Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2746081 C 2014/06/03

(11)(21) 2 746 081

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2009/06/05
(87) Date publication PCT/PCT Publication Date: 2009/12/10
(45) Date de délivrance/Issue Date: 2014/06/03
(85) Entrée phase nationale/National Entry: 2011/06/07
(86) N° demande PCT/PCT Application No.: CA 2009/000803
(87) N° publication PCT/PCT Publication No.: 2009/146560
(30) Priorité/Priority: 2008/06/06 (US61/129,147)

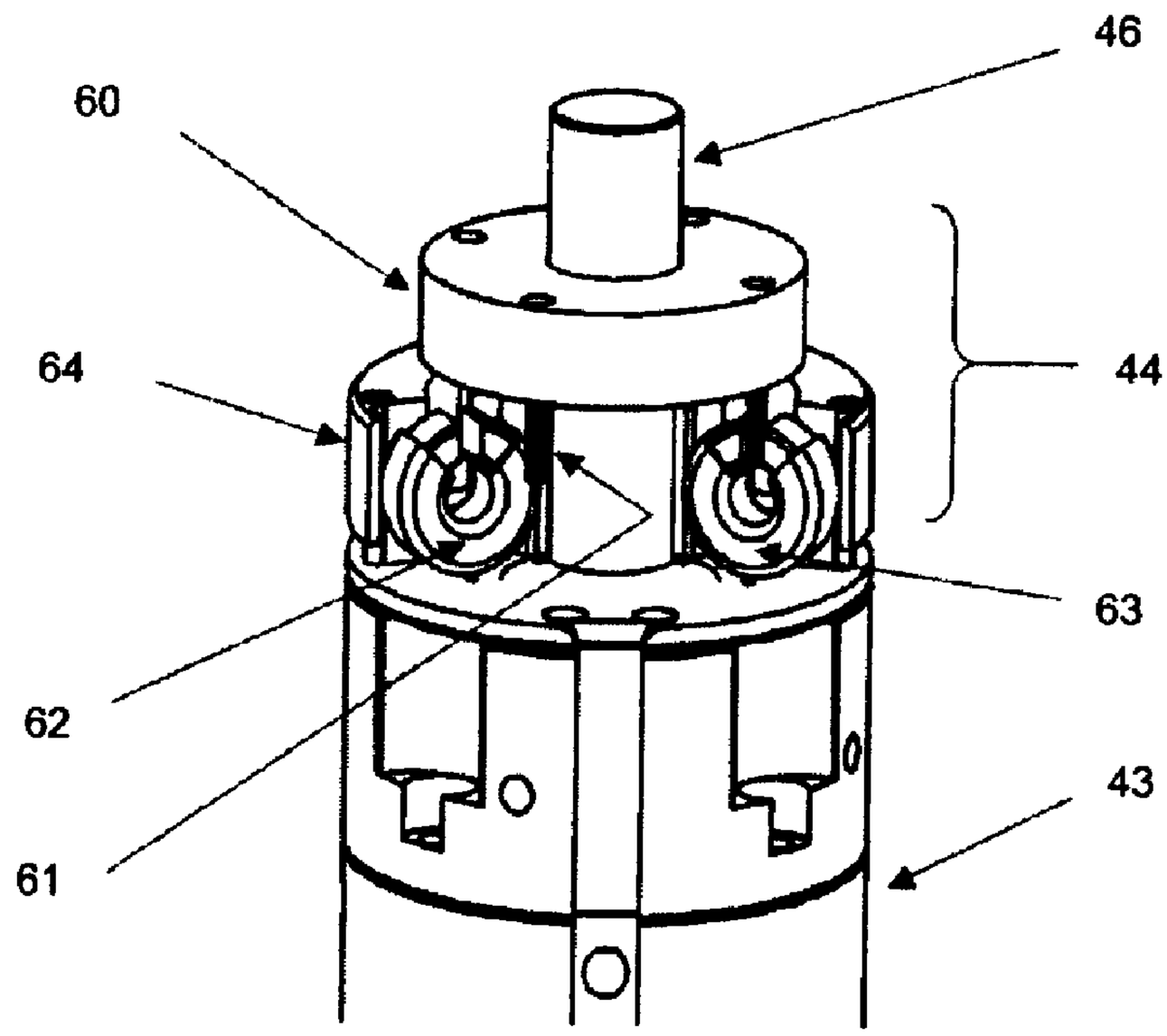
(51) Cl.Int./Int.Cl. *E21B 47/09* (2012.01), *E21B 47/12* (2012.01), *G01D 5/20* (2006.01), *G01D 5/22* (2006.01)

(72) Inventeurs/Inventors:
CAMWELL, PAUL L., CA;
LIU, JILI, CA

(73) Propriétaire/Owner:
SCHLUMBERGER CANADA LIMITED, CA

(74) Agent: GOWLING LAFLEUR HENDERSON LLP

(54) Titre : COMMUTATEUR DE DETECTION DE POSITION SANS CONTACT
(54) Title: CONTACTLESS POSITION DETECTION SWITCH



(57) Abrégé/Abstract:
A position sensor that can be used in high-pressure drilling environments, such as in measurement while drilling applications, is disclosed. It comprises a first member having at least one easily-magnetizable pin fixedly coupled thereto and a second member having one or more coils fixedly coupled thereto. The coils incorporate slots through which the pins can travel when the members rotate relative to each other. Circuitry detects a change in inductance in the coils when pins enter or leave the slots. Consequently, the position of the first member relative to the second can be determined. The position sensor comprises two main sections - a pin/coil arrangement that can withstand high pressure and experiences no wear, and conventional electronic circuitry that is protected from pressure behind a bulkhead.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 December 2009 (10.12.2009)

PCT

(10) International Publication Number
WO 2009/146560 A1

(51) International Patent Classification:
E21B 47/09 (2006.01) *G01D 5/20* (2006.01)
E21B 47/12 (2006.01) *G01D 5/22* (2006.01)

(21) International Application Number:
PCT/CA2009/000803

(22) International Filing Date:
5 June 2009 (05.06.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/129,147 6 June 2008 (06.06.2008) US

(71) Applicant *(for all designated States except US)*: **SCHLUMBERGER TECHNOLOGY CORPORATION** [US/US]; 300 Schlumberger Drive, Sugar Land, Texas, 77478 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **CAMWELL, Paul L.** [CA/CA]; 263 Midvalley Drive SE, Calgary, Alberta T2X 1 M1 (CA). **LIU, JiLi** [CA/CA]; 9 Chaparral Cove SE, Calgary, Alberta T2X 3L4 (CA).

(74) Agents: **LEE, Brian Y.** et al.; Gowling Lafleur Henderson LLP, P.O. Box 30, Suite 2300, 550 Burrard Street, Vancouver, British Columbia V6C 2B5 (CA).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

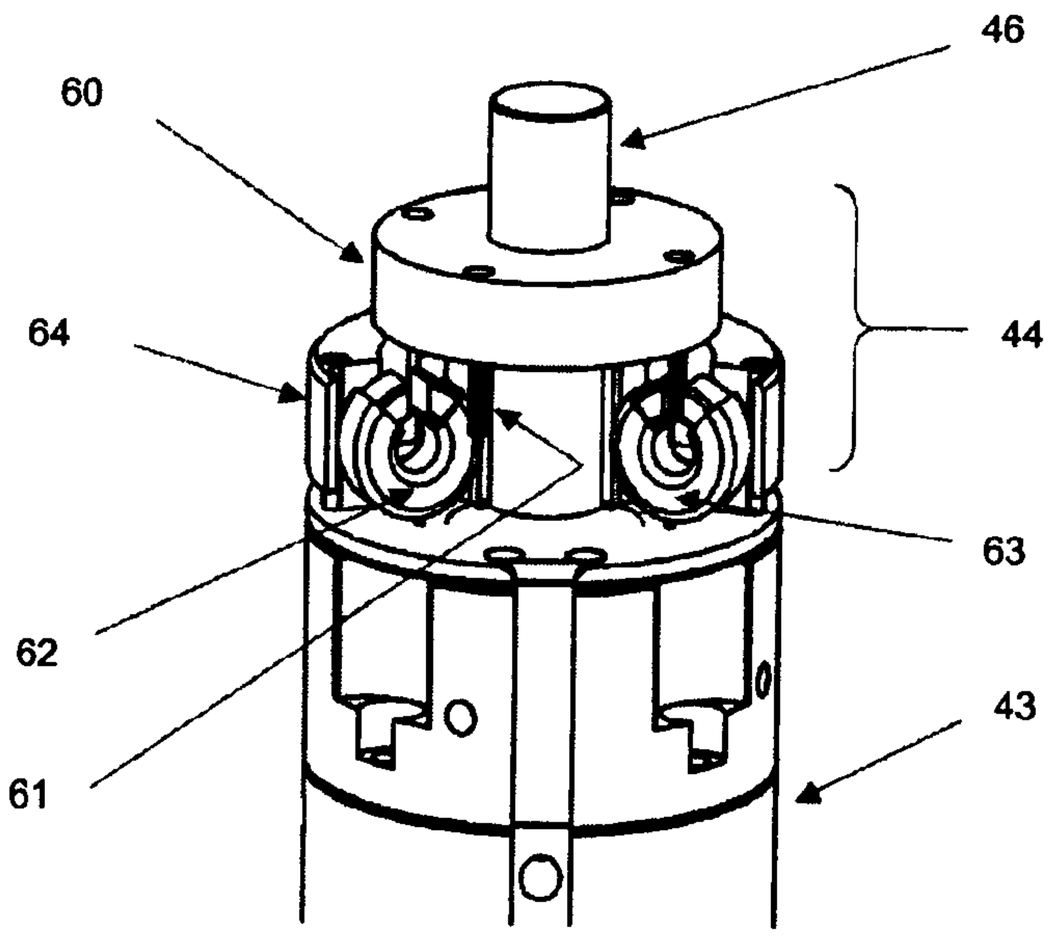
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

[Continued on next page]

(54) Title: CONTACTLESS POSITION DETECTION SWITCH

Figure 4b



(57) Abstract: A position sensor that can be used in high-pressure drilling environments, such as in measurement while drilling applications, is disclosed. It comprises a first member having at least one easily-magnetizable pin fixedly coupled thereto and a second member having one or more coils fixedly coupled thereto. The coils incorporate slots through which the pins can travel when the members rotate relative to each other. Circuitry detects a change in inductance in the coils when pins enter or leave the slots. Consequently, the position of the first member relative to the second can be determined. The position sensor comprises two main sections - a pin/coil arrangement that can withstand high pressure and experiences no wear, and conventional electronic circuitry that is protected from pressure behind a bulkhead.

