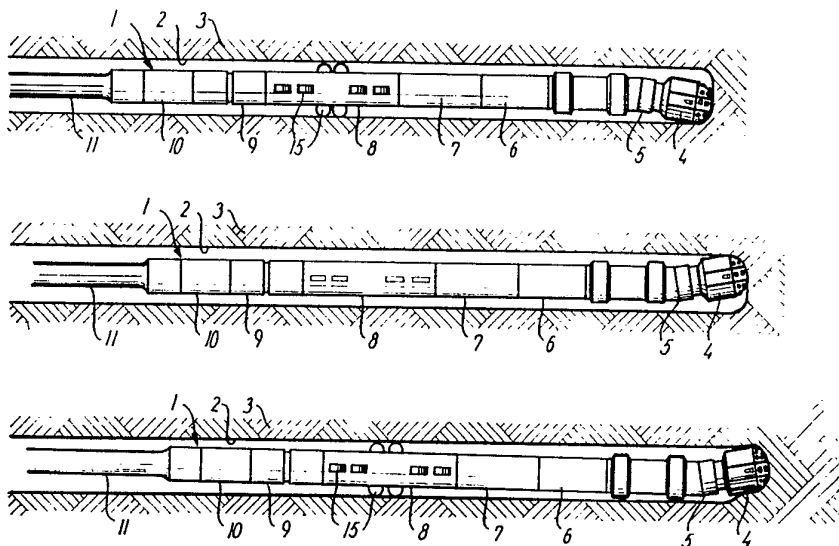


INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁵ : E21B 7/08	A1	(11) International Publication Number: WO 93/10326 (43) International Publication Date: 27 May 1993 (27.05.93)
(21) International Application Number: PCT/DK92/00341 (22) International Filing Date: 18 November 1992 (18.11.92) (30) Priority data: 1884/91 19 November 1991 (19.11.91) DK (71) Applicant (for all designated States except US): HTC A/S [DK/DK]; Granskoven 10, DK-2600 Glostrup (DK). (72) Inventor; and (75) Inventor/Applicant (for US only) : HALLUNDBÆK, Jørgen [DK/DK]; Lyngby Hovedgade 76, DK-2800 Lyngby (DK). (74) Agent: HOFMAN-BANG & BOUTARD A/S; Adelgade 15, DK-1304 Copenhagen K (DK).		(81) Designated States: AT, AU, BB, BG, BR, CA, CH, CS, DE, DK, ES, FI, GB, HU, JP, KP, KR, LK, LU, MG, MN, MW, NL, NO, PL, RO, RU, SD, SE, UA, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: A STEERABLE DRILLING ASSEMBLY FOR MOUNTING ON THE END OF A DRILL STRING TO DRILL A BOREHOLE IN AN UNDERGROUND FORMATION

**(57) Abstract**

A steerable drilling assembly (1) for mounting on the end of a drill string (11) serves to drill a horizontal borehole (2) in an underground formation (3). The drilling assembly comprises a mud motor (12) and a drill bit (4) driven by said mud motor and having an axis of rotation which forms an angle with the axis of the drilling assembly, as well as a self-propelling drive assembly (8) for substantially translatorily advancing the drilling assembly in the formation and exerting on the drill bit the pressure necessary for the drilling, said drive assembly being provided with driven wheels (15) which are pressed against the wall of the borehole by the mud pressure and are pulled free from the wall when the pressure is relieved. A swivel (6) is inserted between the drive assembly (8) and the mud motor (5), said swivel consisting of successively - seen in the flow direction of the mud - arranged first and second mutually rotatable swivel parts (16, 17). The swivel moreover incorporates a brake (21) to impede the rotation of the two swivel parts with respect to each other. Furthermore, the swivel incorporates a coupling arrangement which is so adapted as to be capable of locking the two swivel parts (16, 17) together by varying the volume flow of the mud in a predetermined manner, determining whether the drilling assembly is to drill straight ahead or change direction.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FR	France	MR	Mauritania
AU	Australia	GA	Gabon	MW	Malawi
BB	Barbados	GB	United Kingdom	NL	Netherlands
BE	Belgium	GN	Guinea	NO	Norway
BF	Burkina Faso	GR	Greece	NZ	New Zealand
BG	Bulgaria	HU	Hungary	PL	Poland
BJ	Benin	IE	Ireland	PT	Portugal
BR	Brazil	IT	Italy	RO	Romania
CA	Canada	JP	Japan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo	KR	Republic of Korea	SE	Sweden
CH	Switzerland	KZ	Kazakhstan	SK	Slovak Republic
CI	Côte d'Ivoire	LI	Liechtenstein	SN	Senegal
CM	Cameroon	LK	Sri Lanka	SU	Soviet Union
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	MC	Monaco	TG	Togo
DE	Germany	MG	Madagascar	UA	Ukraine
DK	Denmark	ML	Mali	US	United States of America
ES	Spain	MN	Mongolia	VN	Viet Nam
FI	Finland				

- 1 -

A steerable drilling assembly for mounting on the end of a drill string to drill a borehole in an underground formation

5

The invention concerns a steerable drilling assembly for mounting on the end of a drill string to drill e.g. a horizontal borehole in an underground formation, said drilling assembly comprising a mud motor and a drill bit
10 driven by said mud motor and having an axis of rotation which forms an angle with the axis of the drilling assembly, as well as a self-propelling drive assembly for substantially translatorily advancing the drilling assembly in the formation and exerting on the drill bit
15 the pressure necessary for the drilling, said drive assembly being provided with wheels which are pressed against the wall of the borehole by the mud pressure and are pulled free from the wall when the pressure is relieved.

20

When drilling boreholes in an underground formation it is often necessary to change and correct the direction of drilling. This applies e.g. when shallow oil-bearing strata of the type which are found in the underground
25 below the North Sea are to be exploited. Drilling is then performed first vertically or obliquely downwardly toward the oil bearing stratum, following which drilling continues in curve until the drilling assembly has reached a horizontal position in the oil-bearing stratum, and then
30 the drilling direction is changed again so that drilling continues horizontally straight ahead in the oil-bearing stratum.

The change of direction was originally established quite
35 simply by pulling the entire drill string out of the borehole and inserting a bent section of pipe with an

- 2 -

angle of bend corresponding to the desired change of direction in the string above the drilling mud motor. When the drilling assembly had assumed the intended position and orientation, the drill string was again pulled out of borehole, and the bent section of pipe was replaced by a straight one, following which the drill string was again lowered down into the borehole and drilling continued straight ahead. Of course, the use of this older method is extremely labour-intensive and expensive and reduces the achievable production owing to the long downtimes which occur in connection with the change of direction. Another drawback of this method is that it can practically just control the inclination of the borehole.

Another more efficient method comprises permanently providing the mud motor with one or more bent pipes in a manner such that the axis of rotation of the drill bit will form a small angle of a couple of degrees with the axis of the drill string and the drilling assembly. To reduce the friction between the borehole and the drill string, the drill string normally rotates at a rate of e.g. 60 rpm in the same direction as the drill bit rotates. This causes the drill bit to describe an orbital conical movement while rotating about its own axis, and the two movements together result in the drilling of a straight borehole which has a slightly greater diameter than the drill bit. When the drilling direction is to be changed, the rotation of the drill string is stopped when the bend of the mud motor is in the desired angular position, and then drilling continues in this direction. It is hereby now possible to change the drilling direction without pulling the drill string out of the borehole.

