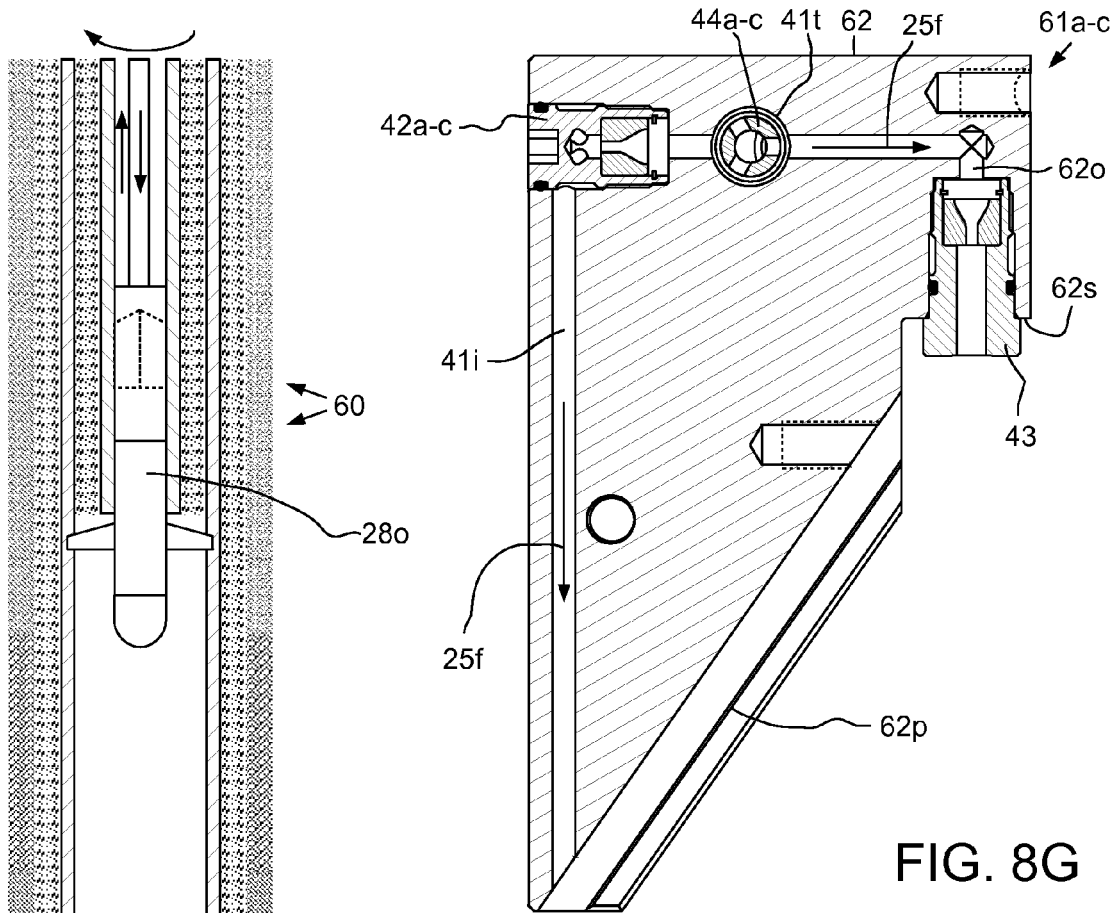


FIG. 7C







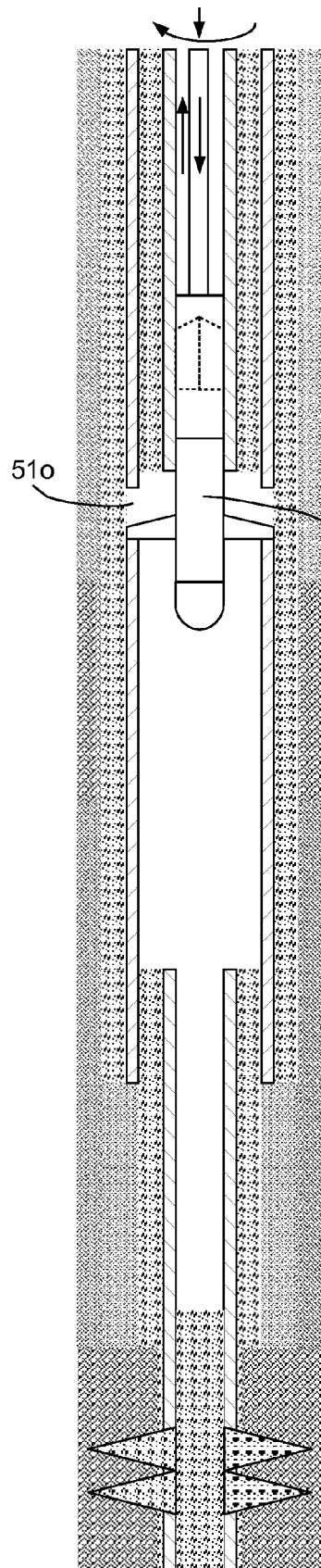


FIG. 9C

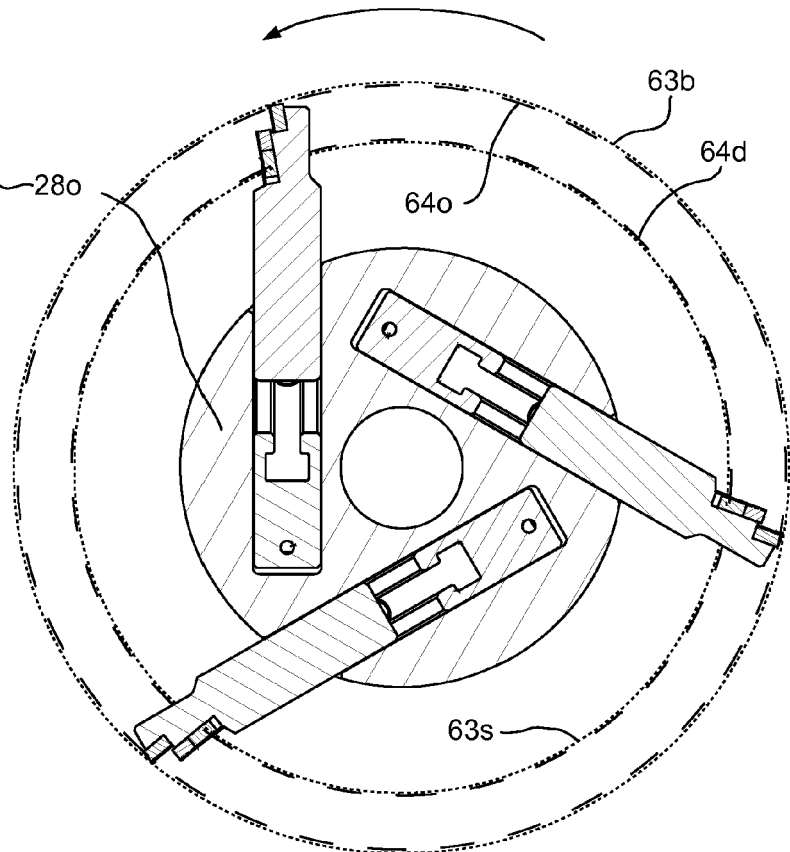


FIG. 9D

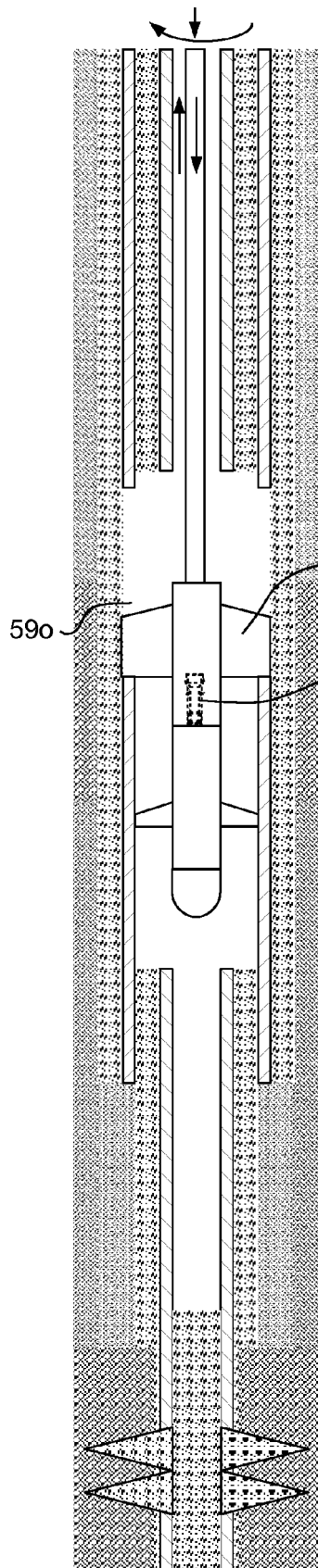