WO 2009/146560 A1

WO 2009/146560 A1

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

CONTACTLESS POSITION DETECTION SWITCH

FIELD OF THE INVENTION

The present invention relates to an apparatus for measuring the position of one part relative to another, and more particularly to a contactless position detection switch for measuring the position of a moving part relative to a stationary part of a telemetry apparatus used in a high pressure environment such as downhole drilling.

BACKGROUND OF THE INVENTION

Modern drilling techniques used for oil and gas exploration employ an increasing number of sensors in downhole tools to determine downhole conditions and parameters such as pressure, spatial orientation, temperature, gamma ray count, etc., that are encountered during drilling. These sensors are usually employed in a process called "measurement while drilling" (or "MWD"). The data from such sensors are either transferred to a telemetry device and thence up-hole to the surface, or are recorded in a memory device by "logging".

The oil and gas industry presently uses a wire (wireline), pressure pulses (mud pulse - MP) or electromagnetic (EM) signals to telemeter all or part of this information to the surface in an effort to achieve near real-time data. In MP telemetry applications there is a class of devices that communicate by a rotary valve mechanism that periodically produces encoded downhole pressure pulses on the order of 200psi. These pulses are detected at the surface and are decoded in order to present the driller with MWD information. These rotary valves are preferentially driven by electric gear-motors.

The rotary valve mechanism is part of a rotating mud vane pulser and comprises a stationary component and a rotating component. The stationary component, the "stator", has gaps that serve as fluid pathways for the drilling fluid as it is

pumped down the drill string housing the pulser. A second component, the "rotor", is designed such that it can rotate relative to the stator to create “open” and “closed” positions; when the rotor moves to the “closed” position the fluid pathway area is significantly restricted, causing the fluid velocity to increase in the vicinity of the rotor/stator assembly. This process is exemplarily described in United States Patent No. 3,739,331.

In order to properly actuate the rotor, it is necessary to know the angular position of the rotor relative to the stator. Particularly, in MWD applications, it is necessary to know when the valve is in the open or closed position, as it is the transition from one to the other that creates a change in a pressure pulse and that consequently communicates data to the surface. If a brushless gear-motor is being used to directly drive the rotor, then the angular position of the rotor can be determined or inferred by using one of the brushless gear-motor's energizing coils. A concern in using one of the brushless gear-motor's coils is efficiency, as the energizing coil used to detect angular position cannot also be used to actuate the rotor. In a typical brushless gear-motor that uses three energizing coils, using one coil to detect position can result in a decline in efficiency of 33%.

Alternatively, a brushed gear-motor can be used to drive the rotor. A brushed gear-motor, however, cannot inherently detect the angular position of the rotor as a brushless gear-motor can. Consequently, if a brushed gear-motor is used and a position measurement is required, a separate position sensor must be employed. Examples of such sensors include optical discs, Hall Effect switches, and inductive couplers. Such sensors are sensitive to pressure, however, and must be shielded from pressures, which can reach as high as 20,000 psi, typically experienced during drilling. One way this is done is to isolate the gear-motor from external pressure by using a robust seal disposed circumferentially around the gear-motor's output shaft. While the use of such a seal effectively shields whatever angular position sensor is used from the ambient pressure, it

also generates a large amount of friction that can only be overcome by substantially increasing gear-motor power. Again, the result is that while angular position can be measured, efficiency dramatically decreases.

One alternative to using pressure-sensitive angular sensors is to instead use a simple wiping contact, or switch, whereby contacts are made and broken as the rotor rotates. While such a device may be generally insensitive to high pressures, it is subject to wear from friction and has questionable reliability, especially in the extreme environments encountered during drilling. See, for example, United States Patent No. 4,914,637 (Goodsman).

There is consequently a need for a position sensor that is inherently insensitive to the high pressures typically experienced during drilling, that does not compromise power efficiency in order to achieve this pressure insensitivity, and that does not measure position in a manner that makes the sensor vulnerable to physical wear.

SUMMARY OF THE INVENTION

According to one embodiment of the invention, there is provided a position detection switch for detecting the position of a movable part relative to a stationary part of a downhole drilling telemetry apparatus. The switch comprises a sensor and circuitry communicative with the sensor. The sensor comprises a pin assembly having at least one magnetizable pin, and a coil assembly having multiple electrically conductive coils. Each coil has a slot through which the pin can travel. The pin and coil assemblies are each connectable to the drilling telemetry apparatus and positioned relative to each other such that the pin travels through the slots when the movable part moves relative to the stationary part. The circuitry is electrically coupled to the coils and configured to detect a change in inductance in the coils as a result of the pin entering or leaving one of

the slots when the coils are energized. The pin assembly can be connected to the movable part and the coil assembly can be connected to the stationary part such that the pin travels through the slots when the movable part moves relative to the stationary part.

The switch allows accurate and precise position measurements to be taken in a high pressure environment and can be especially useful for a certain class of MP systems, although they can also be useful in other telemetry or downhole control applications. When the downhole telemetry apparatus is a mud pulser having a rotor and a stator, the moveable can include the rotor and the stationary part can include the stator. The rotor can be fixed to a shaft which is driven by a gear-motor. In such case, the pin assembly is connected to the shaft such that the pin assembly rotates with the rotor.

The pin can be made of magnetically soft iron; the coils can comprise toroidal transformers with magnet wire wrapped on iron dust cores or ferrite cores. The circuitry can comprises conditioning circuitry used to both drive and analyze the output of the electronics of the position switch.

One benefit of this position detection switch is that precise and accurate position measurements can be taken with a sensor that is insensitive to high pressures and temperatures, especially those pressures and temperatures associated with downhole drilling. Consequently, all the components of the position detection switch do not need to be shielded from ambient pressure or temperature, which means that the position detection switch can be manufactured less expensively and operate with higher power efficiency than alternative devices currently known in the art. As no contact is made between the pins and coils, another benefit is that the position detection switch is not inherently susceptible to mechanical wear as are other position detection switch known in the art, which increases reliability and operational life.

According to another aspect of the invention, there is provided downhole drilling telemetry apparatus comprising a movable part; a stationary part; and a position detection switch. The switch comprises a sensor and circuitry communicative with the sensor. The sensor comprises a pin assembly having at least one magnetizable pin, and a coil assembly having multiple electrically conductive coils. Each coil has a slot through which the pin can travel. The pin and coil assemblies are each connectable to other parts of the drilling telemetry apparatus and are positioned relative to each other such that the pin travels through the slots when the movable part moves relative to the stationary part. The circuitry is electrically coupled to the coils and configured to detect a change in inductance in the coils as a result of the pin entering or leaving one of the slots when the coils are energized.

The apparatus can further comprise a mud pulser having a gear motor, a shaft rotatably connected to the gear motor, a rotor connected to the shaft, and a stator, in which case the movable part comprises the rotatable shaft and the rotor, and the stationary part comprises the stator. The pin assembly can be connected to the shaft and the coil assembly can be fixed relative to the stator such that rotation of the shaft causes the pin to travel through the slots.

Alternatively, the mud pulser can have a gear motor, a shaft in rectilinear reciprocating connection to the shaft, a poppet connected to the shaft, and an orifice for receiving the poppet. In this case, the movable part comprises the shaft and the poppet, and the stationary part comprises the orifice, and the pin assembly is connected to the shaft and the coil assembly is fixed relative to the orifice such that reciprocation of the shaft causes the pin to travel through the slots.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, which illustrate an exemplary embodiment of the present invention:

Figure 1 is a schematic of a wellsite system in which embodiments of the invention can be employed;

Figure 2 is a cross-sectional side elevation view of a rotating vane mud pulser having a contactless position detection switch according to one embodiment;

Figures 3a and 3b are perspective views of a rotor and stator of the mud pulser, with the rotor and stator in an open position in Figure 3a and in a closed position in Figure 3b;

Figure 4a is a perspective view of a contactless sensor of the position detection switch; Figure 4b shows a shaft, disc, pins and coils of the contactless sensor shown in Figure 4a;

Figure 5 is a schematic view of linear variable differential transformer ("LVDT") conditioning circuitry of the contactless position detection switch; and

Figure 6 is a cross-sectional side elevation view of a second embodiment of the contactless position detection switch.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Figure 1 illustrates a wellsite system in which embodiments of the present invention can be employed. The wellsite can be onshore or offshore. In this exemplary system, a borehole 11 is formed in subsurface formations by rotary drilling in a manner that is well known. Embodiments of the invention can also use directional drilling, as will be described hereinafter.

A drill string 12 is suspended within the borehole 11 and has a bottom hole assembly 1 which includes a drill bit 6 at its lower end. The surface system includes platform and derrick assembly 10 positioned over the borehole 11, the assembly 10 including a rotary table 16, kelly 17, hook 18 and rotary swivel 19. The drill string 12 is rotated by the rotary table 16, energized by means not shown, which engages the kelly 17 at the upper end of the drill string. The drill string 12 is suspended from a hook 18, attached to a traveling block (also not shown), through the kelly 17 and a rotary swivel 19 which permits rotation of the drill string relative to the hook. As is well known, a top drive system could alternatively be used. There is also a logging and control 101.

In the example of this embodiment, the surface system further includes drilling fluid or mud 26 stored in a pit 27 formed at the well site. A pump 29 delivers the drilling fluid 26 to the interior of the drill string 12 via a port in the swivel 19, causing the drilling fluid to flow downwardly through the drill string 12 as indicated by the directional arrow 8. The drilling fluid exits the drill string 12 via ports in the drill bit 6, and then circulates upwardly through the annulus region between the outside of the drill string and the wall of the borehole, as indicated by the directional arrows 9. In this well known manner, the drilling fluid lubricates the drill bit 6 and carries formation cuttings up to the surface as it is returned to the pit 27 for recirculation.

