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(54) **BOTTOM HOLE HOLLOW CORE ELECTRIC SUBMERSIBLE PUMPING SYSTEM**

(75) Inventors: **Curt Ring**, Millarville (CA); **Grant George**, Calgary (CA); **Geoff Steele**, Calgary (CA); **Pat McCleer**, Jackson, MI (US)

Correspondence Address:
EDWARD YOO C/O BENNETT JONES
1000 ATCO CENTRE, 10035 - 105 STREET
EDMONTON, ALBERTA, AB T5J3T2 (CA)

(73) Assignee: **STELLARTON TECHNOLOGIES INC.**, Calgary (CA)

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(52) **U.S. Cl.** **417/410.1**

(57) **ABSTRACT**

An electric submersible pumping system includes a motor comprising an inner hollow core rotor and an outer stator, a gearbox comprising a hollow core input shaft connected to the motor rotor, and a hollow core output shaft, and a pump driven by the gearbox output shaft, the pump having an intake, and wherein the pump output is directed through the hollow core output shaft and into the hollow core motor rotor. The motor section is disposed above the gearbox and pump.

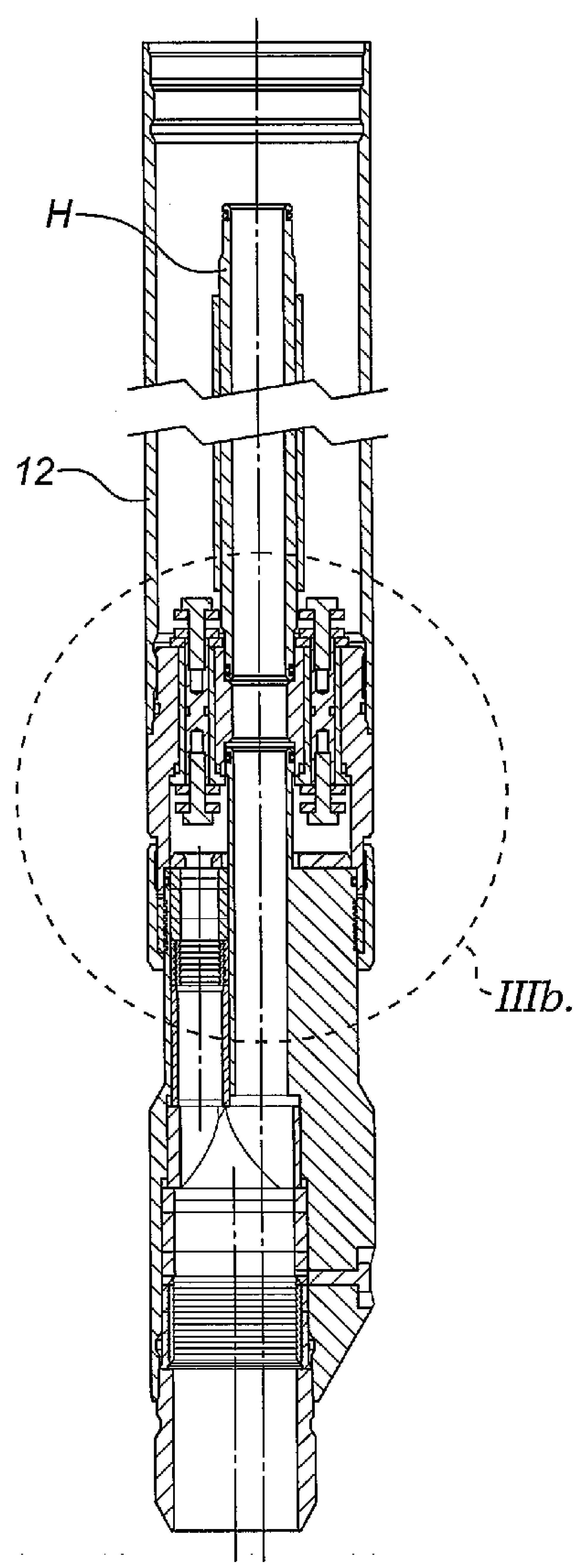


FIG. 1
Prior Art

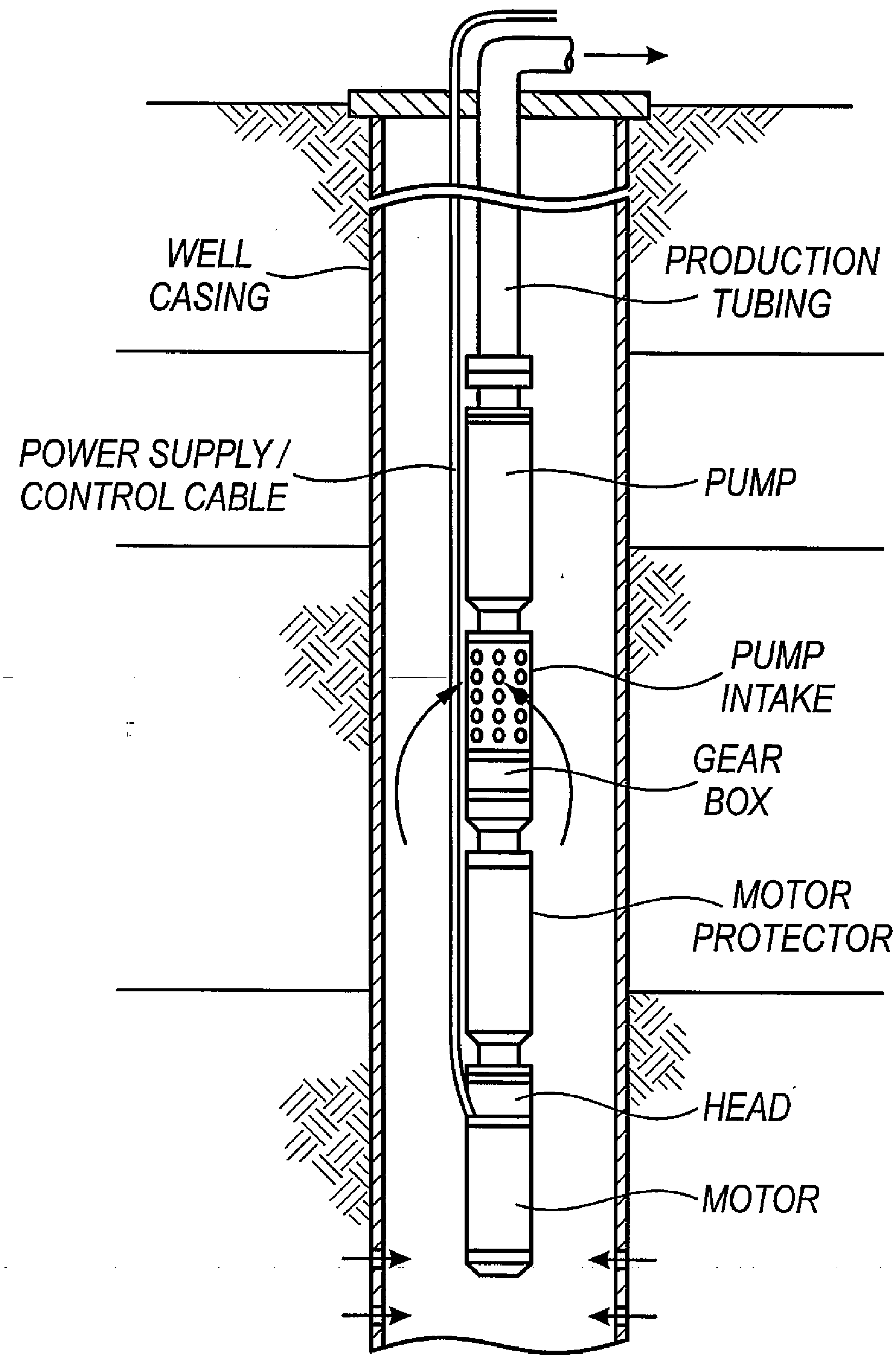
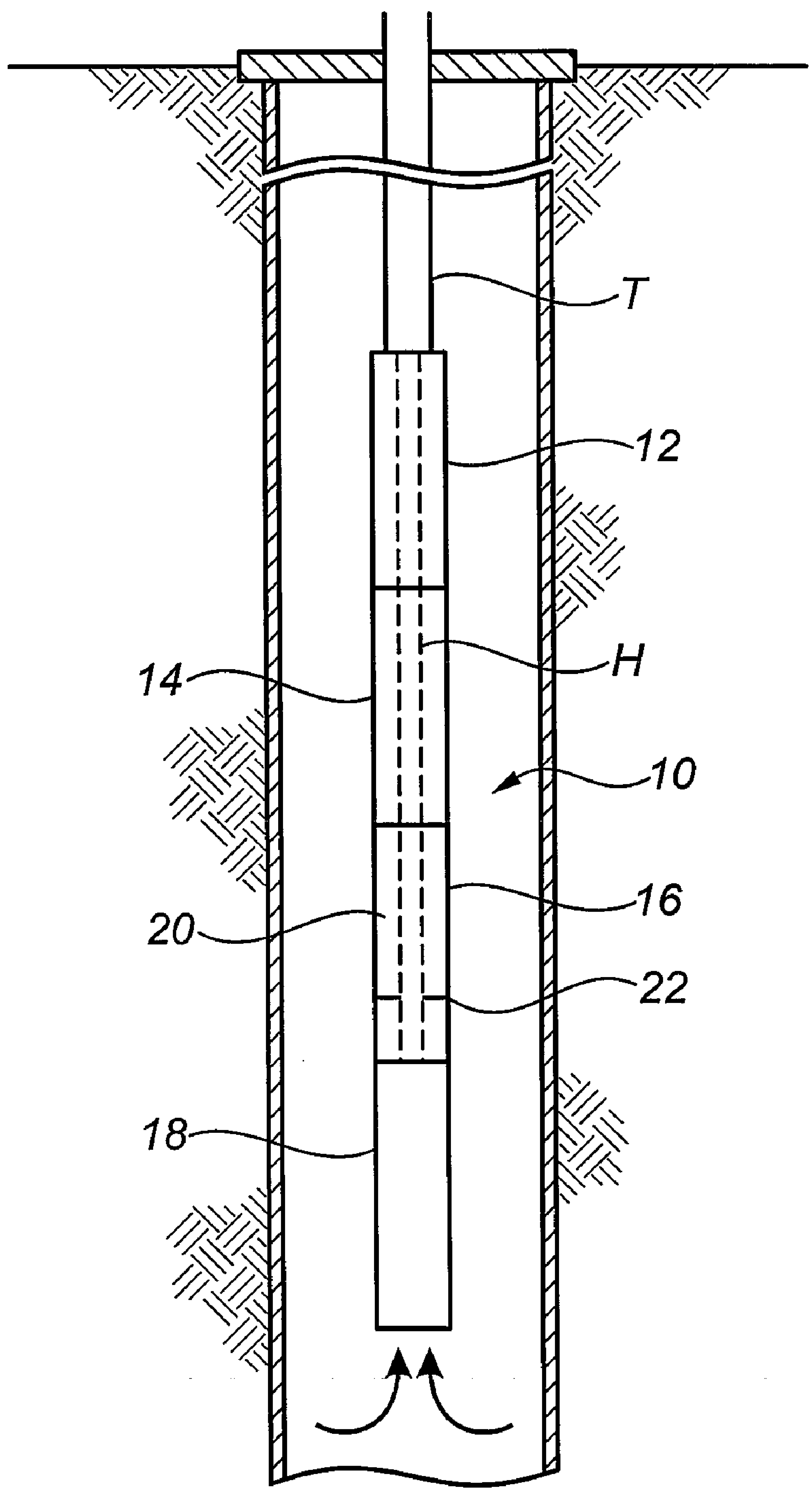