For the drilling direction to be determined with certainty, modern drilling equipment is today provided with a measuring unit, called MWD below, which is an

- 3 -

abbreviation of "Measurement While Drilling". The quantities measured by the MWD are now transmitted as pressure pulses via the drilling mud up to the surface, where the received signals serve to position the mud motor bend in the desired direction by turning the drill string. In this operation it is necessary to allow for the fact that the drill string is twisted elastically by the drilling moment. As will appear, the drill string does not rotate, and this results in a reduction of the pressure on the drill bit since the string now encounters greater friction in the formation.

It is common to the methods described above that the pressure on the drill bit is achieved solely by means of the weight of the drill string, and all the methods therefore have a limited penetration depth.

However, today there is a pronounced need for the ability to penetrate deeper into shallow oil-bearing strata than has been possible in the past by means of the conventional methods. With this end in view the applicant has developed a drilling assembly which is described in the applicant's International Patent Application WO 90/02864, "a borehole, as well as a method and an apparatus for forming it", which is incorporated herein by reference.

The drilling assembly known from this patent application comprises a self-propelling drive assembly for pulling the drill string after it into the formation and exerting the necessary pressure on the drill bit. Since the depth of penetration is no longer limited by the weight of the drill string, the drilling assembly can penetrate considerably deeper into e.g. a horizontal oil-bearing stratum than has been possible in the past. However, the drive assembly travels substantially translatorily in the borehole and thereby prevents rotation of the drill

- 4 -

string. This entails that the depth of penetration is limited by the relatively great friction between the drill string and the borehole, and that the assembly cannot change direction. If the assembly is provided with a mud motor bend, it will constantly drill in a curve determined by the angle of bend.

The object of the invention is to provide a drilling assembly of type mentioned in the opening paragraph which can be directionally steered by turning the drill string, and which moreover permits the drill string to rotate during drilling both straight ahead and during change of direction.

This is achieved by means of the novel and unique features of the invention according to which a swivel is inserted between the drive assembly and the mud motor, said swivel consisting of successively - seen in the flow direction of the mud - arranged first and second mutually rotatable swivel parts, then being incorporated in the swivel a brake to impede the rotation of the two swivel parts with respect to each other, and a coupling arrangement adapted such as to be capable of locking the two swivel parts together by varying the volume flow of the mud in a predetermined manner. The brake causes the drill bit to describe a conical orbital movement in the same manner as takes place in conventional drilling assemblies when the drill string rotates, but the orbital movement takes place in an opposite direction to the direction of rotation of the drill bit itself. When the drill mud flow is relieved, the two swivel parts are locked together, and the driving wheels of the drive assembly are pulled free of the wall of the borehole. The drill bit can now be adjusted in the desired angular position by turning the drill string, and then drilling continues in this direction as long as the swivel is kept locked.

- 5 -

In an advantageous embodiment the coupling arrangement may comprise a coupling, e.g. a claw coupling, which has a flow opening for the passage of the mud stream and consists of a first coupling part which is fixed against rotation, but is axially slidable and is spring loaded against the direction of the mud flow in the first swivel part, and a second coupling which is firmly mounted in the second swivel part. The coupling arrangement may moreover comprise a guide ring arranged freely rotatably between the first coupling part and the first swivel part, said guide ring being axially retained by the first swivel part and being provided with a plurality of guideways equidistantly spaced along the periphery. Finally, in this embodiment at least one outwardly extending guide pin engaging the guideways may be provided in the first coupling part, said guideways being so adapted that the guide ring, when the volume flow of the mud is varied in a predetermined manner, can be turned to positions in which the guideways in cooperation with guide pin allow and does not allow, respectively, the first coupling part to engage the second one. The coupling can be connected and disconnected in this manner merely by varying the volume flow of the drilling mud. The coupling arrangement can thus be operated safely and effectively from the surface by means of simple regulation of the mud pump, which is usually a piston pump.

It is extremely important that the complete coupling arrangement always works in a reliable and safe manner. Once the drilling assembly has penetrated often many kilometers into an underground formation, it will involve considerable costs if it becomes necessary to pull the drill string and the drilling assembly up to repair the coupling arrangement. A particularly exposed part of this is the guide ring, which must necessarily also have a relatively complicated structure. To impart the required

- 6 -

operational reliability to the guide ring, it may be so adapted that it comprises upper and lower ring parts, seen in a vertical position of the drilling assembly with the drill bit lowermost - which are firmly interconnected, and

5 that the upper ring part is provided with a plurality of downwardly facing, equidistantly spaced teeth, and the lower ring part with a corresponding number of upwardly directed teeth, each guide way comprising an upper inclined face on one of the upper teeth to turn the guide

10 ring upon engagement with the guide pin when the first coupling part is displaced oppositely to the direction of coupling, an oppositely directed lower inclined face on the opposed lower tooth to turn the guide ring in the same direction as the upper inclined face upon engagement with

15 the guide pin when the first coupling part is displaced in the engagement direction, a substantially horizontal stop face extending from the lower boundary of the lower inclined face to prevent, upon engagement with the guide pin, the first coupling part from engaging the second one,

20 and a slot extending vertically downwardly from the stop face side directed oppositely to the lower inclined face, said slot having a width at least corresponding to the diameter of the pin and such a vertical extent as to allow the first coupling part to engage the second one when the

25 guide pin slides in the slot. The mud flow can be stopped and initiated again to the full extent by means of this embodiment, without the coupling engaging and locking the swivel. This takes place e.g. each time the drill string is increased by a new drill pipe. However, in this

30 connection it may also be desirable to change the direction of drilling. In that case, the mud flow is first increased to full volume, and then the volume flow is partly relieved so that one of the vertical slots is turned inwardly below the guide pin. When the mud flow is

35 then again increased to full volume, the guide pin will be pushed down in the slot, and the coupling engages and

- 7 -

locks the swivel. In another embodiment of the guide ring only every other stop face is interrupted by a vertically extending slot. In this case the coupling always engages every other time the mud flow is stopped and is initiated again.

For the first coupling part to be pushed into engagement with the second one effectively and safely, the flow opening of the first coupling part may comprise a constriction which is formed by a flow body arranged coaxially in the first swivel part and having a front thinner part and a rear thicker part - seen in the flow direction of the mud - and by a constriction ring arranged in the flow opening, said constriction ring having a smaller diameter than the rest of the flow opening and being so positioned axially in it that the constriction ring is present around the thinner part of the flow body at a predetermined distance from its thicker part when the coupling is disengaged and close to or around the thicker part of the flow body when the coupling is engaged. In the latter case a particularly great pressure drop occurs in the narrow gap between the constriction ring and the thicker part of the flow body, and this pressure drop keeps the coupling safely engaged and can be read at the surface as an indication of the engagement having taken place.

Like more recent conventional drilling assemblies the drilling assembly of the invention may be provided with a measuring unit (MWD) with instruments for measuring e.g. the inclination and azimuth of the drilling assembly as well as the direction of the gravitation field with respect to the drilling assembly and the magnetic field in the drilling zone. This measuring unit is then inserted between the drive assembly and the swivel and is in reality the part of the drilling assembly which is

- 8 -

- oriented by turning of the drill string from the surface in connection with the change of direction. For the swivel then to be locked distinctly and thereby the final drilling direction to be determined, the coupling is so adapted that its two parts can only engage each other in a specific angular position. This may take place e.g. in that the coupling is a claw coupling with just one claw on each coupling part.
- 10 The brake to impede the mutual rotation of two swivel parts may be of any expedient type, e.g. a friction brake, the braking effect being achieved by means of pure surface friction. However, greater reliability and adjustability are achieved when using a hydraulic pump and a hydraulic circuit having one or more throttle valves. Owing to the limited space available in the drilling assembly it will in particular be advantageous to use the pump assembly described in the applicant's DK Patent Application 2926/90 "A motor or pump assembly", which is incorporated herein by reference.