The bottom hole assembly 1 of the illustrated embodiment comprises a logging-while-drilling (LWD) module 2, a measuring-while-drilling (MWD) module 3, a roto-steerable system and motor, and drill bit 6.

The LWD module 2 is housed in a special type of drill collar, as is known in the art, and can contain one or a plurality of known types of logging tools. It will also be understood that more than one LWD and/or MWD module can be employed, e.g. as represented at 2A. (References, throughout, to a module at the position of 2 can alternatively mean a module at the position of 2A as well.)

The LWD module 2 includes capabilities for measuring, processing, and storing information, as well as for communicating with the surface equipment. In the present embodiment, the LWD module 2 includes a pressure measuring device.

The MWD module 3 is also housed in a special type of drill collar, as is known in the art, and can contain one or more devices for measuring characteristics of the drill string and drill bit. The MWD module 3 further includes an apparatus (not shown) for generating electrical power to the downhole system. This may typically include a mud turbine generator powered by the flow of the drilling fluid, it being understood that other power and/or battery systems may be employed. In the present embodiment, the MWD module 3 includes one or more of the following types of measuring devices: a weight-on-bit measuring device, a torque measuring device, a vibration measuring device, a shock measuring device, a stick slip measuring device, a direction measuring device, and an inclination measuring device.

A particularly advantageous use of the system hereof is in conjunction with controlled steering or "directional drilling." In this embodiment, a roto-steerable subsystem 5 (Figure 1) is provided. Directional drilling is the intentional deviation of the wellbore from the path it would naturally take. In other words, directional drilling is the steering of the drill string so that it travels in a desired direction. Directional drilling is, for example, advantageous in offshore drilling because it enables many wells to be drilled from a single platform. Directional drilling also enables horizontal drilling through a reservoir. Horizontal drilling enables a longer length of the wellbore to traverse the reservoir, which increases the production rate from the well. A directional drilling system may also be used in vertical drilling operation as well. Often the drill bit will veer off of an planned drilling trajectory because of the unpredictable nature of the formations being penetrated or the varying forces that the drill bit experiences. When such a deviation occurs, a directional drilling system may be used to put the drill bit back

on course. A known method of directional drilling includes the use of a rotary steerable system ("RSS"). In an RSS, the drill string is rotated from the surface, and downhole devices cause the drill bit to drill in the desired direction. Rotating the drill string greatly reduces the occurrences of the drill string getting hung up or stuck during drilling. Rotary steerable drilling systems for drilling deviated boreholes into the earth may be generally classified as either "point-the-bit" systems or "push-the-bit" systems. In the point-the-bit system, the axis of rotation of the drill bit is deviated from the local axis of the bottom hole assembly in the general direction of the new hole. The hole is propagated in accordance with the customary three point geometry defined by upper and lower stabilizer touch points and the drill bit. The angle of deviation of the drill bit axis coupled with a finite distance between the drill bit and lower stabilizer results in the non-collinear condition required for a curve to be generated. There are many ways in which this may be achieved including a fixed bend at a point in the bottom hole assembly close to the lower stabilizer or a flexure of the drill bit drive shaft distributed between the upper and lower stabilizer. In its idealized form, the drill bit is not required to cut sideways because the bit axis is continually rotated in the direction of the curved hole. Examples of point-the-bit type rotary steerable systems, and how they operate are described in U.S. Patent Application Publication Nos. 2002/0011359; 2001/0052428 and U.S. Patent Nos. 6,394,193; 6,364,034; 6,244,361; 6,158,529; 6,092,610; and 5,113,953 all herein incorporated by reference. In the push-the-bit rotary steerable system there is usually no specially identified mechanism to deviate the bit axis from the local bottom hole assembly axis; instead, the requisite non-collinear condition is achieved by causing either or both of the upper or lower stabilizers to apply an eccentric force or displacement in a direction that is preferentially orientated with respect to the direction of hole propagation. Again, there are many ways in which this may be achieved, including non-rotating (with respect to the hole) eccentric stabilizers (displacement based approaches) and eccentric actuators

that apply force to the drill bit in the desired steering direction. Again, steering is achieved by creating non co-linearity between the drill bit and at least two other touch points. In its idealized form the drill bit is required to cut side ways in order to generate a curved hole. Examples of push-the-bit type rotary steerable systems, and how they operate are described in U.S. Patent Nos. 5,265,682; 5,553,678; 5,803,185; 6,089,332; 5,695,015; 5,685,379; 5,706,905; 5,553,679; 5,673,763; 5,520,255; 5,603,385; 5,582,259; 5,778,992; 5,971,085.

According to one embodiment of the present invention, there is provided a contactless position detection switch that measures the angular position of rotating components within a rotating vane mud pulser of the MWD module 3. Parameters that are valuable to drill operators and that are measured by the MWD module 3 include directional information (e.g. the inclination and azimuth of a wellbore at a particular location), temperature, and the type and severity of downhole vibrations. This information is measured by the MWD module 3 and is communicated to the surface using mud pulse (MP) telemetry, with the pulse generated by actuating a rotor/stator mechanism of the mud pulser.

Referring now to Figure 2 and according to one embodiment of the invention, a rotating vane mud pulser 31 is shown supported in a drill collar 32, the collar 32 being one component of the drill string 12. Typically, the drill string 12 comprises multiple drill pipes that are connected together during drilling as drilling progresses and as deeper depths are reached. At the distal end of the drill pipe is the drill collar 32 and the drill bit 6, the drill bit 6 responsible for boring through the earth. Normally, pumps located at the surface of the borehole 11 pump drilling fluid ("mud") 33, into the drill string. The mud 33 flows towards the distal end of the drill string 12 and in so doing passes through a rotor/stator mechanism 34 comprising a rotor 35 and a stator 36. As will be explained more thoroughly in the discussion relating to Figures 3a and 3b below, the rotor/stator mechanism

34 operates in positions ranging anywhere from fully opened to fully closed. Notwithstanding the state of the rotor/stator mechanism 34, however, the surface pumps are powerful enough such that the volume of mud flowing through the collar 32 remains substantially constant. This is because even when fully closed, there is an axial gap between the rotor 35 and stator 36 that provides a pathway through which the mud flows.

Once the mud passes the rotor/stator mechanism 34 it flows through a support (a "spider") 37 and over an oil-filled housing 38 that incorporates a pressure compensation chamber. The housing 38 extends to the base of the stator 36 and also incorporates a rotary seal 39. The chamber incorporates a flexible membrane 40 that flexes in response to the ambient pressure on the outside of the housing 38, which pressure is transferred to the membrane 40 through ports 41 on the housing 38. The pressure compensated housing 38 allows the pressure of internal oil 42 that surrounds components within the housing 38 to rise to approximately the external ambient pressure experienced by the pulser 31. Components within the housing 38 include a brushed gear-motor 43, contactless sensor 44, bearing sections 45, and gear-motor shaft 46. The gear-motor 43 is located at the distal end of the housing 38 and is rotatably coupled to the shaft 46, which in turn is laterally fixed by the bearing sections 45. The contactless sensor 44 is located on the shaft 46 near the motor 43. The oil 42 is contained within the housing 38 by a feed-through bulkhead 47 located at distal of the housing 38 below the gear-motor 43, and a rotary shaft seal 39 at the proximal end of the housing 38 above the top bearing section 45. Below the feed-through bulkhead 47 is a low-pressure compartment which houses circuitry 70 (not shown in this figure, see Figure 5) at a pressure suitable for circuitry to safely operate. The circuitry 70 is electrically coupled by wires to the contactless sensor 44; the circuitry 70 and sensor 44 together form a contactless position detection switch, as will be described in further detail below. The wires connecting the sensor 44 and circuitry pass through the feed-through bulkhead

47. The mud 33 flows on towards the drilling motor and drill bit and eventually exits through ports in the drill bit and returns to the surface.

Referring now to Figures 3a and 3b, we see perspective views of the rotor/stator mechanism 34. In this exemplary embodiment both rotor 35 and stator 36 comprise four symmetrically-placed arms, with the rotor arms being complementary to the stator arms. One complementary pair of arms consisting of rotor arm 35a and stator arm 36a is labelled in Figures 3a and 3b. When the rotor and stator arms entirely overlap, as they do in Figure 3a, the rotor/stator mechanism 34 is in the "open" position, and four gaps are created, of which only one gap 51 is labelled in Figure 3a. When the rotor arms 35 and stator arms 36 are aligned such that the gap 51 is completely filled, the rotor/stator mechanism 34 is in the "closed" position, as depicted in Figure 3b.

Inspection of Figures 3a and 3b reveals that the rotor 35 is rotated by 45° in order to transition the rotor/stator mechanism 34 between the open and closed positions. While Figures 3a and 3b depict a rotor/stator mechanism 34 having four arms 35, 36, the rotor/stator mechanism 34 may also be constructed with more or less than four arms 35, 36.

In MP telemetry applications a pressure pulse is generated by closing and then opening the rotor/stator mechanism 34. When the rotor/stator mechanism 34 is in an open position, mud flow from the surface is relatively unimpeded by the arms of the rotor 35 and stator 36. When the rotor/stator mechanism 34 is in a fully closed position, the axial gap between the rotor 35 and stator 36 allows mud 33 to flow, but also increases the local velocity of the mud 33. As explained by Bernoulli's Principle, this increased velocity results in a commensurate change in fluid pressure above the rotor/stator mechanism 34. It is this timed change in fluid pressure which corresponds to actuating the rotor/stator mechanism 34 that encodes the telemetry data that is communicated to the surface.

The rotor 35 is moved relative to the stator 36 by means of the gear-motor shaft 46 that is supported by the bearing sections 45. The rotor 35 is fixedly connected to the gear-motor shaft 46, and thus rotation of the gear-motor shaft 46 is translated directly to the rotor 35. Consequently, knowledge of the angular position of the gear-motor shaft 46 results in knowledge of the angular position of the rotor 35, more particularly of whether the rotor/stator mechanism 34 is in an open or closed position, and thereby of the nature of the pressure pulse status as sent to the surface.