FIG. 9E

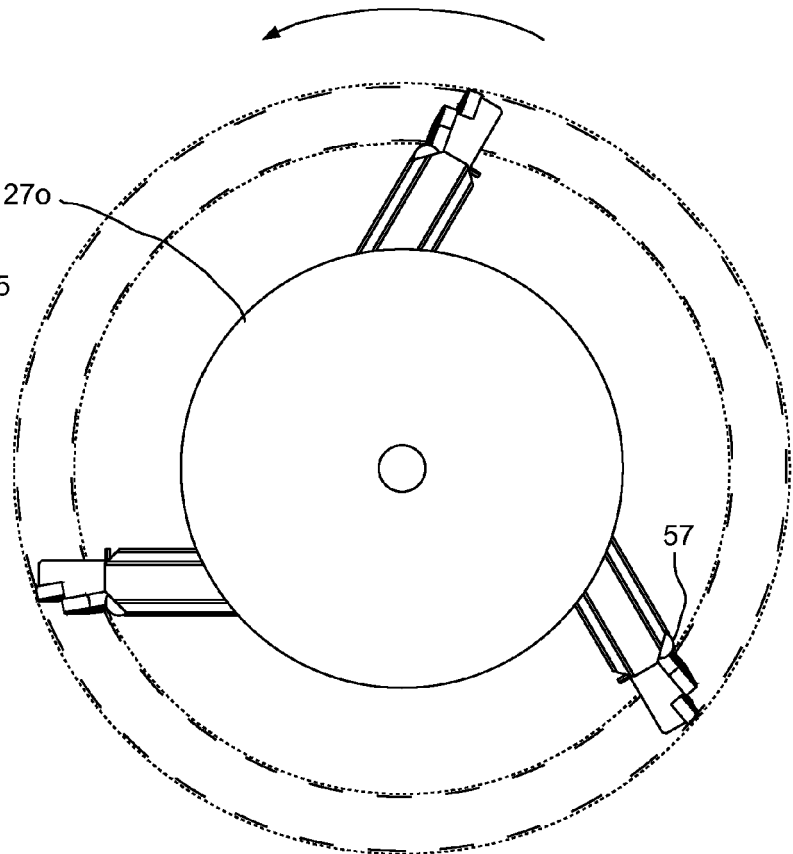


FIG. 9F

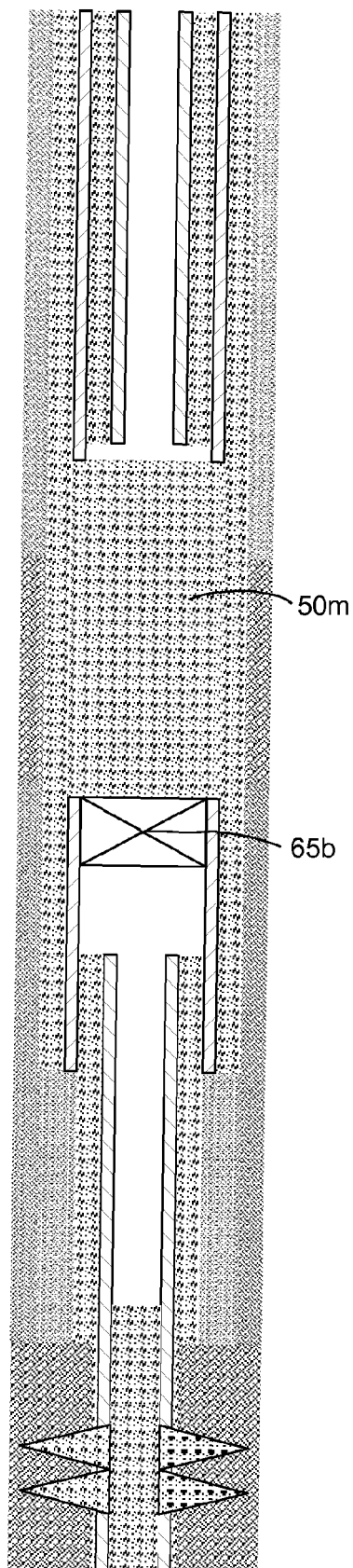


FIG. 10A

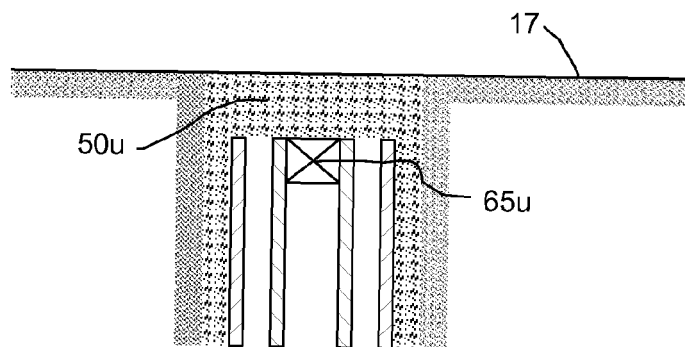


FIG. 10B