By inserting between the drill string and the drive assembly a second swivel consisting of a first swivel part and a second swivel part the drill string can be rotated during straight drilling as well as curve drilling, thereby reducing the friction between the drill string and the wall of the borehole considerably and diminishing the risk of the drill string getting jammed.

- 30 In an advantageous embodiment the second swivel may have incorporated in it a coupling, e.g. a claw coupling, which has a flow opening for the passage for the mud flow and consists of a first coupling part firmly arranged in the first swivel part, and a second coupling part which, spring loaded against the direction of the mud flow, is arranged axially slidably and fixed against rotation in

- 9 -

- the second swivel part. This entails that the two parts of the swivel can always rotate freely with respect to each other when the mud flow is running, and that the swivel is locked so that the drill string can turn the drilling assembly when the mud flow is interrupted. To ensure this function effectively, the flow opening of the second coupling part may accommodate a constriction ring having a smaller inside diameter than the rest of the flow opening.
- 10 The invention will be explained more fully by the following description of the embodiments, which just serve as examples with reference to the drawing, in which
- fig. 1a-c shows a preferred embodiment of a drilling assembly according to the invention in three typical situations during drilling of a horizontal borehole,
- 15 fig. 2 is an enlarged view, wherein part of the outermost jacket is removed, of a mud motor pipe bend with a drill bit associated with the drilling assembly shown in fig. 1a-c,
- 20 fig. 3 shows a fragment of an axial section through a lower swivel, seen in the vertical position of the drilling assembly, for the drilling assembly of the invention in a free position,
- 25 fig. 4 shows the same, but in a locked position,
- 30 fig. 5 is an enlarged axial section through a fragment of the uppermost portion of the lower swivel shown in figs. 3 and 4, seen in the horizontal position of the drilling assembly,
- 35 fig. 6 is an enlarged perspective view of an axial section through a first embodiment of a guide ring for the lower

- 10 -

swivel shown in figs. 3 and 4,

fig. 7a-d show a development of the guide ring shown in
fig. 6 in four successive guide positions which do not
5 result in locking of the swivel,

fig. 8a-d shows the same, but in four other successive
guide positions which result in locking of the swivel,

10 fig. 9a-d shows a development of a second embodiment of a
guide ring for the lower swivel shown in figs. 3 and 4 in
four successive guide positions which lock the swivel
every second time,

15 fig. 10 is a diagram showing how the pump pressure at the
surface varies in dependence on the time in different
state of operation,

fig. 11 is a diagram showing how the volume flow of the
20 drilling mud varies in dependence on the time in various
states of operation,

fig. 12 is an axial section through a first embodiment of
an upper swivel seen in the vertical position of the
25 drilling assembly,

fig. 13 is an axial section through a second embodiment of
an upper swivel seen the vertical position of the drilling
assembly and having a coupling which is shown in a
30 disengaged state, and

fig. 14 shows the same, but with a engaged coupling.

Fig. 1a-c shows a preferred embodiment of a drilling
35 assembly, which is generally designated 1 and is shown in
three different typical situations during drilling of a

- 11 -

horizontal borehole 2 in an underground formation 3. The drilling assembly is composed of a plurality of elements, which, seen in succession from the right, are a drill bit 4, a mud motor pipe bend 5, a lower swivel 6, a measuring unit 7, a drive assembly 8, an upper swivel 9, and a connecting pipe 10 which is connected the drill string 11; when the parts are designated here and below on the basis of their spatial orientation, this is to be taken to mean that this applies when the drilling assembly is present in a vertical position with the drill bit lowermost.

Fig. 2 is a schematic, enlarged view of the mud motor pipe bend 5 with the drill bit 4. As shown, a mud motor 12 is arranged in the bend 5, driving via a cardan shaft 13 the drill bit 4 whose axis forms an angle α with the axis of the mud motor or the drilling assembly. Exteriorly, the bend 5 is provided with two stabilizer rings 14 to support the bend against the wall of the borehole. The mud motor pipe bend 5 with a drill bit 4 shown in fig. 2 is of a conventional type and may be of any expedient structure, but there must always be a small angle α of e.g. a couple of degrees between the axes of the bend 5 and the drill bit 4. In conventional drilling assemblies the rotation of the drill string during drilling will hereby cause the axis of the drill bit to orbit along a conical surface while the drill bit rotates about its own axis. The drill bit will hereby drill a rectilinear borehole with a diameter which is slightly greater than the diameter of the drill bit. When the drilling direction is to be changed using a conventional drilling assembly, the rotation of the drill string is stopped in the desired angular position, following which drilling continues along a curve until the drill string is rotated again.

In the above-mentioned case the pressure on the drill bit is provided by the weight of the drill string. This

- 12 -

restricts the depth of penetration in particular in horizontal drillings where the weight of the drill string acts transversely and merely contributes to increasing the friction against the wall of the borehole. To remedy this drawback, the drilling assembly shown in fig. 1a-c comprises the drive assembly 8, which may e.g. be of the type described in the applicant's International Patent Application WO 90/02864. This drive assembly is provided with driven wheels 15 which are directly or indirectly pressed against the wall of the borehole by the drilling mud pressure and are retracted when this pressure is relieved. The drilling assembly receives from this assembly a direct traction force to pull the drill string 11 after it into the borehole and to exert the necessary pressure on the drill bit 4. The previous radius of action for drilling of horizontal boreholes can hereby be extended considerably, thereby making it technically and economically possible to intensively exploit even shallow oil-bearing strata of the type which are found in the underground below the North Sea.

The wheels 15 of the drive assembly 8 are positioned such that they travel substantially translatorily on the wall of the borehole 2. The drive device 8 itself therefore prevents the drill string rotation from being transmitted to the drill bit and thus from serving to steer the drilling assembly. However, this steering now takes place by means of the lower swivel 6, which contains a brake to impede the mutual rotation of the swivel parts, and a coupling arrangement for locking the two swivel parts together. This device will be described more fully below. The upper swivel 9, whose structure will likewise be described more fully below, simultaneously allows the drill string to rotate as usual during drilling to reduce the friction between the drill string and the wall of the borehole.

- 13 -

Figs. 3 and 4 are enlarged, fragmentary axial sections through the lower swivel 6. The swivel substantially consists of a first swivel part 16 and a second swivel part 17. The first swivel part 16 upwardly has a conical sleeve for screwing the spindle onto a complementary nipple 19 (not shown) on the measuring unit 7. Correspondingly, the second swivel part 17 downwardly has a conical nipple 19 (not shown) for screwing the spindle onto a complementary sleeve (not shown) on the pipe bend 5. The two swivel parts are rotatably journaled in each other by means of roller bearings 19 and 20. A brake is interposed between the two swivel parts, said brake consisting in the shown case of a plurality of the pump devices which are described the applicant's previously mentioned DK Patent Application 2926/90. With respect to their efficiency these pump devices have very small mounting dimensions and therefore lend themselves extremely well for incorporation in the narrow gap between the two swivel parts. The structure of the pump devices will not be described more fully here, reference being made to the applicant's above-mentioned Danish patent application. When the two swivel parts rotate with respect to each other, the pump devices 21 generate an oil pressure in a hydraulic circuit, which is just shown by way of suggestion in the figure. The hydraulic circuit moreover includes at least one throttle valve (not shown) which can be adapted or adjusted so that the desired braking effect is achieved. When the drill bit rotates about its own axis at e.g. 100-200 rpm, the axis of the drill bit will describe an orbital conical movement in the opposite direction to the rotation of the drill bit about its own axis when the throttle valve is suitably adjusted. This orbital movement can e.g. take place at about 25 rpm. As will be seen, by means of this device the drilling assembly of the invention can drill a straight borehole in a formation in the same manner as conventional drilling

- 14 -

assemblies, in which it is the rotation of the drill string which is transmitted directly to the orbital movement of the drill bit. The only difference is that the drill bit and the orbital movement in conventional assemblies normally have the same direction of rotation, while the opposite is always the case in the drilling assembly of the invention.