Referring now to Figures 4a and 4b, we see a detailed perspective view of the contactless sensor 44 (Figure 4a), and a perspective view of the contactless sensor 44 as used in conjunction with a gear motor 43 and coil support structure 64 (see Figure 3b). The support structure 64 is mounted on top of the gear-motor 43 and supports a first coil 63, which includes a first slot 66, and a second coil 62, which includes a second slot 65. The gear-motor 43 is connected to the gear-motor output shaft 46. Near the proximate end of the gear-motor output shaft 46 is, in this exemplary embodiment, a pin assembly comprising a disc 60 which is coaxially aligned with and fixed to the output shaft 46 and from which downwardly protrude four pins 61, of which a first pin 61a and a second pin 61b are individually labelled for explanatory purposes. While the pins 61 are illustrated as being cylindrical, pins 61 of other shapes (e.g.: pins having a rectangular cross-section) can also be used. The pins 61 should be easily magnetized and for this purpose can be manufactured from a material such as soft iron. The four pins 61 correspond in both number and position to the four arms of the rotor 35 of the rotor/stator mechanism 34; thus, in the exemplary embodiment of Figure 4a, each pin is separated from the next by 90 degrees. As the pins 61 are fixedly connected to the disc 60, which itself is fixedly connected to the output shaft 46, the location of the pins 61 directly corresponds to the angular position of the output shaft 46. The output shaft 46 also extends axially along the drill collar 62 and is fixedly coupled to the four arms of the rotor 35.

Consequently, the location of the pins 61 directly corresponds to the location of the four arms of the rotor 35.

Both slots 65, 66 are wide enough to allow the pins 61 to pass through them as the disc 60 rotates. The coils 62, 63 are constructed as simple transformers, with each coil comprising a single primary winding 73, 74 and a single secondary winding 75, 76 (not shown in Figures 4a and 4b but shown schematically in Figure 5). The windings themselves comprise many turns of fine magnet wire wrapped around toroidally-shaped cores 77, 78, which in exemplary embodiments are an iron dust core or a ferrite core. Note that as the components illustrated in Figures 4a and 4b do not incorporate any semiconductor-based devices they are relatively immune to applied isotropic pressure and can therefore properly function in the high pressure environment within the housing 38.

In the exemplary embodiment of Figures 4a and 4b the two coils 62, 63 are angularly separated about the shaft 46 by 135 degrees. A review of Figures 4a and 4b shows the need for the sensor 44 to determine the rotor/stator angular positions at incremental values of 45 degrees. Referring back to Figure 4a, it is apparent that rotating disc 60 by 45 degrees will take the first pin 61a out of the first slot 66 and move the second pin 61b into the second slot 65. This provides detection of the repeating open/closed positions of the rotor/stator mechanism 34 every 45 degrees as the shaft 46 rotates. In our embodiment 135 degrees is chosen simply for manufacturing convenience; if symmetries other than four-fold are used (for example two or three-fold), the coil's angular spacing will need to commensurately changed. For an embodiment having two coils, the coils can be angularly separated according to the following equation:

$$(180/p)(1+2n) \text{ degrees, wherein } p = \text{number of pins and } n = 0, 1, 2, 3.$$

For example, for an embodiment having four equally spaced pins (p = 4) the coils

can be separated by 45 degrees (n=0), 135 degrees (n=1), 225 degrees (n=2) and 315 degrees (n=3).

The coils' support structure 64 is stationary relative to the gear-motor 43. The effect of having the slots 65, 66 is to reduce the maximum coupling, or flux linkage, between the primary and secondary windings of the coils 62, 63. Consequently, when one of the pins 61 passes through either slot 65, 66 when the coils are energized, the inductance of the corresponding coil 62, 63 increases to some extent, thereby increasing its electrical impedance. For example, as pin 61a enters the slot 66 of coil 63, as illustrated in Figures 4a and 4b, the slot 65 of coil 62 is empty. Further rotation takes pin 61a out of the slot 66 of coil 63, but brings pin 61b into the slot 65 of coil 62. As pins 61a, 61b enter and exit the slots 65, 66, the AC current through the associated windings changes, which in turn modifies the amplitude of the output of the secondary winding. The change in output of the windings is measured by conditioning circuitry 70 and allows the circuitry 70 to determine the position of the rotor 35 relative to the stator 36, as described with reference to Figure 5, below.

Referring now to Figure 5 we describe an embodiment of circuitry used to analyze the electrical output of the contactless sensor 44. Figure 5 depicts a simplified schematic view of a linear variable differential transformer ("LVDT") conditioning circuitry 70 used in conjunction with the mechanical aspects of the contactless sensor 44. The contactless sensor 44 and circuitry 70 together form a contactless position detection switch. Note that the circuitry 70, with the exception of the coils 62, 63, incorporates semiconductor-based devices and thus is housed on the low pressure side of the feed-through bulkhead 47.

In this embodiment, each core 77, 78 comprises an easily-magnetizable material in the shape of a toroid with each toroid incorporating one of the slots 65, 66 ("slotted toroid"). Apart from the coils 62, 63, the circuitry 70 shown in Figure 4 is available commercially from a number of sources, such as from Analog Devices

in the form of its AD698 (Universal LVDT Signal Conditioner) integrated circuit.

Consider now what happens as the gear-motor output shaft 46 rotates. At all times an oscillator signal 71 is amplified and buffered by a first amplifier 72, the output of which drives the primary windings 73, 74 of the coils 62, 63, respectively, and also drives the input of a second amplifier 79. Consequently, the output of the second amplifier 79 is largely constant despite any changes that occur elsewhere in the sensor system. As the shaft 46 rotates, the disc 60 and pins 61 also rotate. For most of the rotation the slots 65, 66 contain only oil 42. In this case the output of each secondary winding 75, 76 is reasonably equal in magnitude, within manufacturing tolerances. As the secondary windings 75, 76 are connected in series opposition the differential input to, and consequently the output of a third amplifier 80, whose inputs are connected to the secondary windings 75, 76, will be minimized. This is because if neither coil 62, 63 has a pin 61 in its slot 65 or 66, the combined output of the secondary windings 75, 76 will be very small. This could lead to difficulties in a subsequent dividing circuit 81 whose inputs would be the reasonably constant AC voltage from the second and third amplifiers 79 and 80. A simple solution is to provide a constant offset voltage 84 from a voltage divider 85 to the third amplifier 80; thus, even with a net zero differential input the output of this amplifier 80 will be the DC value of the offset voltage 84. The offset voltage 84 can be conveniently chosen such that the output of the divider 85 (which is the ratio of the outputs of the second and third amplifiers 79, 80) is approximately the middle of the divider's 81 output range. The output of the divider 81 is then essentially replicated by filter 82 and output amplifier 83.

As the shaft 46 rotates, one of the pins 61 will enter one of the slots 65, 66. For illustrative purposes, consider what happens when the first pin 61a enters the first slot 66, which corresponds to the first coil 63. As previously noted, if this slot 66 contains a pin, the other slot 65 does not. Now, when the first pin 61a is

within the first slot 66 the flux in the first coil 63 changes, resulting in an increased output from the corresponding secondary winding 76. Because there is no pin 61 in the second slot 65, the output of its secondary winding 75 remains unchanged. The differential input to the third amplifier 80 changes, modifying its quiescent output. The output of the third amplifier 80 will depend on its configuration details, which details are obvious to a person skilled in the art. However, for illustrative purposes assume the output of the third amplifier 80 increases. This increased output leads to a corresponding change in the output of the divider circuit 81, filtering circuit 82, and amplifier 83. Subsequent gear-motor control circuitry (not shown) detects this change in output and stops rotation of the rotor/stator mechanism 34 for a predetermined period of time, in an open or closed position (as determined by the requirements of the particular data encoding protocol being used). This timed stopping and starting of rotation ends or initiates a pressure pulse.

While pressure pulses are being produced, a further rotation of 45 degrees in the same direction will cause the first pin 61a to exit the first slot 66 and the second pin 61b will enter the second slot 65. In this case the output of the secondary winding 75 that corresponds to the second slot 65 will increase and the output of the secondary winding 76 that corresponds to the first slot 66 will have decreased. This reverses the differential input to the amplifier 80, primarily because the secondary windings 75, 76 are wound in series opposition, causing the output level of the third amplifier 80 to become as much below the offset voltage 84 as it was above the offset voltage 84 when the first pin 61a was in the first slot 66. As before, subsequent gear-motor control circuitry can now stop rotation for a predetermined period in a closed or open position and thereby initiate or end a pressure pulse. Thus the telemetry requirements in producing timed pressure pulses are met by the position switch 70 determining when one of the pins 61 is within the slot 65, 66 of a specific coil 62, 63.

The dimensions of the slots, pins and the radial distance of the pins from the shaft determine the angular precision of the sensor 44. In practise, determining the angle to within 3 degrees at specific 45 degree increments is easily attainable. This is quite adequate in controlling the electric gear-motor 43 and hence the shaft 46 in order to produce adequately-shaped telemetry pressure pulses in downhole MWD environments.

It is evident from the foregoing that while a preferred embodiment utilizes two coils and four pins, different numbers of coils and/or pins can be used according to the specific operational requirements of the valve mechanism needed to produce pressure changes. The innovative aspects of our invention apply equally in embodiments such as these.

According to a further embodiment of the invention, there are provided non-rotary embodiments of the contactless position sensor 44. Figure 6, for example, depicts a sensor 44 capable of detecting the position of members engaged in relative rectilinear reciprocating motion. In Figure 6, a poppet/orifice valve 90, composed of a poppet 92 and orifice 93, is used to generate pressure pulses. Rectilinear reciprocating motion of the poppet 92 into and out of the orifice 93 impede and facilitate, respectively, the passage of drilling fluid 33 through the orifice 93, thereby causing commensurate changes in fluid pressure above the poppet/orifice valve 90. As with the aforedescribed rotary embodiment, it is this timed change in fluid pressure, which corresponds to actuating the poppet/orifice valve 90, that encodes telemetry data that is communicated to the surface. Also as with the aforementioned rotary embodiment, the components that make up this rectilinear reciprocating embodiment of the sensor 44 do not include semiconductor-based components, and can therefore be contained within the high-pressure environment of the oil-filled housing 38.