FIG. 2



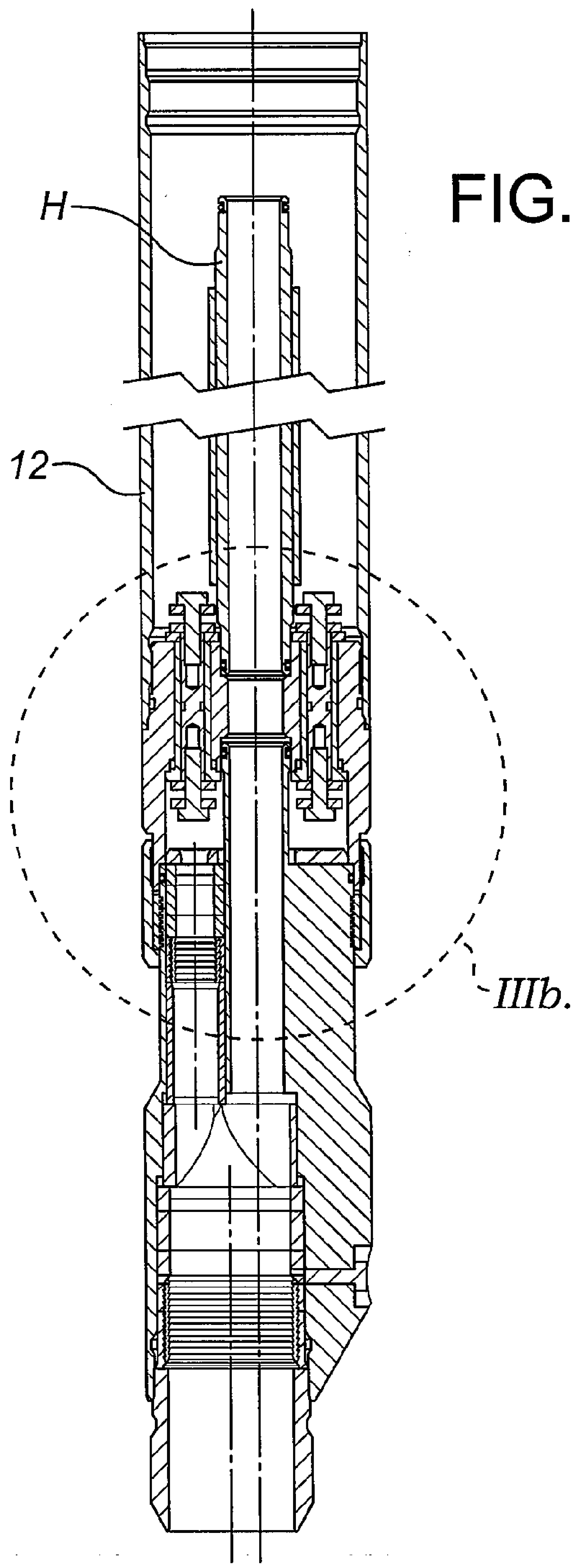


FIG. 3

FIG. 3B

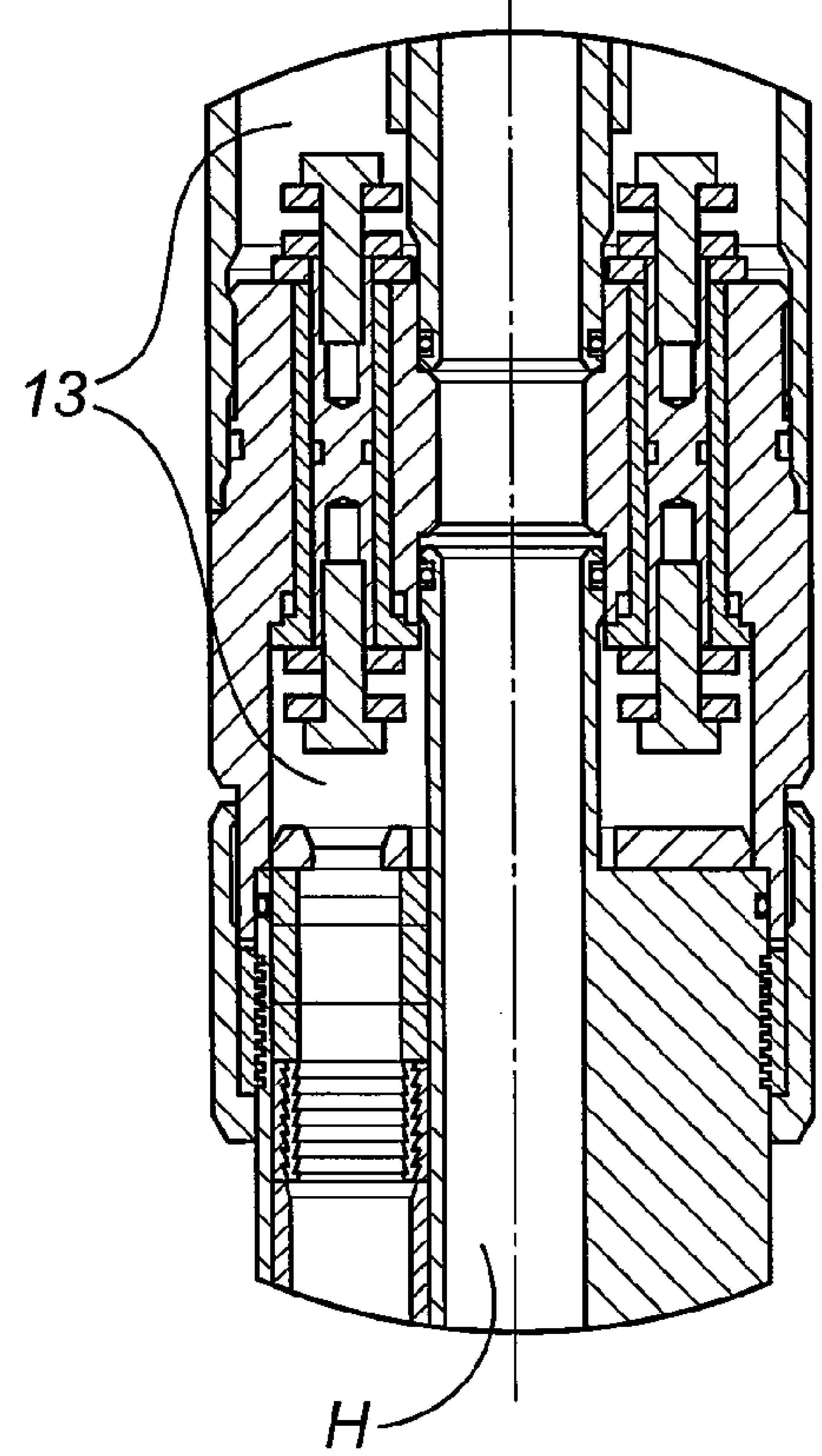
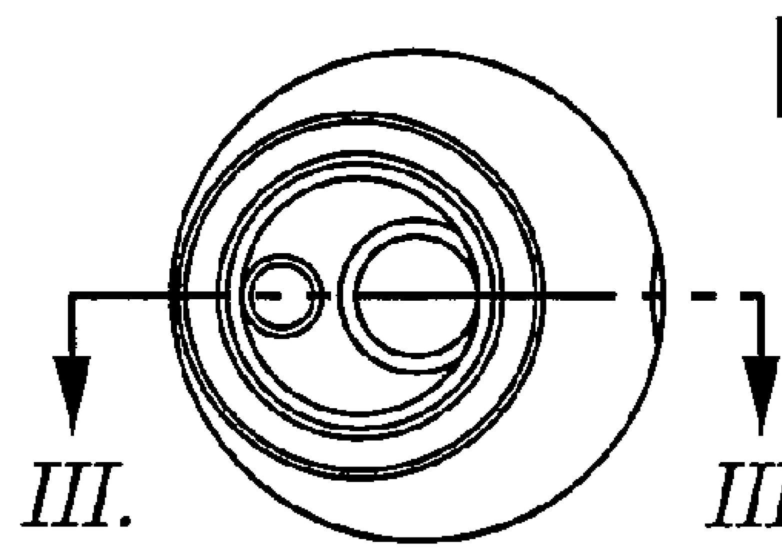