The lower swivel 6 moreover comprises a coupling arrangement for locking the swivel when the drilling direction is to be changed. This arrangement substantially consists of a first coupling part 22 which, with a multi-spline 24, is arranged fixed against rotation, but axially slidable in the first swivel part 16, and a second coupling part 23 which is firmly mounted in the second swivel part 17. In the shown case the two coupling parts 22, 23 form a claw coupling with just one claw on each of the two coupling parts, which when connected will always lock the two swivel parts in one and the same mutual angular position. The coupling parts 22, 23 are provided with a flow opening 25 for the passage of the mud flow. As will be seen best from fig. 5, a constriction ring 26 is arranged upwardly in this flow opening 25 around an elongate flow body 27, which is firmly connected to the first swivel part 16 by means of a transom or a cross member 30.

When the mud pump at the surface works, a flow of mud is conveyed through the entire drill string and the drilling assembly out to the drill bit. Because of the constriction formed by the constriction ring 26 and the flow body 28, a pressure difference occurs at this point, said pressure difference trying to displace the first coupling part 22 in the same direction as the flow of the mud, i.e. in the direction of engagement. In the opposite direction the first coupling part 22 is affected by a plurality of compression springs 31. The pressure difference in the mud

- 15 -

- flow above the constriction in the flow opening and the oppositely directed pressure force from the compression springs 31 enable the operator to displace the first coupling part to and fro in the first swivel part merely by varying the volume of the mud flow. This can take place in a simple manner by varying the number of revolutions of the mud pump, or, if several pumps are provided, by operating a larger or smaller number of these.
- 10 A guide ring 32, which is rotatably arranged between the first coupling part 22 and the first swivel part 16 and axially retained by said swivel part, serves to choose whether axial displacement of the first coupling part is to cause engagement with the second coupling part or not.
- 15 With this end in view the first coupling part has at least one guide pin 33 extending radially into a plurality of guideways, which are equidistantly spaced along the periphery of the guide ring.
- 20 The structure of the guide ring appears more fully from fig. 6, which is an enlarged perspective view of an axial section through the guide ring, which consists of an upper and a lower ring part 34, 35 firmly interconnected by means of an outer spacer ring 36 and a plurality of pins or screws 37. The upper ring part 34 is provided with a plurality of upper, equidistantly spaced teeth 38, and the lower ring part 35 is provided with a corresponding number of lower teeth 39. Each of the upper teeth 38 is formed with an upper inclined face 40, and each of the lower teeth 39 is formed with an oppositely directed lower inclined face 41, as well as a horizontal stop face 42. Further, a vertical slot 43 is provided between adjacent lower teeth 39. Each of these slots has a width which is at least just as great as the diameter of the guide pin 33. In fig. 6 the guide pin 33 is shown in solid line in its position in the bottom of one of the slots 43 and in

- 16 -

dotted line positioned on one of the stop faces 42.

Fig. 7a-d shows schematically how the guide ring shown in fig. 6 cooperates with the guide pin, which always follows the axial displacements of the coupling part and therefore represents the relative position of the first coupling part in fig. 7a-d. In fig. 7a the mud flow is interrupted. This takes place e.g. each time a new drill pipe is to be inserted in the drill string. The first coupling part and thereby the guide pin are pushed up into the uppermost position in which the guide pin is now present in the gap between two of the teeth 38 in the upper part 34 of the guide ring. When the mud flow is initiated again with full volume, the first coupling part and thereby the guide pin are pushed downwardly by the pressure difference above the constriction in the flow opening of the first coupling part, the guide pin sliding along the lower inclined face 41 and thereby turning the guide ring to the left in the direction of the arrow until the guide pin is stopped by the stop face 42. In this position the two coupling parts 22, 23 are not capable of engaging with each other, as shown in fig. 3. The two swivel parts 16, 17 can therefore rotate freely with respect to each other, and drilling will therefore continue straight ahead in the manner previously described, in which the drill bit describes a conical orbital movement in the opposite direction to the rotation of the drill bit about its own axis. When the mud flow is stopped again, the first coupling part is again pushed upwardly by the compression springs 31 and thereby, when engaging one of the upper inclined faces 40, turns the guide ring an additional step to the left in the direction of the arrow until the guide pin is again present in one of the gaps between two of the upper teeth. This situation is shown in fig. 7c, which quite corresponds to fig. 7a except that the guide ring has now been turned a whole tooth forward in the direction of the

- 17 -

arrow. When the mud flow is initiated again, the process described above will therefore be repeated, the guide pin being again stopped by one of the stop faces such that the coupling is not connected, and the swivel is not locked.

5 The mud pump can be stopped and initiated again in this manner as often as desired, e.g. in connection with the extension of the drill string without at any time implementing a procedure which aims at changing the drilling direction.

10

Such a change of direction can take place only when the two coupling parts are engaged with each other, and the swivel is therefore locked, as shown fig. 4. In this case the guide ring functions in the manner shown in fig. 8a-d.

15 In fig. 8a the mud flow is stopped and the guide pin is present, like in fig. 7a, in a gap between two of the teeth in the upper part of the guide ring. When the mud flow is then initiated again to the full extent, the guide pin, when engaged with the lower inclined face, will
20 therefore turn the guide ring to the same position as shown in fig. 7b, in which the guide pin rests against a stop face 42. In this position the coupling is not engaged, and the two swivel parts can rotate with respect to each other. For the coupling to be engaged now, the
25 volume flow of the mud is reduced so that the pressure difference above the constriction in the flow opening of the coupling part is correspondingly reduced so much as to enable the compression springs 31 to push the first coupling part and thereby the guide pin partly back
30 against the pressure of the mud flow, viz. to the position shown in fig. 8c in which the guide pin has turned the guide ring precisely so much that a vertically extending slot 43 is present opposite the guide pin. As shown in
fig. 8d, the guide pin will therefore slide downwardly in
35 this slot without meeting any obstacle when the mud flow is again initiated to the full extent. Therefore, as shown

- 18 -

in fig. 4, the two coupling parts are fully engaged and thereby lock the swivel. In case of further drilling, the drilling will then change direction, as described before with reference to fig. 1b and fig. 1c.

5

Fig. 9a-d schematically shows how a second embodiment of a guide ring according to the invention operates. This guide ring is constructed in the same manner as the guide ring described above, but every second one of the vertical slots 43 is omitted. When this guide ring type is used in the drilling assembly, there are only two states for the mud flow, viz. either full stop or full volume flow. Each time the mud flow is stopped, the first coupling part will therefore always be pushed right back to its upper position. This position is shown fig. 9a. When the mud flow is initiated again, the guide pin will therefore rest against the under lying stop face, as shown in fig. 9b. The coupling is not engaged, and the two swivel parts can rotate with respect to each other. When the mud flow is stopped again, the guide ring is turned forwardly to the position shown in fig. 9c, in which a vertical slot is now present below the guide ring, which will therefore slide down in this slot, as shown in fig. 9d, when the mud flow is again initiated to the full extent. The coupling is now engaged and the swivel locked, following which drilling continues in a new direction. As appears, engagement consistently takes place in this manner every second time the mud flow is stopped and initiated again.