During operation, rotary motion of the motor 43 is converted to rectilinear reciprocating motion by a rotary-to-linear converter 91 examples of which are

well known in the art, which in turn causes rectilinear reciprocation of the shaft 46 along the shaft's 46 longitudinal axis. One pin 61 is disposed on the shaft 46 and the coils 62, 63 are located on the interior of the housing 38 such that the pin 61 can pass through the slots 65, 66 of the coils 62, 63 as a result of the rectilinear motion of the shaft 46. The locations of the pin 61 and the coils 62, 63 are selected so that the pin 61 is always either contained within one of the slots 65, 66 or in the area between the coils 62, 63, although this is not necessary for all embodiments. Consequently, in the illustrated embodiment, when the pin 61 is in the slot 66 of coil 63, the poppet/orifice valve 90 is in an "open" position, and when the pin 61 is in the slot 65 of coil 62, the poppet/orifice valve 90 is in a "closed" position. As with the rotor/stator mechanism 34 of the rotary embodiment described above, when the valve 90 is in the open position, velocity of the drilling fluid 33 is slower than when the valve 90 is in the closed position, and actuation of the valve 90 can therefore be used to initiate or end a pressure pulse. Also as with the rotary embodiment described above, passing the pin 61 into and out of the slots 65, 66 induces changes in the output of the windings of the coils 62, 63, which are measured by the conditioning circuitry 70 in order to determine the position of the pin 61 and, consequently, the position of the shaft 46 and the state of the poppet/orifice valve 90.

In either of the rotary or rectilinear embodiments, or in any other embodiments not expressly disclosed herein, the position of an easily magnetizable pin corresponds to the position of a shaft, which in turn corresponds to the state of a valve mechanism. The position of the pin can be determined because in certain positions, the pin changes the inductance of slotted coils, and this change in inductance is detected by circuitry coupled to the coils. Once the position of the pin is determined, so can the state of the valve mechanism, and consequently the valve mechanism can be actuated to create timed pressure pulses that are transmitted to the surface. As the pin, coils, and slots are not manufactured using semiconductor-based components, they can operate in the high pressures

typical of downhole drilling.

While a particular embodiment of the present invention has been described in the foregoing, the scope of the claims should not be limited by the embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

CLAIMS:

1. A position detection switch for detecting the position of a movable part relative to a stationary part of a downhole drilling telemetry apparatus, the switch comprising:

(a) a sensor comprising

a pin assembly having at least one magnetizable pin; and

a coil assembly having multiple electrically conductive coils, each coil with a slot through which the pin can travel;

the pin and coil assemblies each connectable to the drilling telemetry apparatus and positioned relative to each other such that the pin travels through the slots when the movable part moves relative to the stationary part; and

(b) circuitry electrically coupled to the coils and configured to detect a change in inductance in the coils as a result of the pin entering or leaving one of the slots when the coils are energized.

2. A position detection switch as claimed in claim 1 wherein the pin assembly is connectable to the movable part and the coil assembly is connectable to the stationary part such that the pin travels through the slots when the movable part moves relative to the stationary part.

3. A position detection switch as claimed in claim 2 wherein the downhole telemetry apparatus includes a mud pulser comprising a rotor and a stator and the moveable part includes the rotor and the stationary part includes the stator.

4. A position detection switch as claimed in claim 3 wherein the movable part includes a rotatable shaft, the rotor is fixed to the shaft, and the pin assembly is connectable to the shaft such that the pin rotates with the rotor.

5. A position detection switch as claimed in claim 4 wherein the pin is composed of soft iron.

6. A position detection switch as claimed in claims 4 or 5 wherein the coil assembly consists of two coils.

7. A position detection switch as claimed in claim 6 wherein the coils are angularly separated by (180/p)(1+2n) degrees, wherein p = number of equally spaced pins and n = 0, 1, 2, 3.

8. A position detection switch as claimed in claim 7 wherein the pin assembly consists of four pins.

9. A position detection switch as claimed in claim 1 wherein each coil is a transformer comprising a magnetizable slotted toroidal core with an electrically conductive primary winding and an electrically conductive secondary winding each wrapped around the core.

10. A position detection switch as claimed in claim 9 wherein the core is an iron dust core or a ferrite core.

11. A position detection switch as claimed in claim 10 wherein the circuitry is a linear variable differential transformer conditioning circuit.

12. A position detection switch as claimed in claim 11 wherein the circuitry comprises an oscillator signal source communicative with the primary winding for energizing the coil, and a voltage divider and filter circuit communicative with the primary and secondary windings for detecting a

13. A downhole drilling telemetry apparatus comprising

(a) a movable part;

(b) a stationary part; and

(c) the position detection switch as claimed in claim 1, wherein the pin assembly is connected to one of the movable and stationary parts and coil assembly is connected to the other of the movable and stationary parts.

14. An apparatus as claimed in claim 13 further comprising a mud pulser having a gear motor, a shaft rotatably connected to the gear motor, a rotor connected to the shaft, and a stator, wherein the movable part comprises the rotatable shaft and the rotor, and the stationary part comprises the stator.

15. An apparatus as claimed in claim 14 wherein the pin assembly is connected to the shaft and the coil assembly is fixed relative to the stator such that rotation of the shaft causes the pin to travel through the slots.

16. An apparatus as claimed in claim 13 further comprising a mud pulser having a gear motor, a shaft in rectilinear reciprocating connection to the shaft, a poppet connected to the shaft, and an orifice for receiving the poppet, wherein the movable part comprises the shaft and the poppet, and the stationary part comprises the orifice.

17. An apparatus as claimed in claim 16 wherein the pin assembly is connected to the shaft and the coil assembly is fixed relative to the orifice such that reciprocation of the shaft causes the pin to travel through the slots.