FIG. 3A



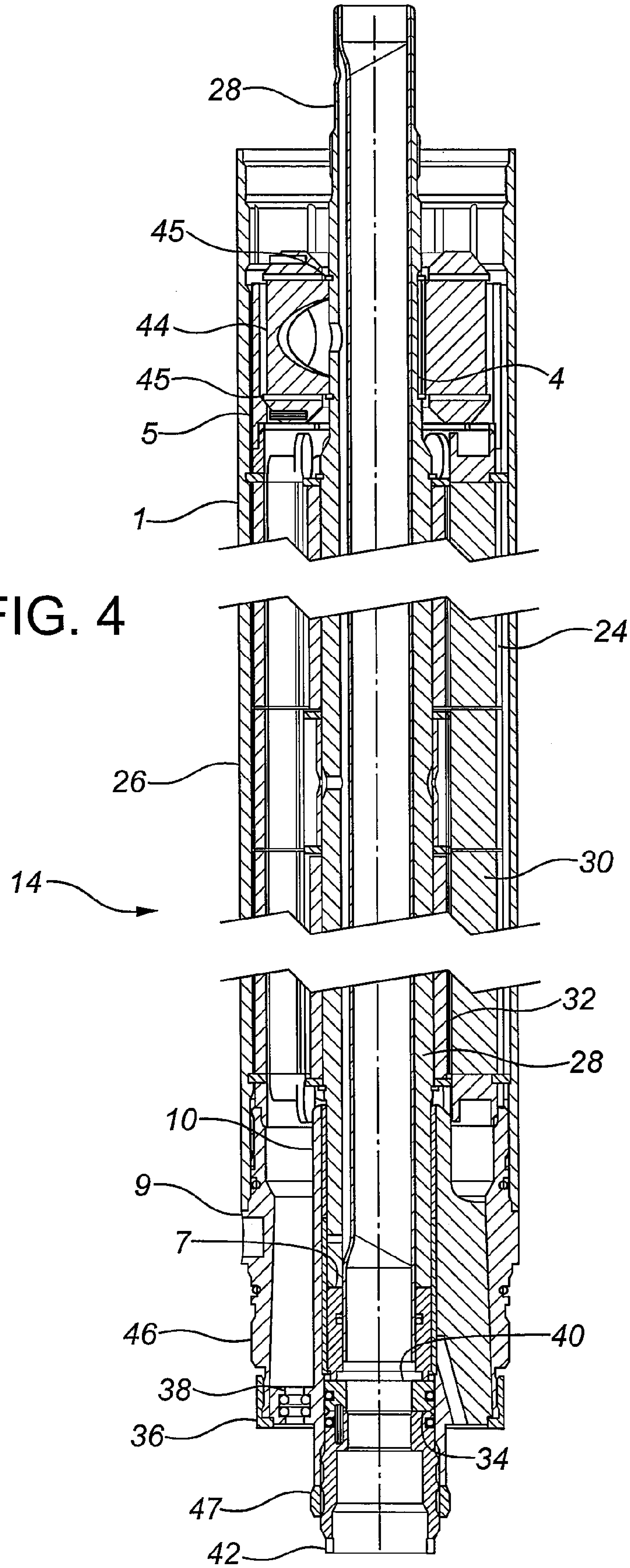


FIG. 4

FIG. 4a

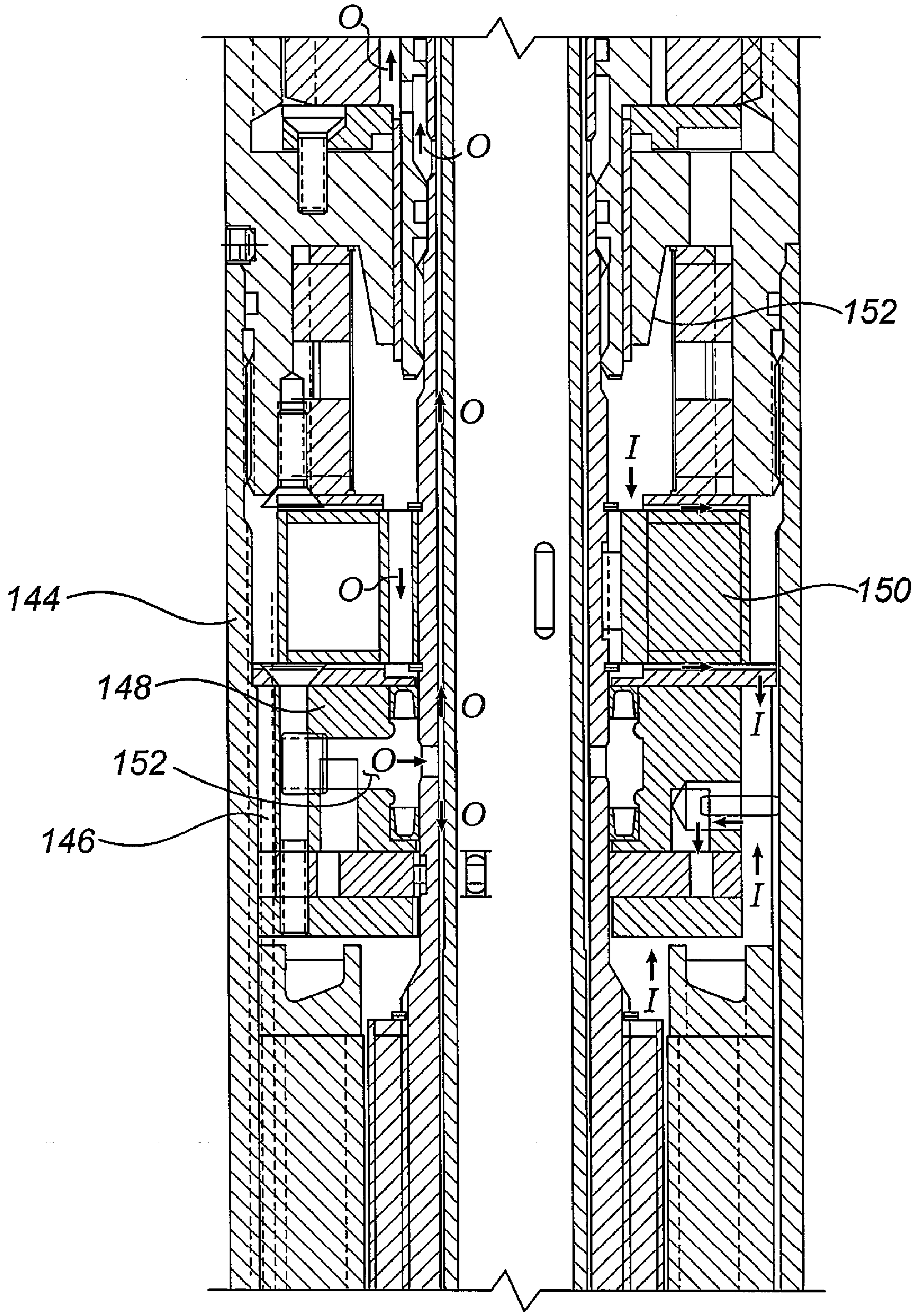
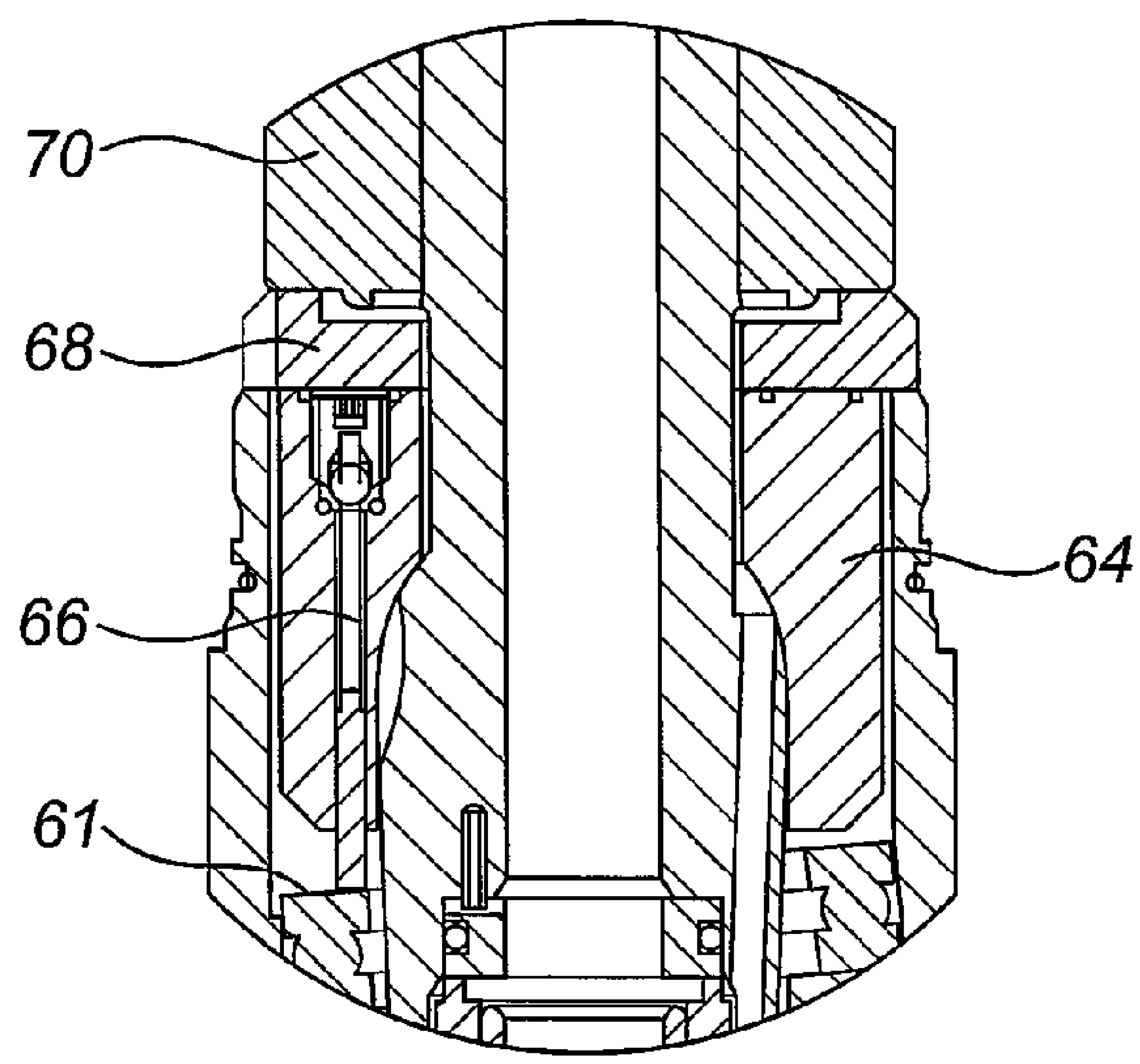