30 It is important that the operator can satisfy himself from the surface that the coupling engagement has taken place, and that the drilling assembly now changes direction as intended. This is possible merely by reading the size of the mud pressure, as will be explained more fully below with reference to figs. 10 and 11, which show diagrams of
35 the pressure and volume flow, respectively, of the

- 19 -

drilling mud. The curves show when the mud pump operates, and the space between the curves when the pump is stopped. The first of these curves in each diagram illustrates the sequence of the steering shown in fig. 8a-d. The engagement illustrated in fig. 8 takes place at the pressure p_x in fig. 10 and the volume flow v_x in fig. 11. As shown in fig. 4, the constriction ring 26 has now been pushed to the thicker part 29 of the flow body 28, thereby providing a noticeable increase in the flow resistance. Since the mud pump is a piston pump and the volume flow is therefore constant, the increased flow resistance will cause a considerable increase Δp in the mud pressure. When this pressure increase takes place in connection with the steering process shown in fig. 8a-d, this is a sure sign to the operator that the coupling is now engaged.

As previously mentioned, a measuring unit 7 of a conventional type is inserted between the lower swivel 6 and the drive assembly 8. This measuring unit serves to measure the inclination and azimuth of the drilling assembly as well as the direction of the gravitation field with respect to the drilling assembly and the magnetic field in the drilling zone. The measurements are transmitted in the form of pressure pulses up through the oil flow to the surface, where they are converted in a computer into electrical signals indicating the instantaneous position and place of the measuring unit with great accuracy. If it is decided now that the drilling assembly is to change direction, the measuring unit is turned by means of the drill string in one of the ways described more fully below. The first swivel part 16 is firmly connected with the measuring unit 7, and since the coupling can only be engaged and the swivel be locked in one specific mutual angular position, the angular position of the mud motor pipe bend 5 and the drill bit 4 will therefore always be determined distinctly by the angular position of the

- 20 -

measuring unit when changing direction.

If the drill string is firmly connected with the drive assembly 8, the measuring unit can be turned directly to the desired angular position by means of the drill string when the mud flow is stopped and the wheels of the drive assembly are hereby pulled clear of the wall of the borehole. However, this method is not particularly expedient, because the drill string cannot rotate in normal operation. This is unfortunate in particular in horizontal boreholes where debris from the drilling site tends to settle below the drill string, thereby increasing the friction between the drill string and the wall of the borehole, and involving a risk of the drill string getting jammed.

For the drill string to be able to rotate also when a translatorily travelling drive assembly is used for propelling the drilling assembly, a swivel 9 of the type shown in fig. 12 may be inserted between the drive assembly and the drill string. This swivel consists of a first swivel part 44 which is firmly connected with the drill string, and a second swivel part 45 which is firmly connected with the drive assembly 8. The two swivel parts are freely rotatably interconnected by means of roller bearings 46 and 47. Thus, the swivel cannot be locked, and the angular position of the measuring unit cannot therefore be changed by means of the drill string. However, the operator can check the angular position of the measuring unit from the surface and lock the swivel between the measuring unit and the drill bit when he finds that the measuring unit has assumed the desired angular position. However, this method is somewhat cumbersome, and the change of direction cannot be controlled completely accurately.

- 21 -

In the preferred embodiment of the drilling assembly of the invention shown in fig. 1a-c the swivel 9, a fragment of which is shown on an enlarged scale in an axial section in figs. 13 and 14, contains a claw coupling which serves to lock the swivel when the mud flow is stopped. This swivel consists of a first swivel part 48 and a second swivel part 49, which are freely rotatably interconnected via roller bearings 50. The coupling consists of a first coupling part 51 which is firmly arranged in the first swivel part 48, and a second coupling part 52 which is arranged fixed against rotation, but axially slidably in the second swivel part 49 by means of a multi-spline 53. The coupling includes a flow opening 54 for the passage of the mud flow, and a constriction ring 55 is provided in the flow opening 54 of the second coupling part 52. Further, a plurality of compression springs 56 is provided between the second swivel part 49 and the second coupling part 52, said compression springs serving to push the second coupling part 52 into engagement with the first coupling part 51 when the mud flow is stopped. In normal operation where the mud flows through the flow opening 54, a pressure difference will occur at the constriction ring 55, and this pressure difference overcomes the spring force from the compression springs 56 and thereby keeps the coupling open, so that the first swivel part 48 and thereby the drill string can rotate freely with respect to the second swivel part 49, which is firmly connected with the drive assembly.

When in this case the drilling direction is to be changed, the mud flow is stopped, the second coupling part 52 being thereby pressed into engagement with the first coupling part 51 by the spring force of the compression springs 56. The swivel 9 is now locked and forms a firm connection between the drill string 11 and the drive assembly, whose wheels have simultaneously been pulled clear of the wall

- 22 -

of the borehole. The measuring unit 6 can now be turned to the desired angular position with great accuracy, which indicates the direction in which drilling is now to be continued. When the mud flow is initiated again the wheels
5 of the drive assembly are pressed against the wall of the borehole. At the same time the drill bit begins to rotate about its own axis and to orbit about the axis of the drilling assembly, until the coupling in the swivel 6 locks the swivel distinctly and thereby the drill bit with
10 respect to the drive assembly in the correct angular position of drill bit. The drilling assembly then continues drilling along the intended curve. In contrast to the conventional drilling assembly which does not allow the drill string to rotate under a change of direction
15 with the consequent drawbacks by way of increased friction and risk of the drill string getting jammed in the borehole, the drill string can now advantageously also rotate during a change of direction using the drilling assembly of the invention, because the coupling 51, 52 of
20 the swivel 9 opens immediately when the mud flow is initiated, so that the two parts of the swivel can rotate freely with respect to each other.

25

30

35

- 23 -

P a t e n t C l a i m s :

1. A steerable drilling assembly (1) for mounting on the
5 end of a drill string (11) to drill e.g. a horizontal
borehole (2) in an underground formation (3), said
drilling assembly comprising a mud motor (12) and a drill
bit (4) driven by the mud motor and having an axis of
rotation which forms an angle with the axis of the
10 drilling assembly, as well as a self-propelling drive
assembly (8) for substantially translatorily advancing the
drilling assembly (1) in the formation (3) and exerting on
the drill bit (4) the pressure necessary for the drilling,
said drive assembly (8) being provided with wheels (15)
15 which are pressed against the wall of the borehole by the
mud pressure and are pulled free from the wall when the
pressure is relieved, c h a r a c t e r i z e d in that a
swivel (6) is inserted between the drive assembly (8) and
the mud motor (12), said swivel consisting of successively
20 - seen in the flow direction of the mud - arranged first
and second mutually rotatable swivel parts (16, 17),
there being incorporated in the swivel (6) a brake (21) to
impede the rotation of the two swivel parts (16, 17) with
respect to each other, as well as a coupling arrangement
25 so adapted as to be capable of locking the two swivel
parts by varying the volume flow of the mud in a pre-
determined manner.

2. A drilling assembly according to claim 1,
30 c h a r a c t e r i z e d in that the coupling arrange-
ment comprises a coupling (22, 23), e.g. a claw coupling,
which has a flow opening (25) for the passage of the mud
flow and consists of a first coupling part (22) which is
fixed against rotation, but axially slidable and is spring
35 loaded against the direction of the mud flow in the first
swivel part (16), and a second coupling part (23) which is

- 24 -

firmly mounted in the second swivel part (17); and that the coupling arrangement moreover comprises a guide ring (32) arranged freely rotatably between the first coupling part (22) and the first swivel part (16), said guide ring
5 being axially retained by the first swivel part (16) and being provided with a plurality of equidistantly spaced guideways along the periphery; as well as at least one outwardly extending guide pin (33) which is firmly arranged in the first coupling part (22) and engages the
10 guide ways, said guide ways being so adapted that the guide ring (32), by varying the volume flow of the mud in a predetermined manner, can be turned by the guide pin (33) to positions in which the guideways in cooperation with a guide pin (33) allow and do not allow, respective-
15 ly, the first coupling part (22) to engage the second one.