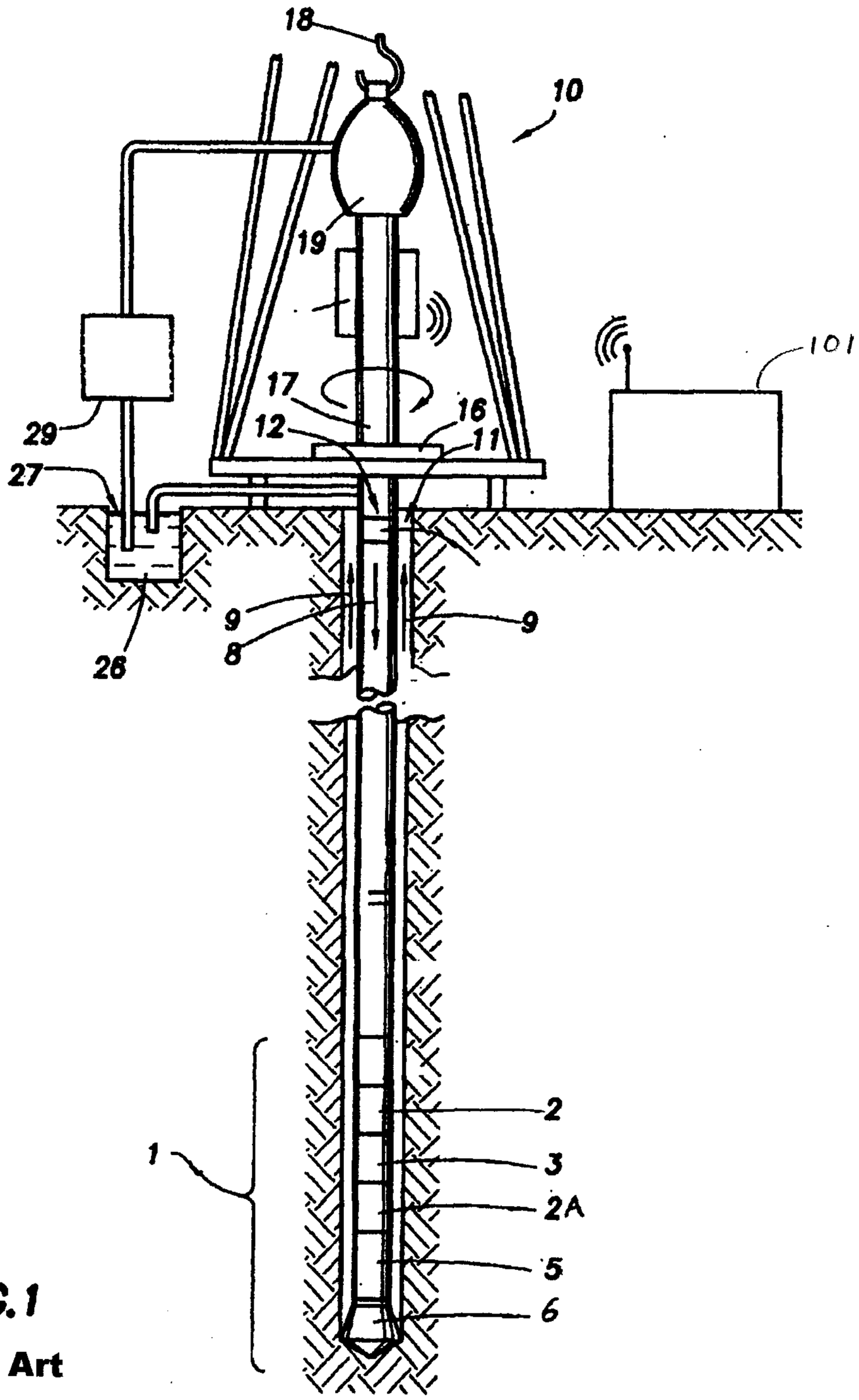


FIG. 1
Prior Art

Figure 2

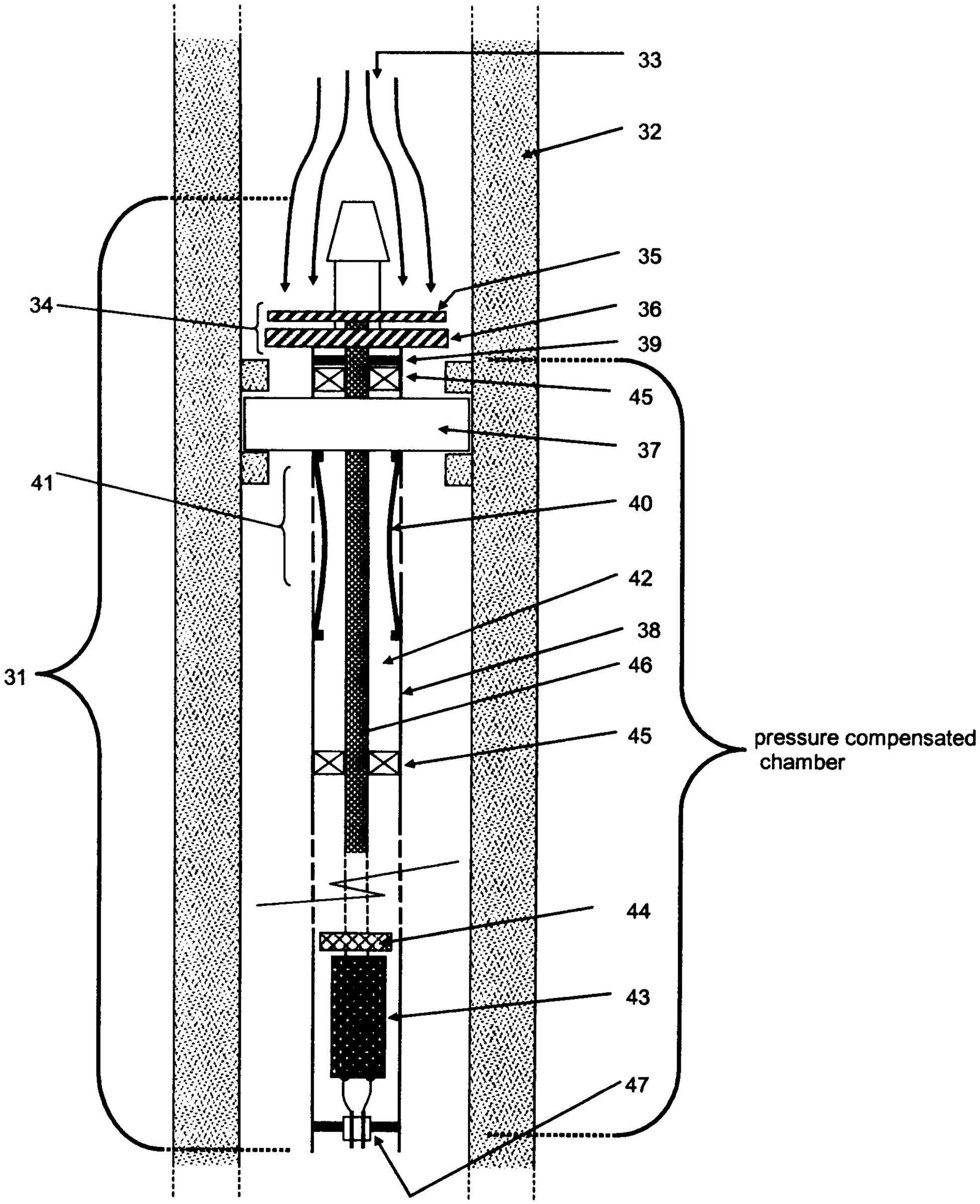

33
32
35
34
36
39
45
37
41
40
42
38
46
31
45
pressure compensated chamber
44
43
47