FIG. 7



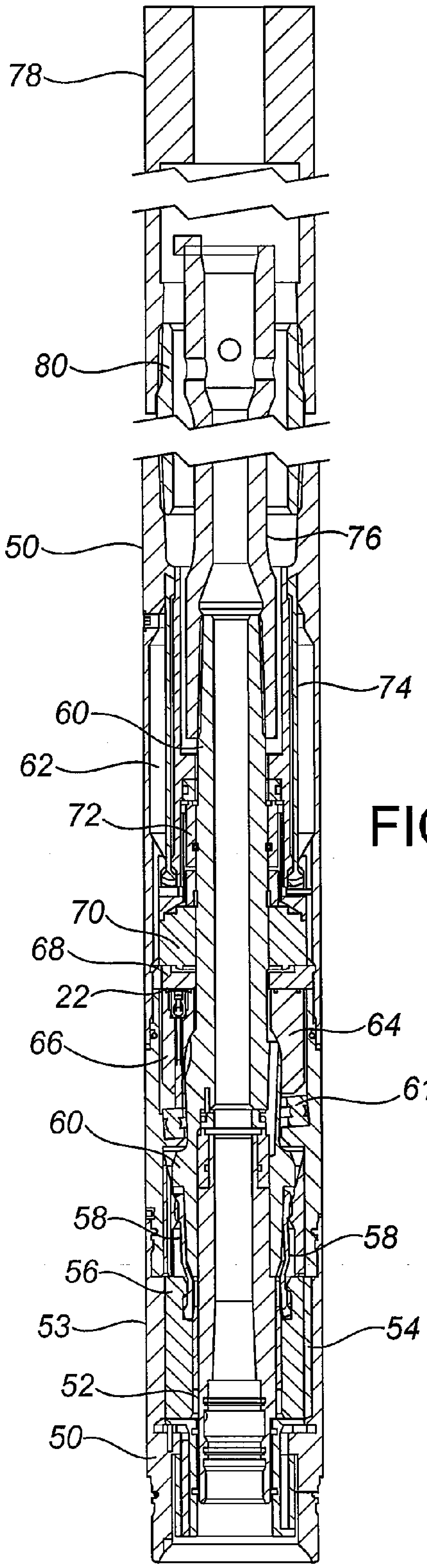
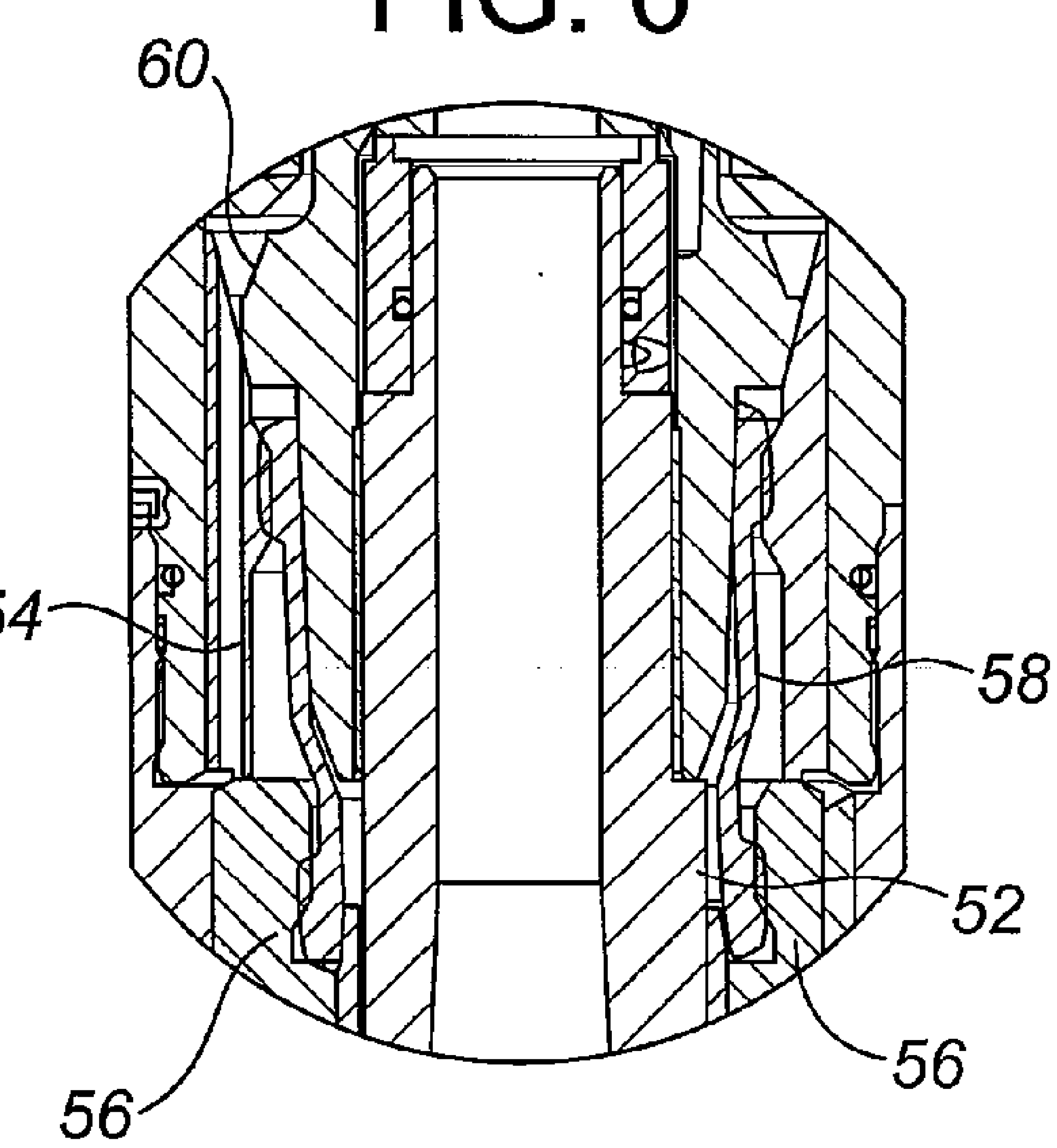