3. A drilling assembly according to claim 1 or 2, characterized in that the guide ring comprises an upper and a lower ring part (34, 35) - seen
20 in a vertical position of the drilling assembly with the drill bit (4) lowermost - which are firmly connected with each other, and that the upper ring part (34) is provided with a plurality of equidistantly spaced, downwardly directed teeth (38) and the lower ring part with a corresponding number of upwardly directed teeth (39), each
25 guideway comprising an upper inclined face (40) on one of the upper teeth (38) for turning the guide ring (32), upon engagement with the guide pin (33), when the first coupling part (22) is displaced oppositely to the engagement direction, an oppositely directed lower inclined face
30 (41) on the opposed lower tooth (39) for turning the guide ring (32), upon engagement with the guide pin (33), in the same direction as the upper inclined face (40) when the first coupling part (22) is displaced in the engagement
35 direction, a substantially horizontal stop face (42) extending from the lower boundary of the lower inclined

- 25 -

face (41) for preventing, upon engagement with the guide pin (33) the first coupling part (22) from engaging the second one (23), and a slot (43) extending vertically downwardly from the side of the stop face (42) directed oppositely to the lower inclined face (41), said slot (43) having a width at least corresponding to the diameter of the pin (33) and such a great vertical extent as to allow the first coupling part (22) to engage the second one (23) when the guide pin (33) slides in the slot (43).

10

4. A drilling assembly according to claim 3, characterized in that only every second stop face (42) is interrupted by a vertically extending slot.

15 5. A drilling assembly according to one or more of claims 1-4, characterized in that the flow opening (25) in the first coupling part (22) has a constriction.

6 A drilling assembly according to claim 5, characterized in that the constriction in the flow opening (25) of the first coupling part (22) is formed by a flow body (27) coaxially arranged in the first swivel part (16) and comprising a front thinner part (28) and a rear thicker part (29) - seen in the flow direction of the mud - as well as by a constriction ring (26) arranged in the flow opening (25), said constriction ring having a smaller diameter than the rest of the flow opening and being axially positioned in it so that the constriction ring (26) is present around the thinner part (28) of the flow body (27) at a predetermined distance from its thicker part (29) when the coupling (22, 23) is disengaged, and close to or around the thicker part (29) of the flow body when the coupling part (22, 23) is engaged.

35

- 26 -

7. A drilling assembly according to one or more of claims 1-6, characterized in that a measuring unit (7), in MWD, is inserted between the drive assembly (8) and the swivel (9), said measuring unit having instruments for measuring e.g. the inclination and azimuth of the drilling assembly (1) as well as the direction of the gravitation field with respect to the drilling assembly and the magnetic field in the drilling zone.
8. A drilling assembly according to one or more of claims 1-7, characterized in that the coupling is adapted such that its two parts (22, 23) can engage with each other in one and just one relative angular position.
9. A drilling assembly according to claim 8, characterized in that the coupling is a claw coupling with just one claw on each coupling part.
10. A drilling assembly according to one or more of claims 1-9, characterized in that the brake (21) to inhibit the mutual rotation of the two swivel parts (22, 23) consists of at least one hydraulic pump and one hydraulic circuit having at least one throttle valve.
11. A drilling assembly according to one or more of claims 1-10, characterized in that a second swivel (9) is inserted between the drill string (11) and the drive assembly (8), said swivel consisting of successively arranged first and second mutually rotatably swivel parts (48, 49) seen in the flow direction of the mud.
12. A drilling assembly according to claim 11, characterized in that the second swivel (9) incorporates a coupling, e.g. a claw coupling, which has a flow opening (54) for the passage of the mud flow and

- 27 -

consists of a first coupling part (51) firmly arranged in the first swivel part (48) and a second coupling part (52) which, spring loaded against the direction of the mud flow, is arranged axially slidably and fixed against rotation in the second swivel part (49).

13. A drilling assembly according to claim 11 or 12, characterized in that the flow opening (54) of the second coupling part accommodates a constriction ring (55) having a smaller inside diameter than the rest of the flow opening.