Figure 3a

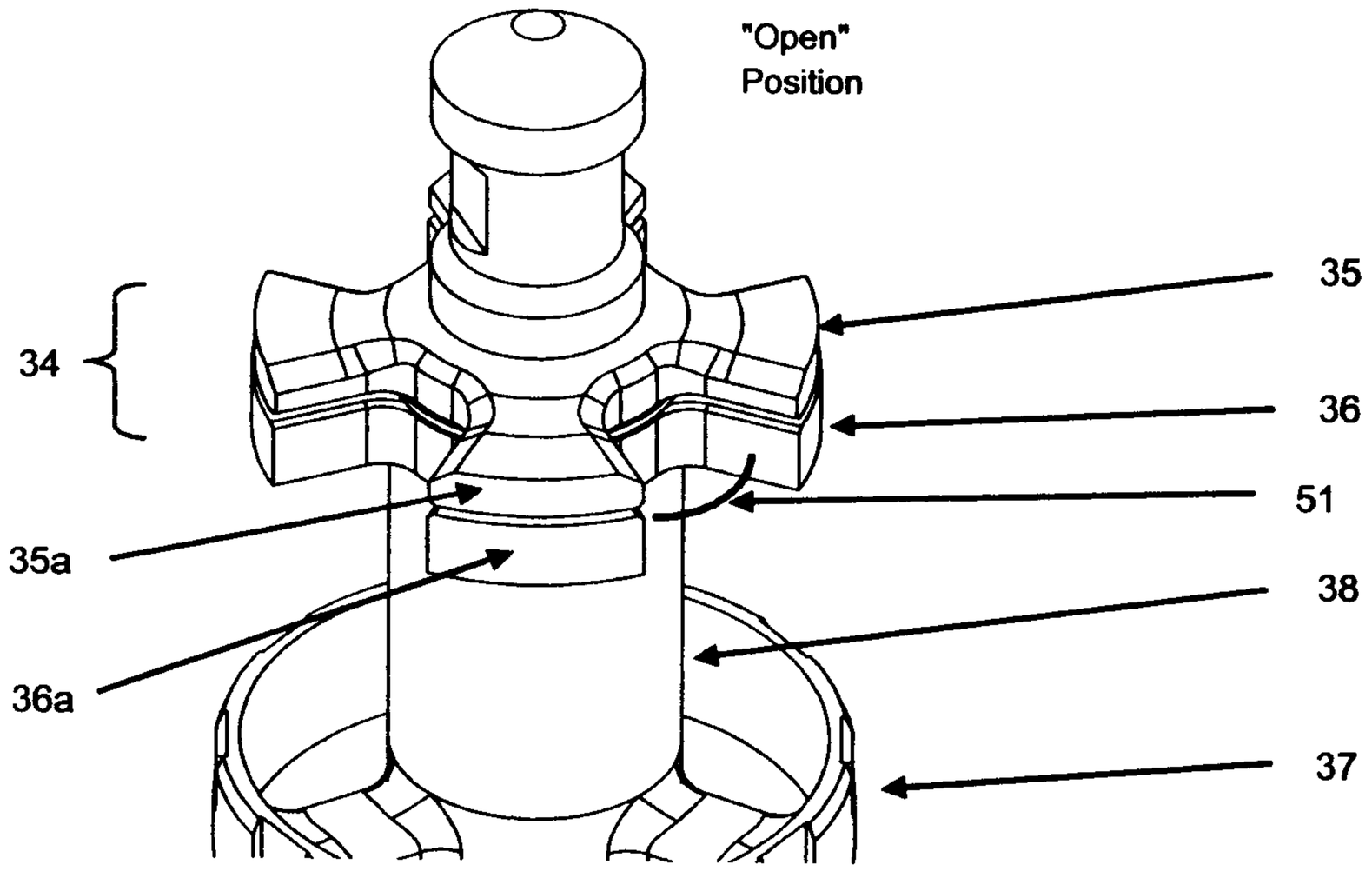


Figure 3b

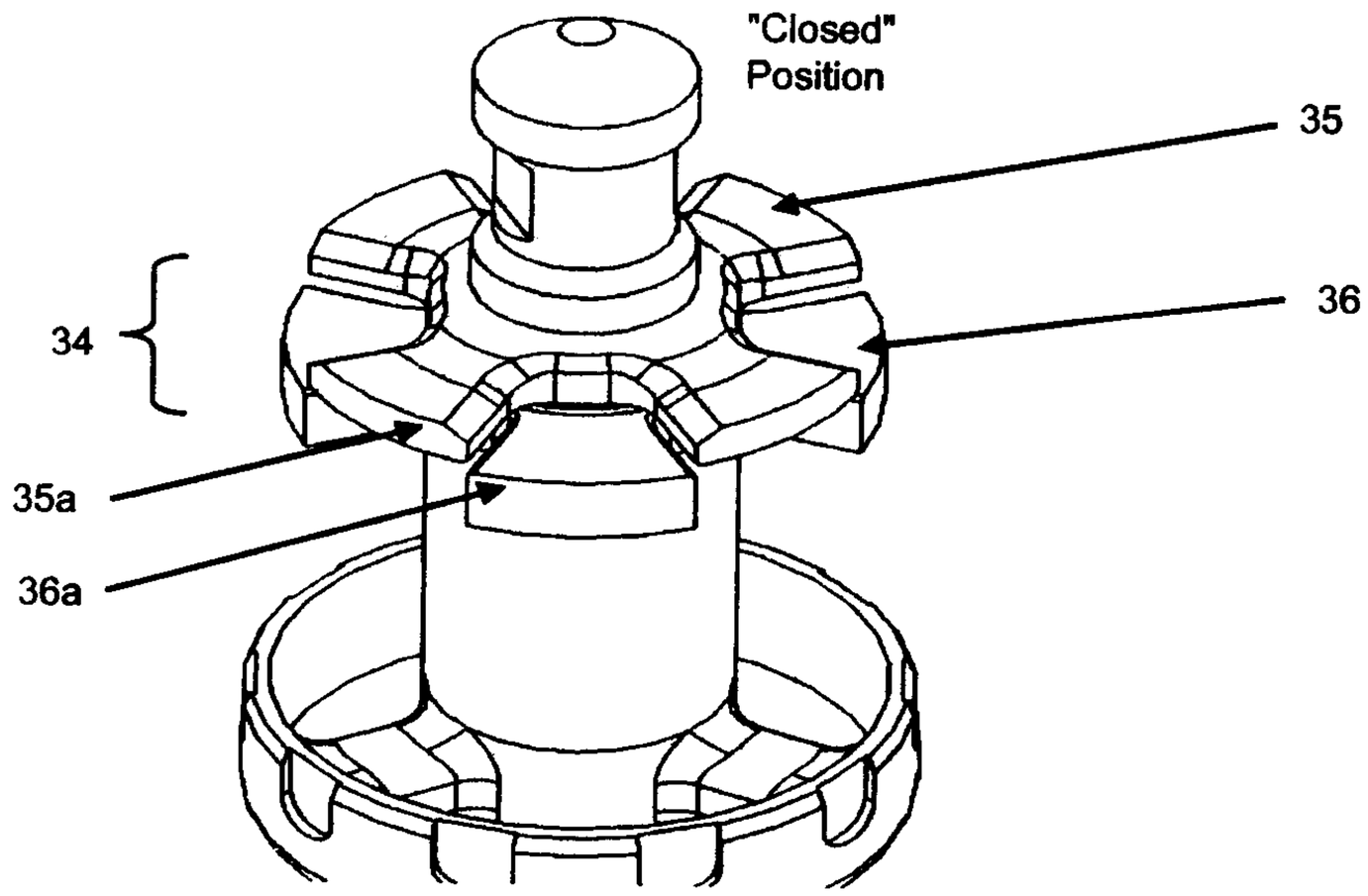


Figure 4a

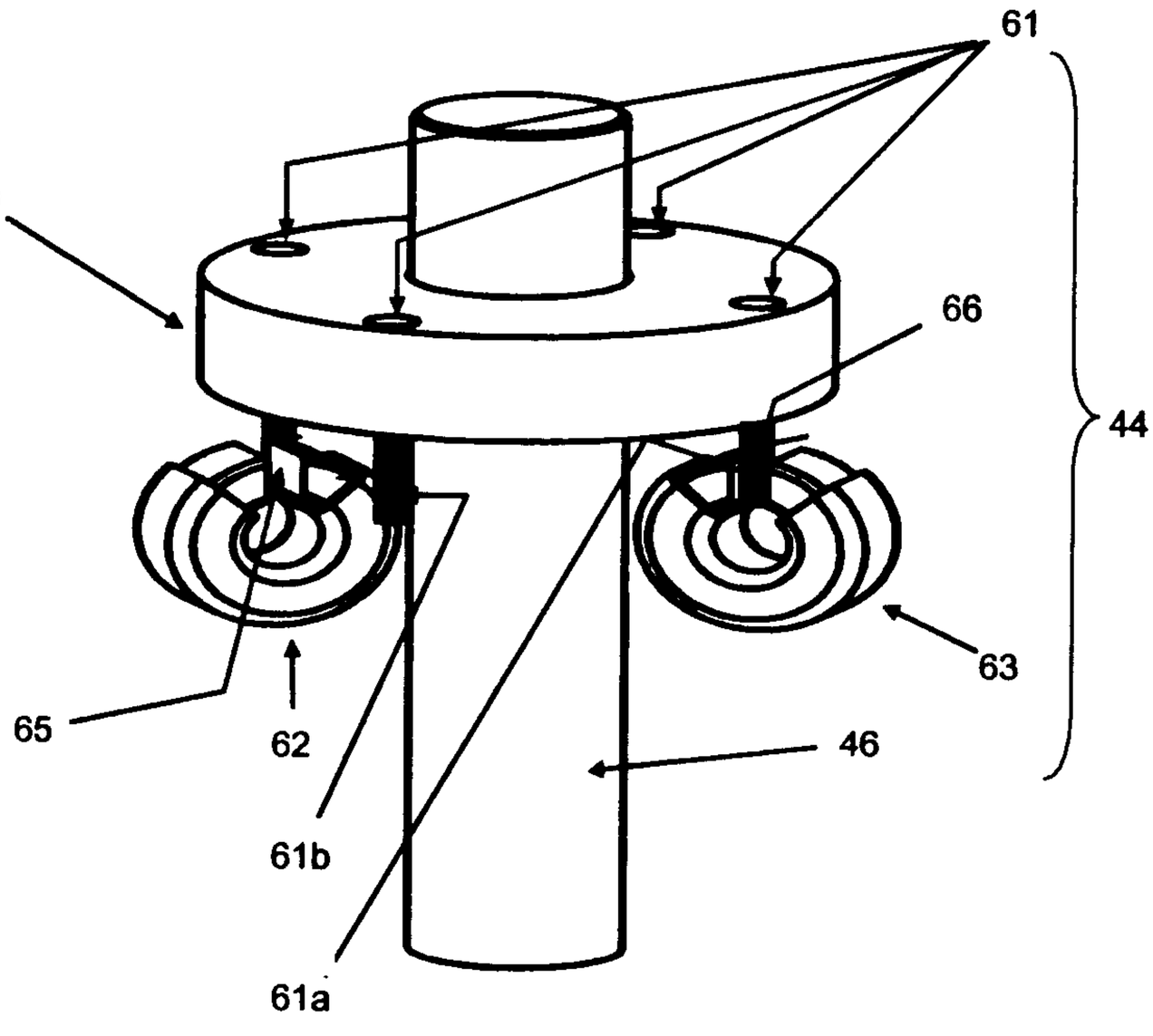


Figure 4b