FIG. 5

FIG. 6



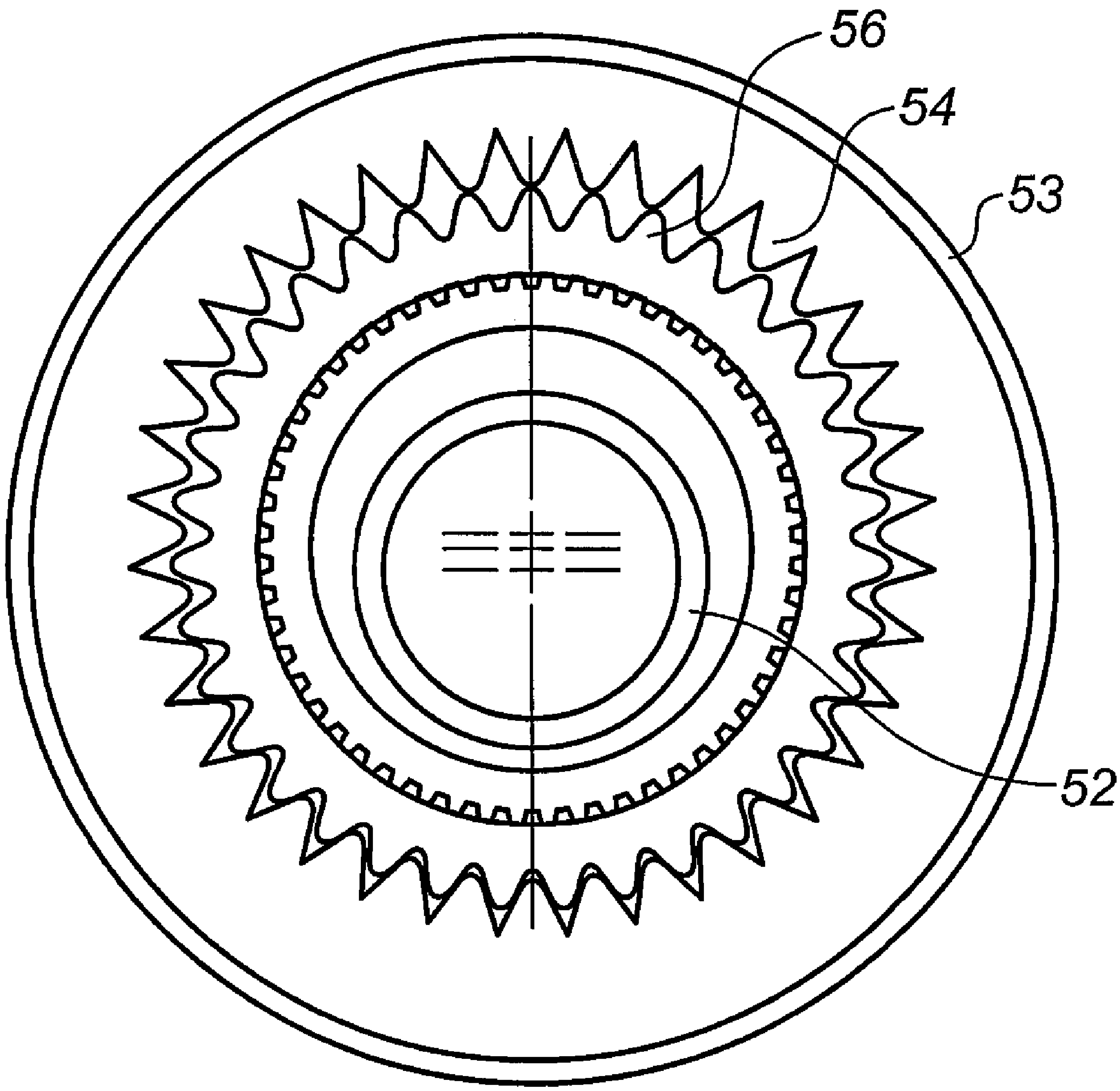


FIG. 6A

BOTTOM HOLE HOLLOW CORE ELECTRIC SUBMERSIBLE PUMPING SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of U.S. Provisional Application No. 60/991,497 filed on Nov. 30, 2007 entitled "Bottom Hole Hollow Core Electric Submersible Pumping System", the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to the bottom hole components of an electric submersible pumping (ESP) system, and in particular, an ESP system having a hollow core motor disposed above the pump.

BACKGROUND

[0003] Many systems are known for producing fluids by artificial lift from oil and gas wells, including many forms of downhole pumps which are rotated by a surface motor and a rod string. Pumps driven by downhole electric motors are known as electric submersible pumps. The pumps themselves may be centrifugal pumps or positive displacement pump, such as a progressive cavity pump.

[0004] In a conventional electric submersible pump system, shown in prior art FIG. **1**, a motor is placed at the bottom of the production tubing string, and drives a pump located at the top of the pump system, which pumps production fluid up the tubing string to the surface. A pump intake section is placed between the motor and the pump.

[0005] This setup requires that electrical connections to the motor be provided in a separate external line, shown in FIG. **1** as the power supply and control cable. Control systems are obviously provided at the surface. Because it is advantageous to use coiled tubing as the production tubing, use of an external power supply and control cable can be difficult. In addition, installation of the pump components requires that the motor and pump assembly be assembled at the surface, and lowered downhole on the tubing string.

SUMMARY OF THE INVENTION

[0006] In one aspect, the invention comprises an electric submersible pumping system comprising:

[0007] (a) a motor comprising an inner hollow core rotor and an outer stator;

[0008] (b) a gearbox comprising a hollow core input shaft connected to the motor rotor, and a hollow core output shaft;

[0009] (c) a pump driven by the gearbox output shaft, the pump having an intake, and wherein the pump output is directed through the hollow core output shaft and into the hollow core motor rotor;

wherein the motor is disposed above the gearbox and pump.