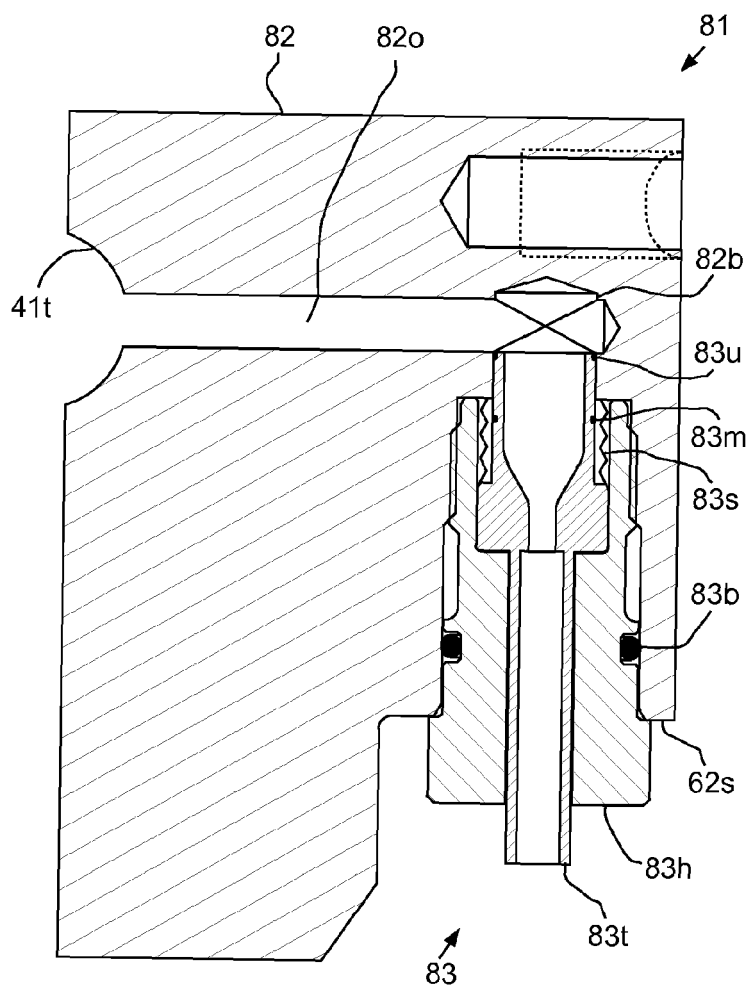


FIG. 13

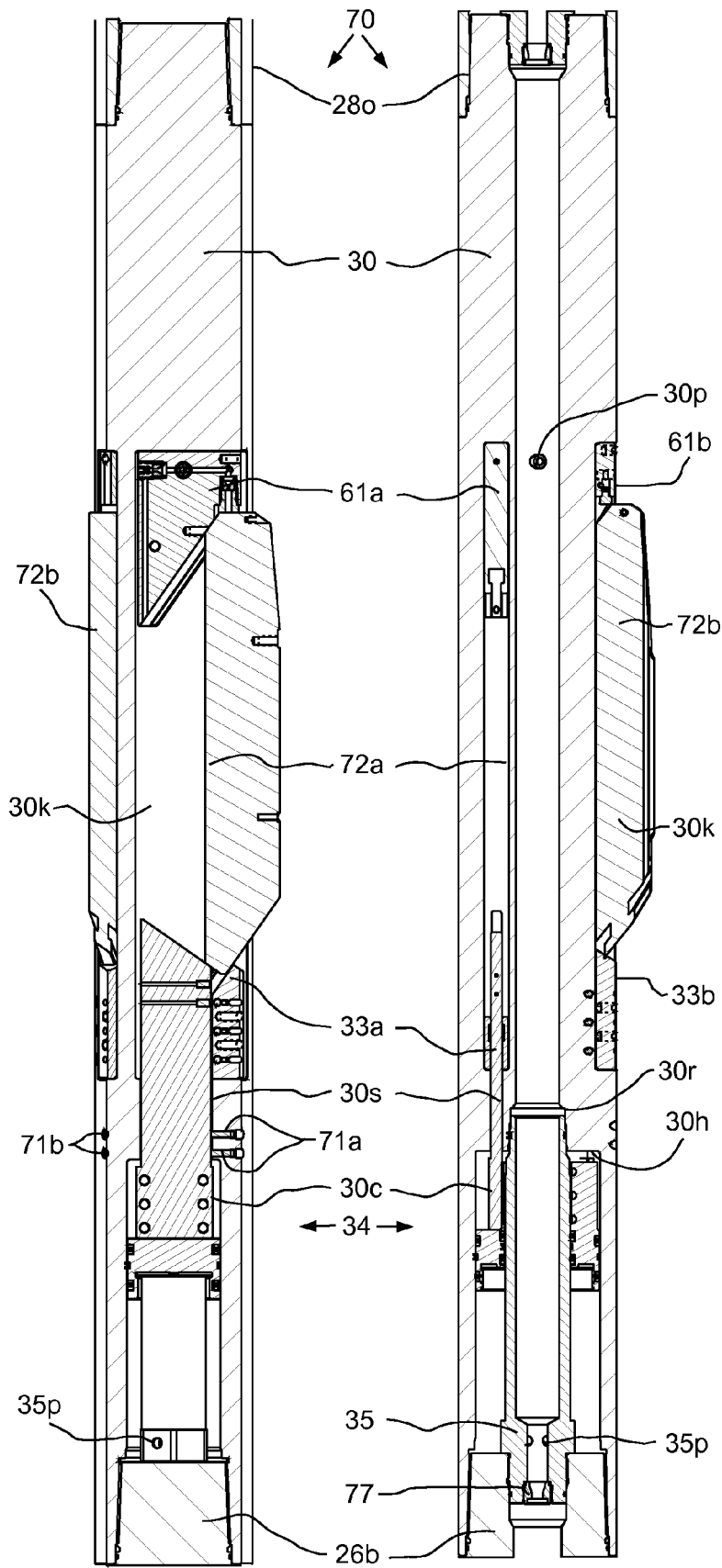


FIG. 11A

FIG. 11B

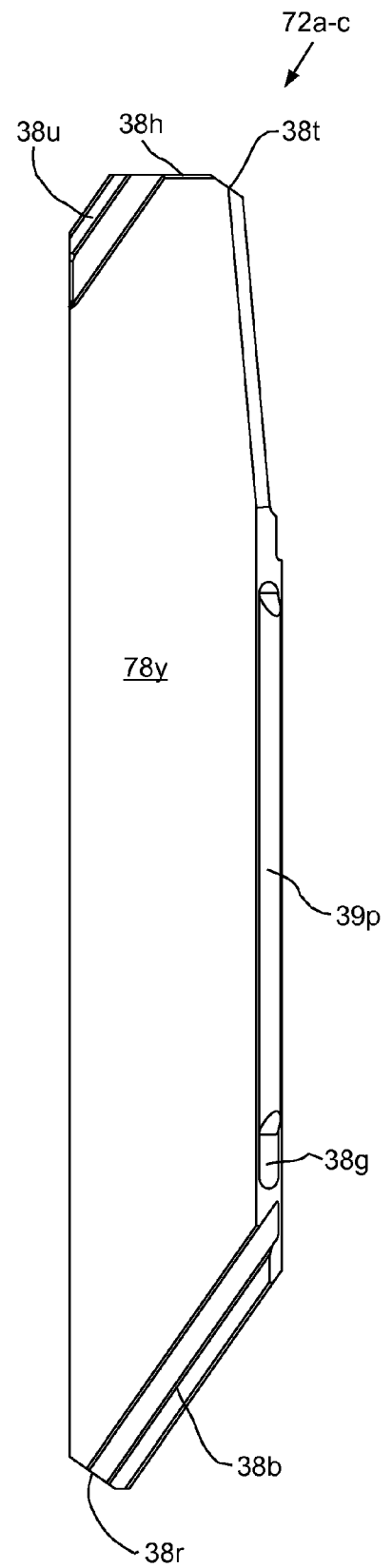
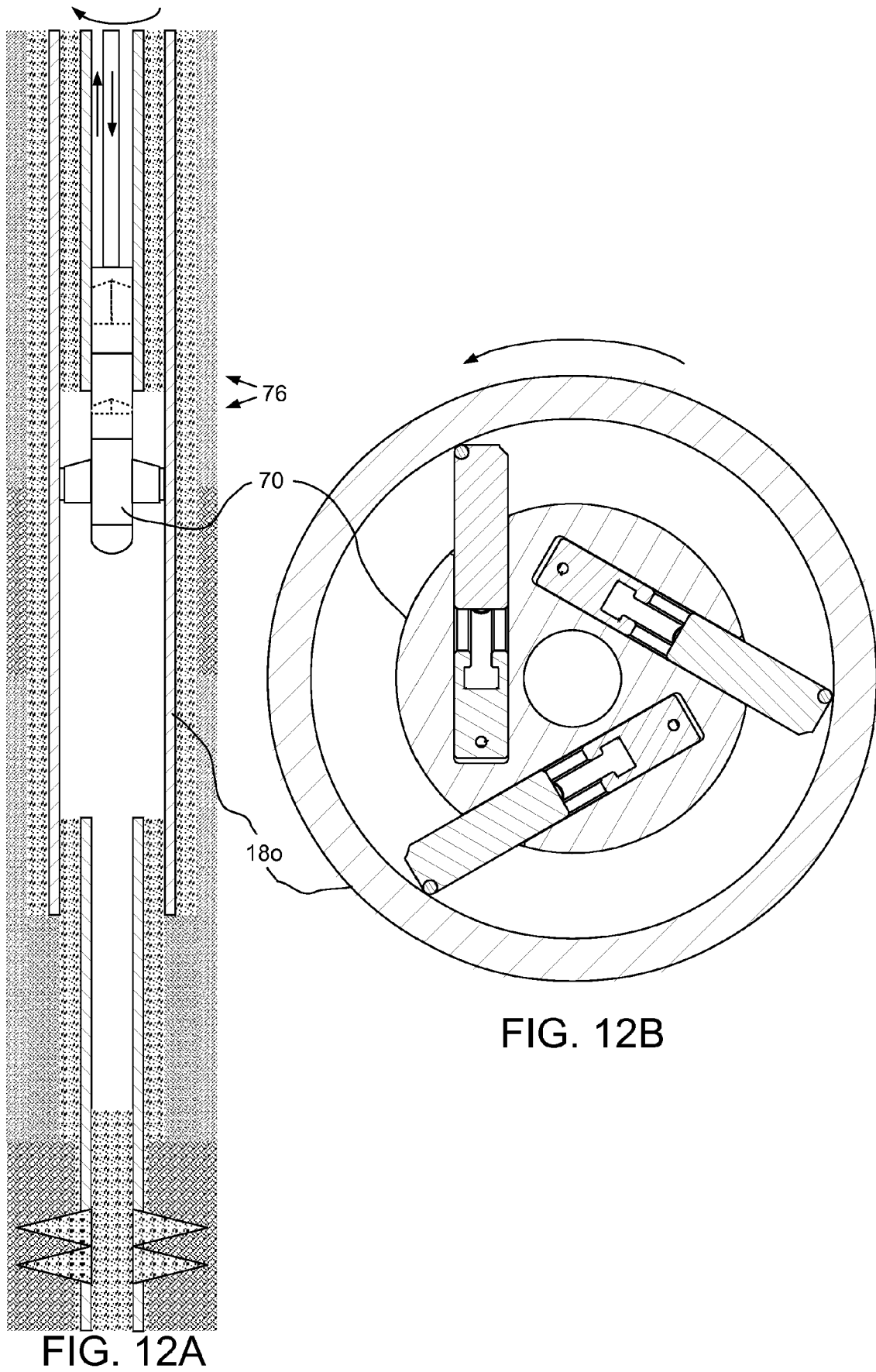