15

20

25

30

35

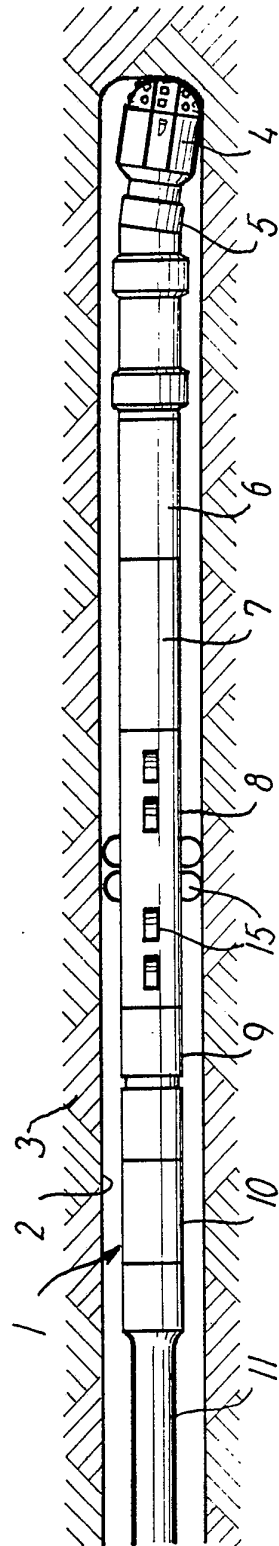


FIG. 1a

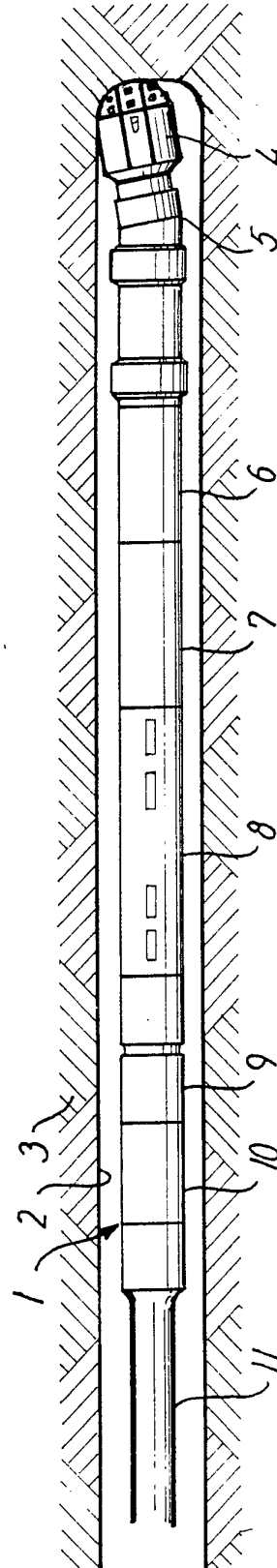


FIG. 1b

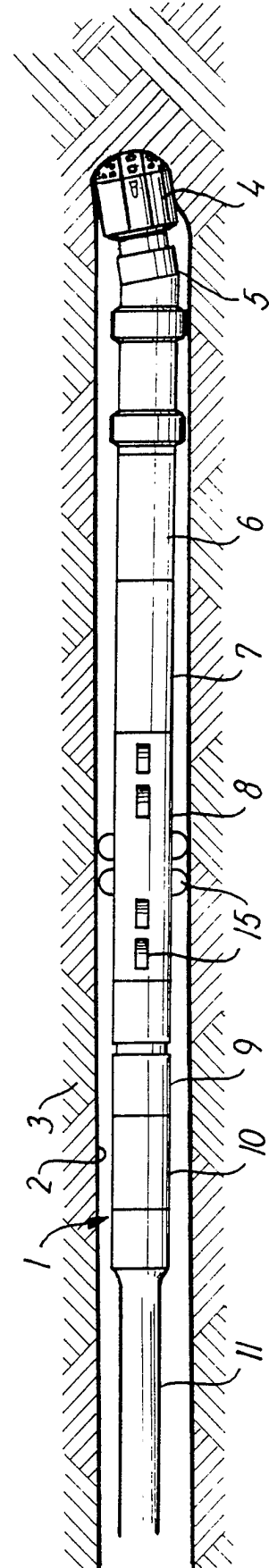


FIG. 1c

2/10

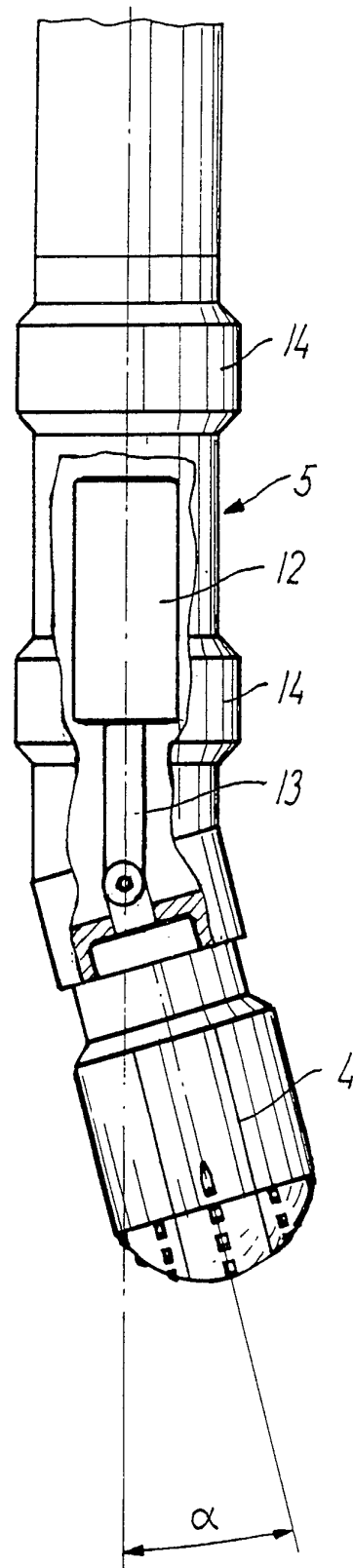


FIG. 2

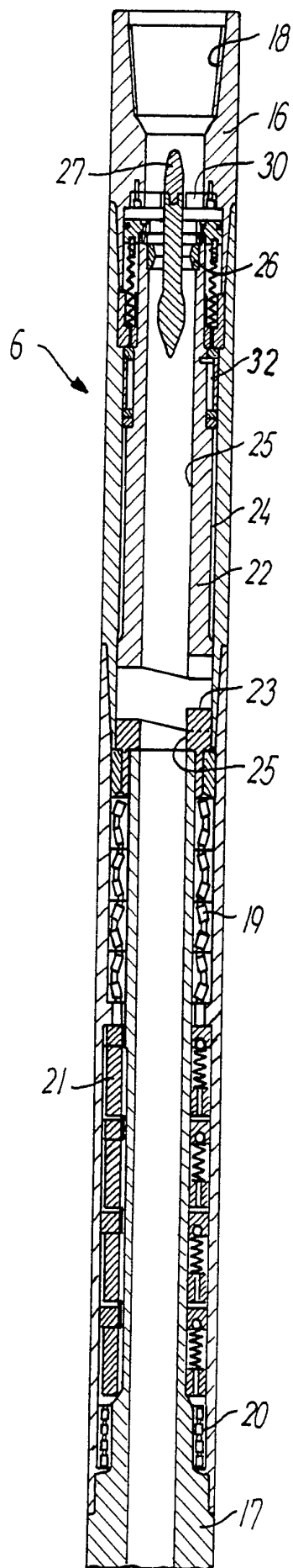


FIG. 3

3/10

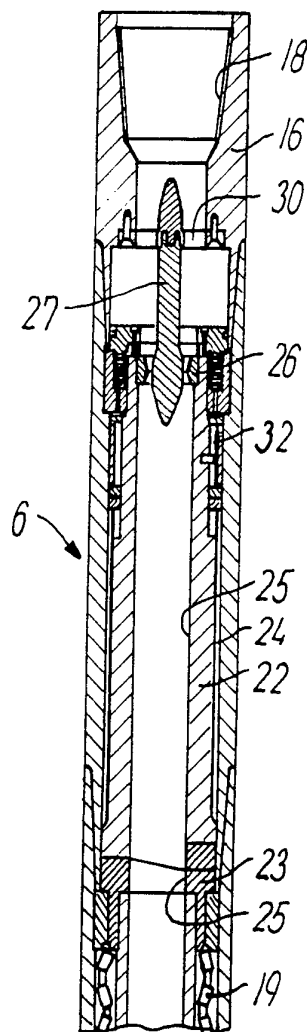


FIG. 4