[0010] In one embodiment, the gearbox section comprises a thrust bearing which comprises a hydraulic force chamber.

[0011] In one embodiment, the system further comprises a closed lubricating oil circulation system including a low-pressure pump, and pressure equalization means for equalizing pump pressure and the lubricating oil circulation system pressure. In one embodiment, the oil circulation system comprises a positive displacement pump.

[0012] In one embodiment, the motor comprises a synchronous AC motor and the gearbox comprises an epicyclic planetary gear set. The pump may comprise a progressive cavity pump.

[0013] In one embodiment, the system further comprises a motor control section, which houses means for controlling pump operation, and which is operatively connected to a surface power source and the motor. The motor control section may also house means for dynamically braking the pump.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In the drawings, like elements are assigned like reference numerals. The drawings are not necessarily to scale, with the emphasis instead placed upon the principles of the present invention. Additionally, each of the embodiments depicted are but one of a number of possible arrangements utilizing the fundamental concepts of the present invention. The drawings are briefly described as follows:

[0015] FIG. **1** is a view of a prior art electric submersible pumping system.

[0016] FIG. **2** shows a schematic of the system components.

[0017] FIG. **3** shows a cross-sectional view of the motor control section. FIG. **3**A shows a top end view of the stab-in connections. FIG. **3**B shows a detail of the atmospheric chamber.

[0018] FIG. **4** shows a cross-sectional view of the motor section. FIG. **4**A shows a detailed view of a positive displacement lubrication pump.

[0019] FIG. **5** shows a cross-sectional view of the gearbox section.

[0020] FIG. **6** shows a detailed view of the planetary gears of the gearbox section. FIG. **6**A shows a cross-sectional view of FIG. **6**.

[0021] FIG. **7** shows a detailed view of the hydraulic force chamber of the gearbox section.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0022] The present invention relates to an electric submersible pumping system. When describing the present invention, all terms not defined herein have their common art-recognized meanings. To the extent that the following description is of a specific embodiment or a particular use of the invention, it is intended to be illustrative only, and not limiting of the claimed invention. The following description is intended to cover all alternatives, modifications and equivalents that are included in the spirit and scope of the invention, as defined in the appended claims.

[0023] In the following description and claims, references to "top" and "above" shall mean closer to the surface end of the system, while references to "bottom" or "below" shall mean closer to the downhole end of the system. Reference to a horizontal direction shall mean a direction perpendicular to the longitudinal axis of the production string, including the motor and gearbox sections of the system. Such references shall not be considered to limit use of the invention in a strictly vertical orientation. The present invention may be used in any below-ground orientation suitable for producing fluids to the surface by artificial lift.

[0024] In one embodiment, shown in FIG. **2**, the invention comprises a hollow core electric submersible pumping system (**10**) comprising a motor control section (**12**), a motor section (**14**), a gearbox section (**16**) and a pump (**18**). The system (**10**) connects to production tubing (T) which is preferably coiled tubing but may also be conventional jointed tubing. The gearbox section (**16**) includes a gearbox (**20**) and a thrust bearing. In one embodiment, the thrust bearing comprises a hydrodynamic thrust bearing, referred to herein as a force chamber (**22**). The motor and gearbox are situated above the pump, and therefore include a hollow core (H) through which production fluids pass on their way into the production tubing (T) and to the surface.

[0025] The components of the system may be implemented in diameters typical of coiled tubing operations, including slim-line tubing in the order of 3.75".

[0026] The motor control section (**12**) comprises a control system disposed within the annular space between the section housing and the hollow core (H). The control system provides power to the electric motor, and may sense and/or transmit data regarding downhole conditions. In one embodiment, the control system simply controls power on and off to the motor, and motor speed. In one embodiment, the control system comprises electronic components which receive and inverts power to the electric motor, receives command information from a surface station, as well as receives and transmits to the surface station downhole data information regarding downhole conditions and performance of the motor and pump.

[0027] In one embodiment, where the motor comprises a brushless DC motor (also known as a synchronous AC motor), the motor control system comprises the electronic speed controllers required for motor operation. The controller inverts DC power transmitted from the surface and converts it to 3-phase AC variable frequency power to drive the motor. The phasing of the motor excitation voltages are controlled by suitable circuitry to synchronize with the motor rotor instantaneous position. In one embodiment, the control system comprises a mechanical sensorless vector control system, which relies on microcontroller based computations, enabling close control of motor torque and pump output. Such controllers are well known in the art, and need not be further described herein.

[0028] The system may also comprise means for dynamically braking the pump, such as in the event of power loss. The dynamic brake may comprise brake resistors (not shown) in the motor control section, or alternatively, the circuit may permit current reversal in a regenerative braking process. The dynamic brake may permit slow dissipation of the production hydrostatic head.

[0029] The upper end of the motor control section (**12**) is adapted to connect to the production tubing and includes, in one embodiment, a sealed stab-in connection for both electrical connection and the production fluid connection. Stab-in connectors are well-known in the art and need not be further described herein. In one embodiment, the stab-in connectors are adapted to permit simple fluid-tight connections, as well as suitable electrical connections through the elements of the bottom-hole assembly. Power may be provided to the system by a conductor running internal to the production tubing (T). In one embodiment, power and other cables may be formed integral with coiled tubing, as described in Applicant's co-pending application entitled "Electrified Coiled Tubing", U.S. patent application Ser. No. ______, docket no. 52987.41, filed on Dec. 1, 2008, the contents of which are incorporated herein by reference, where permitted.

[0030] As the hollow core section of the motor control housing is centralized within the housing, the stab-in electrical connector is offset, as is shown in FIG. **3**. In one embodiment, an atmospheric chamber (**13**) is concentrically disposed about the hollow core and provides a sealed chamber housing the motor control components. The atmospheric chamber (**13**) prevents both pressure and contaminating fluids from entering the chamber which houses the downhole motor controls and power electronics: The chamber (**13**) further provides a hermetically sealed passage for conductive lines internal to the motor control housing, unlike prior art ESP systems which require conductive lines external to the assembly. Also this provides the means for passage of additional lines enabling the use of additional motor sections.

[0031] As seen in FIG. **4**, in one embodiment, the motor section (**14**) comprises an electric motor (**24**). The motor includes a stationary outer housing (**26**) which houses the stator (**30**), and a concentric hollow rotor (**28**) which provides the internal production fluid conduit. The motor may comprise any suitable electric motor. In one embodiment, the motor may comprise a brushless DC motor, which is also known as an AC synchronous motor. In such motors, current and torque, voltage and rpm are linearly related. The stator (**30**) comprises a plurality of stator teeth, having electric windings (not shown) as is well known in the art. The rotor (**28**) comprises a plurality of permanent magnets (**32**). The input currents are AC, and the phasing of the motor excitation voltages are controlled to be synchronous with the rotor instantaneous position.

[0032] The upper end of the motor section (**24**) is adapted to provide a sealed connection to the lower end of the motor control section, and includes a seal assembly (**34**) and a locknut assembly (**36**) for the hollow core connection, and a sealed port (**38**) for the electrical connection.

[0033] The seal assembly comprises a mechanical seal (**40**) at the upper end of the rotor (**28**) and a seal stop (**42**) which receives the lower end of the motor control section hollow core (H).