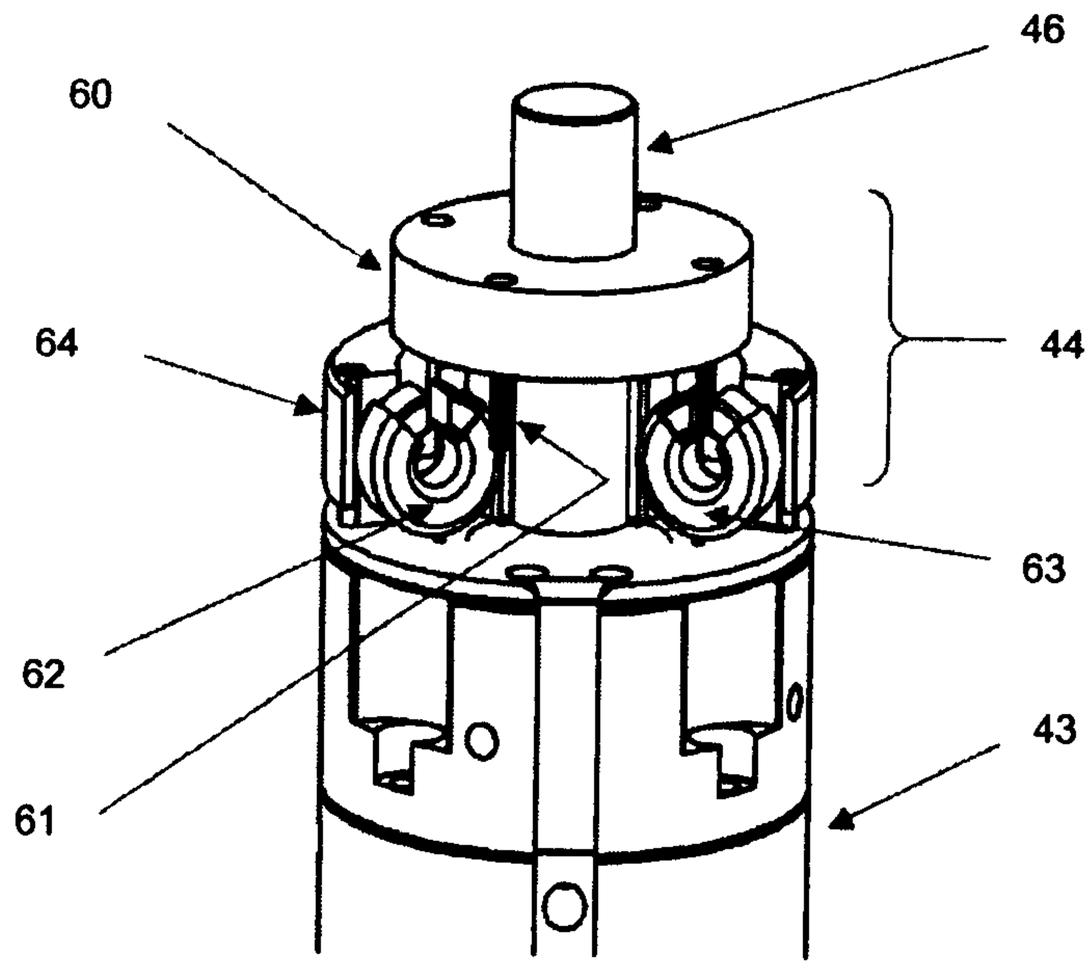


Figure 5

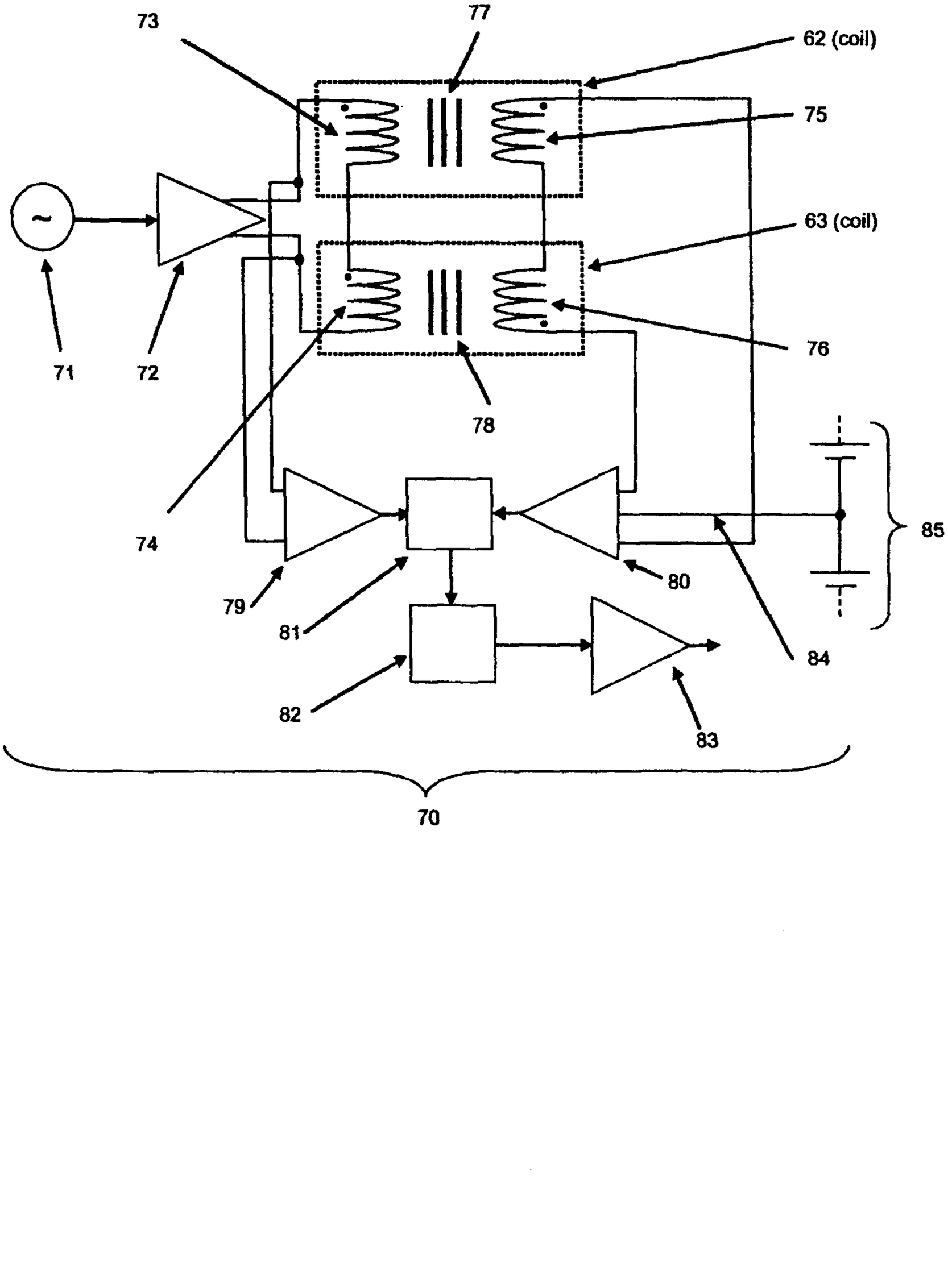
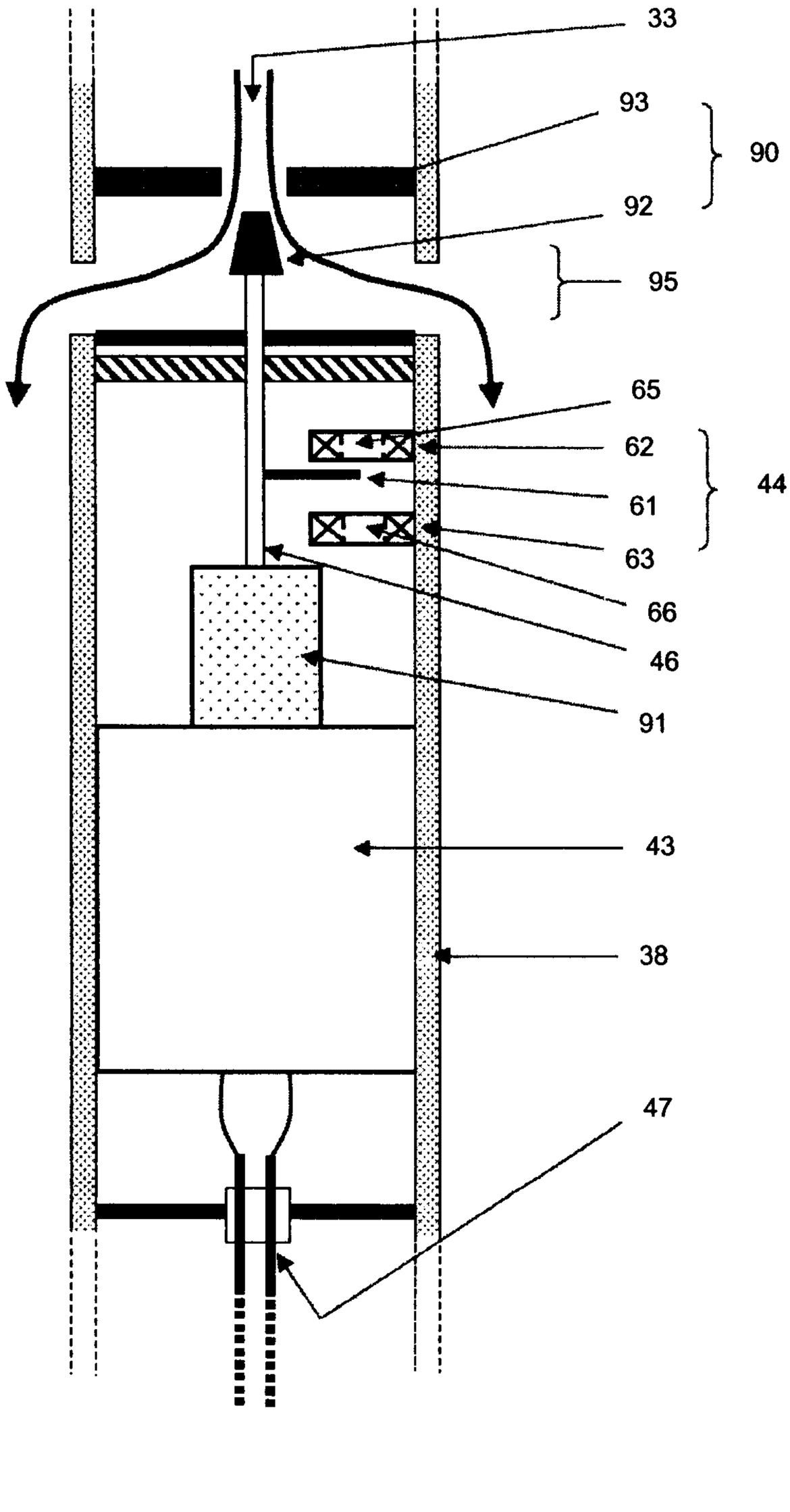
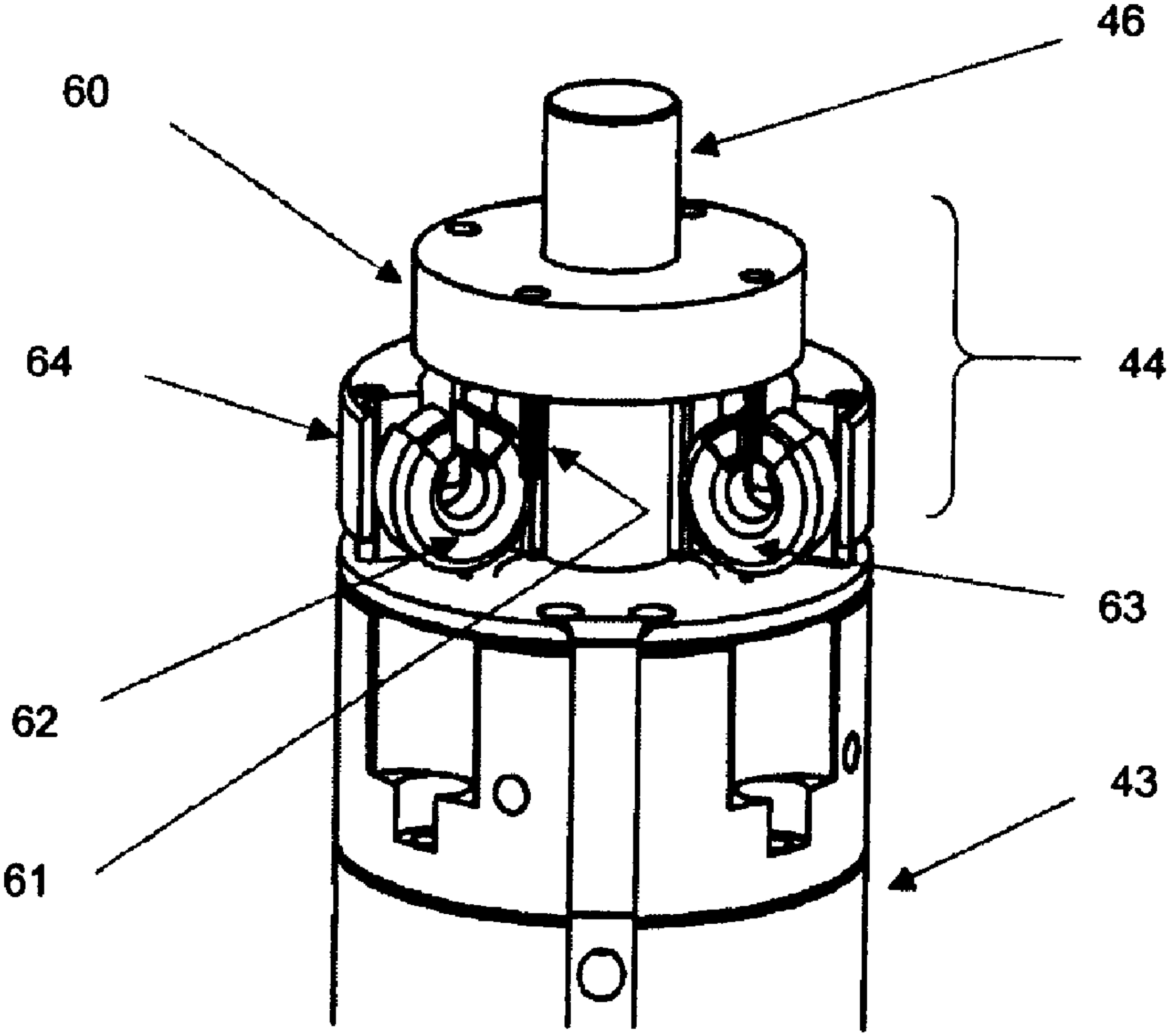


Figure 6




46
60
64
44
63
62
43
61