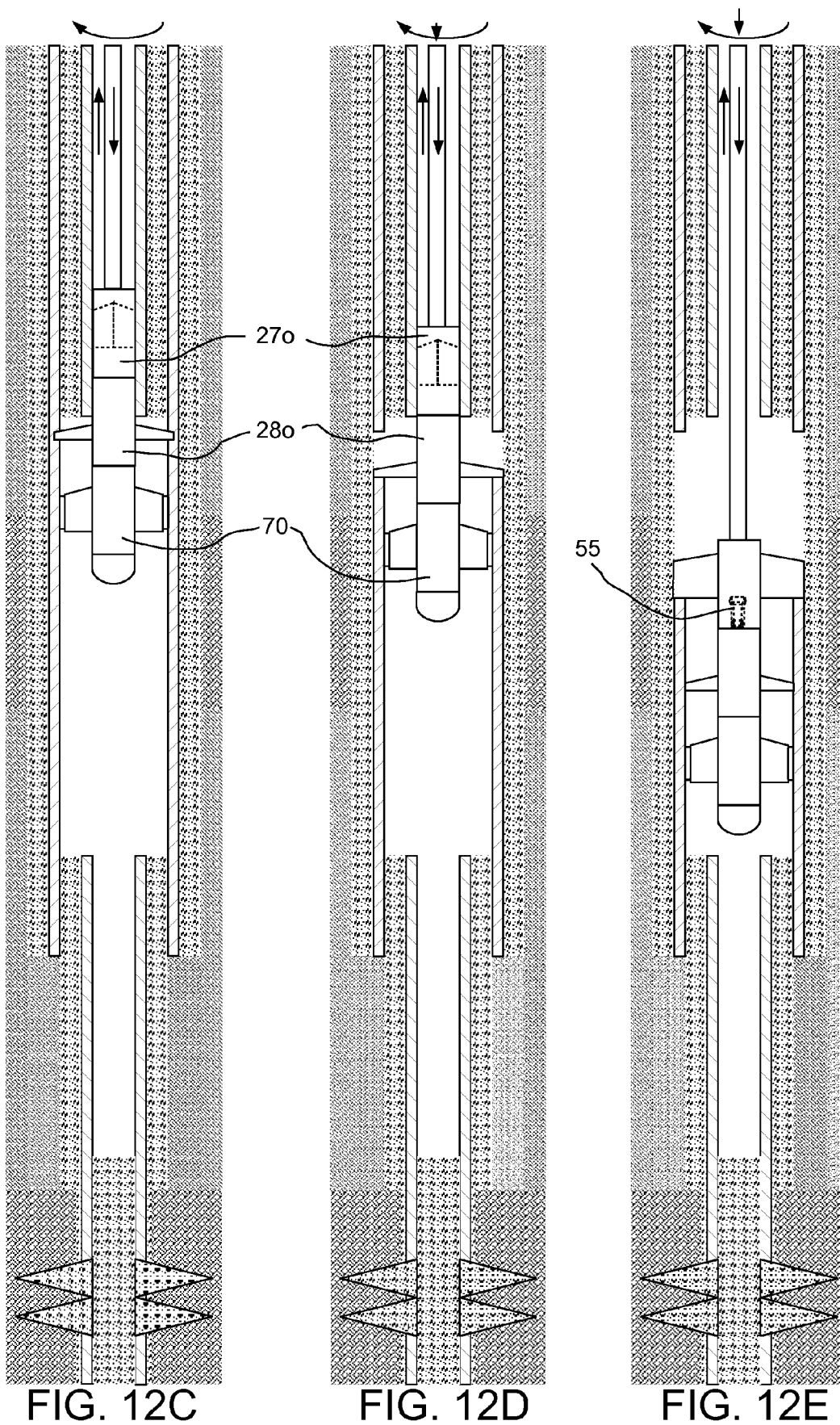


FIG. 11C







EUROPEAN SEARCH REPORT

Application Number

EP 21 20 4876

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EPO FORM 1503 03.82 (P04C01)

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A	* paragraph [0051]; figure 3B * -----	2, 3, 5-15	E21B33/13 E21B10/26
X	CA 2 366 134 A1 (TESCO CORP [CA]) 21 June 2003 (2003-06-21)	7, 8, 14, 15	E21B10/32
Y	* the whole document * -----	1, 4	
			TECHNICAL FIELDS SEARCHED (IPC)
			E21B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 21 January 2022	Examiner Beran, Jiri
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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ON EUROPEAN PATENT APPLICATION NO.**

EP 21 20 4876

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