[0034] At the lower end of the motor section (**14**), an oil pump (**44**) rotates with the rotor (**28**) to provide low pressure oil to lubricate the gearbox (**20**). In one embodiment, the oil pump (**44**) is an oil slinger type design which is weighted to counterbalance the gearbox (**20**). The oil pump (**44**) is rotatably supported by a thrust bearing (**45**) above and below the oil slinger.

[0035] In an alternative embodiment, the oil pump comprises a positive displacement pump which may comprise a vane impeller, a gear or gear rotor type design. As shown in FIG. **4**A, the pump (**144**) comprises a stationary pump housing (**146**) and a pump impeller (**148**). A rotating counterweight (**150**) may be provided to balance the gearbox (**20**). The pump builds oil pressure in the vane slot (**152**) and the lubrication oil flows out through passages marked by arrows "O" and returns through intake marked by arrow "I". In one embodiment, the pump may comprise an intake screen (**152**) and a pressure relief valve (not shown). In one embodiment, a magnet (**154**) may be provided in the oil return path to magnetically attract and retain metallic particles, thereby removing them from circulation. In one embodiment, a shuttle valve system may be provided comprising a dogbone and check valves in order to maintain unidirectional flow of the lubrication oil.

[0036] The locknut assembly (**36**) at the upper end of the motor section (**14**) provides means for engaging the motor control housing (**12**) and comprises a locknut profile member (**46**), and a locknut taper seat (**47**), as shown in FIG. **4**. The lower end of the motor control section (**12**) releasably engages the locknut profile member (**46**) as is well known in the art.

[0037] The lower end of the rotor (**28**) is adapted to engage the upper end of the gearbox (**20**) and the lower end of the motor section (**14**) or stator housing (**26**) is adapted to engage the gearbox section housing (**50**), as shown in FIG. **5**.

[0038] In one embodiment, the gearbox is an epicyclic planetary gear assembly. The bottom end of the rotor (**28**) stabs into the upper end of the gearbox input shaft (**52**). As shown in FIGS. **5** and **6**, the input shaft (**52**) has an eccentric portion and the inner surface of the gearbox housing (**53**) forms an eccentric stationary ring gear (**54**). The stationary ring gear (**54**) is concentric with the pinion gear (**56**), which rotates eccentrically within the stationary ring gear. This eccentric motion is induced by the eccentric gearbox input shaft (**52**). A dogbone coupling (**58**) is connected at its upper end to the pinion gear (**56**), and the lower end of the dogbone coupling (**58**) rotates concentrically with the output shaft (**60**) of the gearbox.

[0039] In one embodiment, the gearbox provides a large speed reduction, for example a 35:1 reduction. If the motor output spins at about 3500 rpm and the gearbox output shaft thus spins at about 100 rpm. The gearbox thus provides high torque, low rpm power to the pump. Speed reduction gearboxes are preferred with the combination of brushless DC motors, and progressive cavity pumps due to the optimal speed output and requirements of each.

[0040] A mechanical seal (**61**) is disposed between the input shaft (**52**) and the output shaft (**60**). In one embodiment, the mechanical seal (**61**) comprises finely honed surfaces on the bearing surfaces of the input and output shafts. The pressure differential across the mechanical seal is largely equalized by the pressure equalization bladder described below.

[0041] The lower end of the gearbox houses two components of the system, a thrust bearing system (**22**) and the oil equalization bladder (**62**), described in further detail below. In one embodiment, the thrust bearing system comprises a hydraulic thrust bearing, herein referred to as the force chamber (**22**). The force chamber (**22**) and the equalization bladder (**62**) are necessitated by the anticipated forces on the thrust bearings of the system, caused by the hydrostatic head of the production fluid within the production tubing. In some applications, it is anticipated that the thrust bearings must support 10,000 to 14,000 pounds of force. The present invention incorporates a hydraulic means to create a hydraulic force (**22**) which acts as a hydrostatic thrust bearing.

[0042] In one embodiment, a swash plate (**61**) is fixed to the gearbox housing and remains stationary. A barrel assembly (**64**) is keyed to the output shaft (**60**) and includes a plurality of small piston pumps (**66**) which reciprocate against the swash plate. The piston pumps (**66**) thus create a high pressure hydraulic pocket in the force chamber (**22**), between the barrel assembly (**64**) and a stationary bushing (**68**). The bushing (**68**) bears on a taper roller bearing (**70**) The inner rotating portion of the roller bearing (**70**) is positioned with an adjusting nut (**72**) affixed to the output shaft. Accordingly, the combination of the force chamber (**22**) and the taper roller bearing (**70**) provides sufficient thrust bearing capacity to deal with the hydrostatic head of the production fluid column.

[0043] The oil equalization bladder (**74**) comprises a trapped elastomer sleeve, which is open to pump (**18**) pressure on the inside, and open to the lube oil circulation path from the oil slinger pump (**44**) on the other side. As a result, the pressure differential across the dynamic seals of the system is only the oil pressure generated by the oil pump, which may be in the order of about 15 p.s.i.

[0044] The lower end of the output shaft is connected to a wobble shaft (**76**) which drives the pump rotor (not shown). The pump stator (**78**) is connected to the gearbox housing (**50**) by means of a pup joint member (**80**). The pump itself (**18**) may be any downhole pump such as a centrifugal pump or a progressive cavity pump. In one embodiment, the pump comprises a progressive cavity pump, which is well known in the art and need not be further described. The pump intake at the lower end of the pump (**18**) may be screened as is well known in the art.

[0045] The pump output is directed into the hollow output shaft (**60**) and hollow input shaft (**52**) of the gearbox, and thereafter through the hollow motor rotor and motor control section, into the production tubing.

What is claimed is:

1. An electric submersible pumping system comprising:

(a) a motor comprising an inner hollow core rotor and an outer stator;

(b) a gearbox comprising a hollow core input shaft connected to the motor rotor, and a hollow core output shaft;

(c) a pump driven by the gearbox output shaft, the pump having an intake, and wherein the pump output is directed through the hollow core output shaft and into the hollow core motor rotor;

wherein the motor section is disposed above the gearbox and pump.

2. The system of claim **1** wherein the gearbox section comprises a thrust bearing comprising a hydraulic force chamber.

3. The system of claim **2** further comprising a closed lubricating oil circulation system including a low-pressure pump, and pressure equalization means for equalizing pump pressure and the lubricating oil circulation system pressure.

4. The system of claim **1** wherein the motor comprises a brushless DC motor or a synchronous AC motor.

5. The system of claim **3** wherein the gearbox comprises eccentric rotating components and the low pressure pump acts as a counterbalance to the gearbox.

6. The system of claim **1** or **5** wherein the gearbox comprises an epicyclic planetary gear set comprising a stationary outer gear, a rotating input shaft, an eccentric pinion gear engaging the input shaft and the outer gear, and an output shaft connected to the pinion gear by means of elongate coupling members.

7. The system of claim **2** wherein the hydraulic force chamber is pressurized by means of a hydraulic pump comprising a swash plate and a rotating barrel comprising reciprocating pistons bearing on the swash plate.

8. The system of claim **1** further comprising a motor control section, which houses a motor controller operatively connected to a surface power source and the motor.

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