4/10

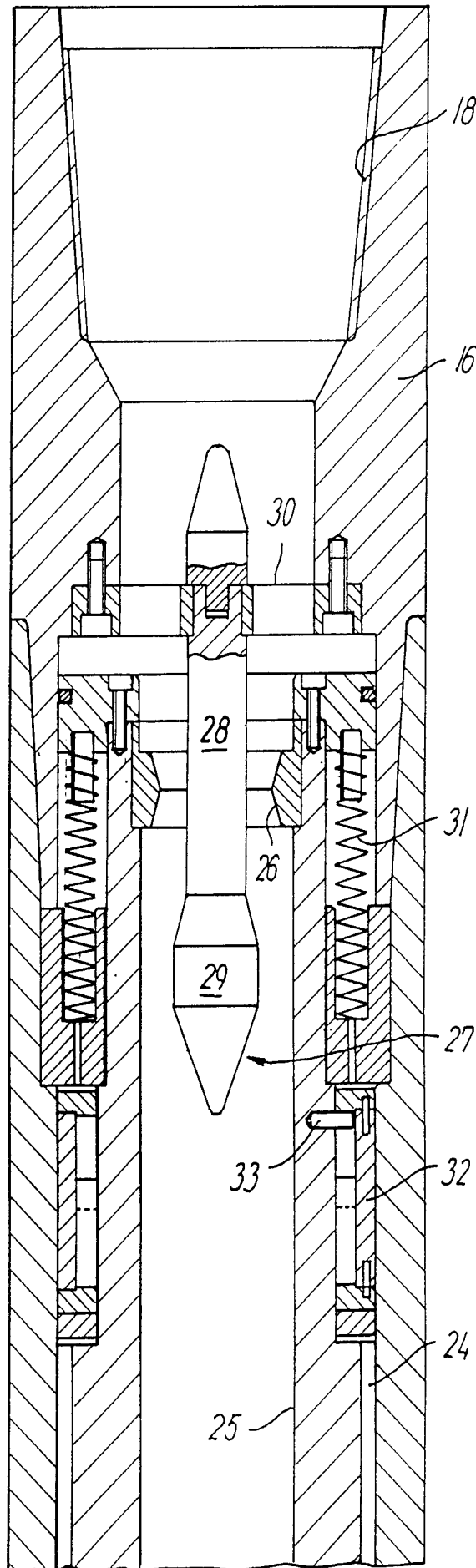


FIG.5

5/10

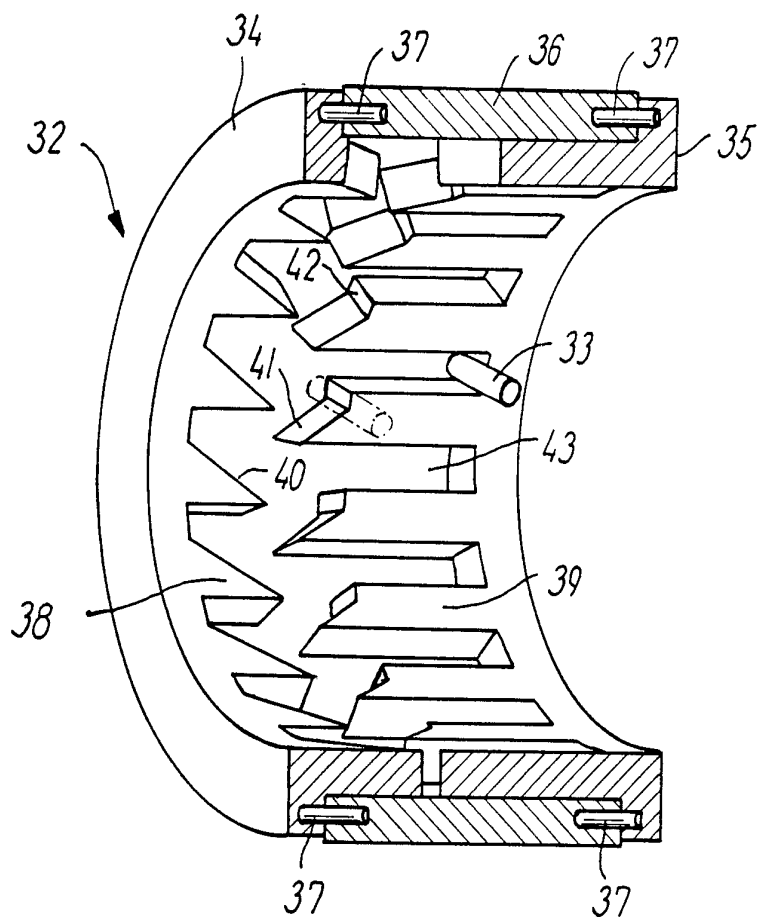


FIG. 6

6/10

FIG. 7a

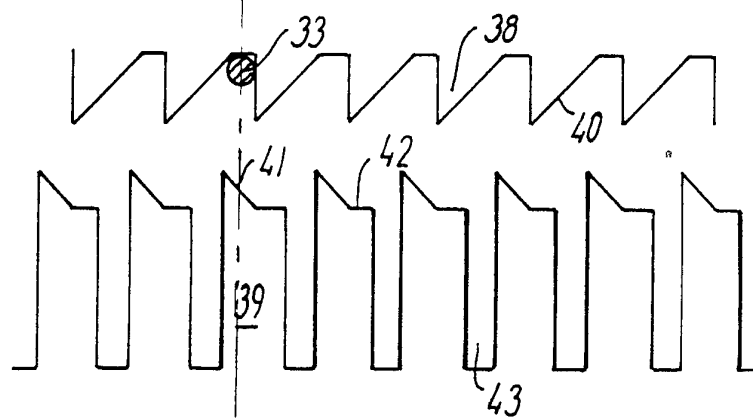


FIG. 7b

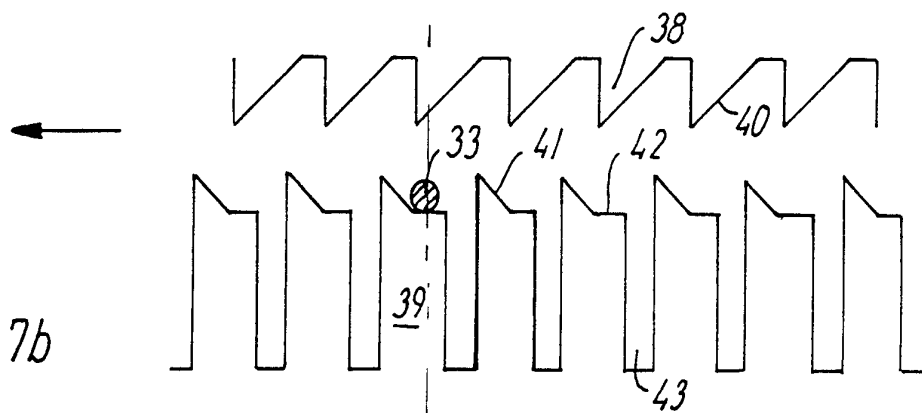


FIG. 7c

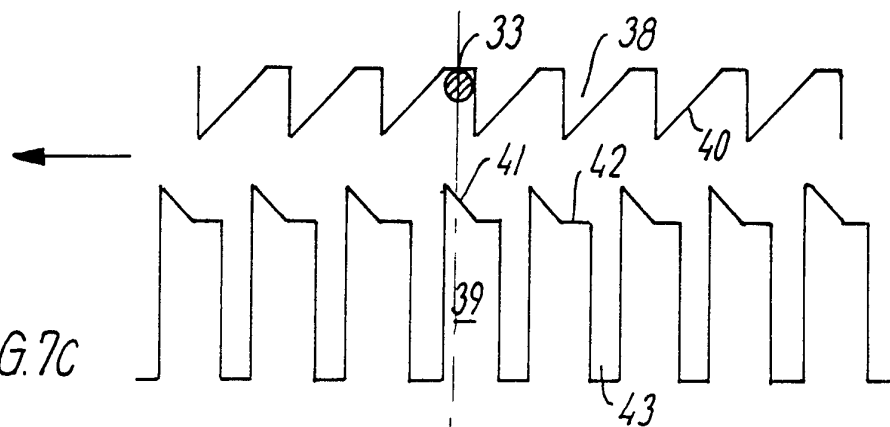
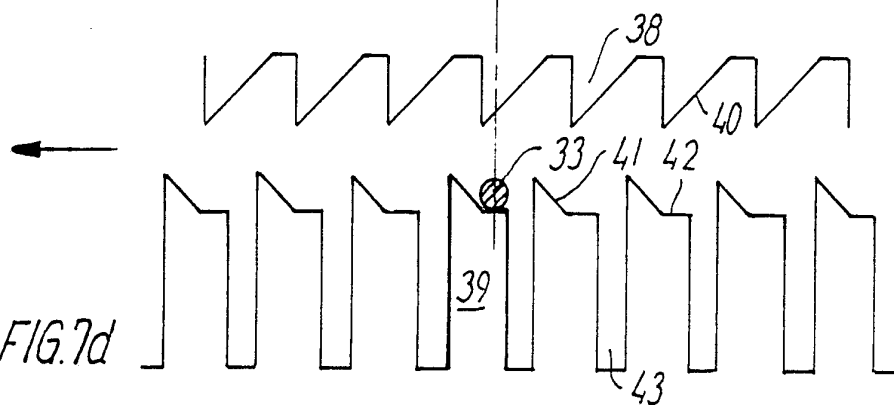


FIG. 7d



7/10

FIG. 8a

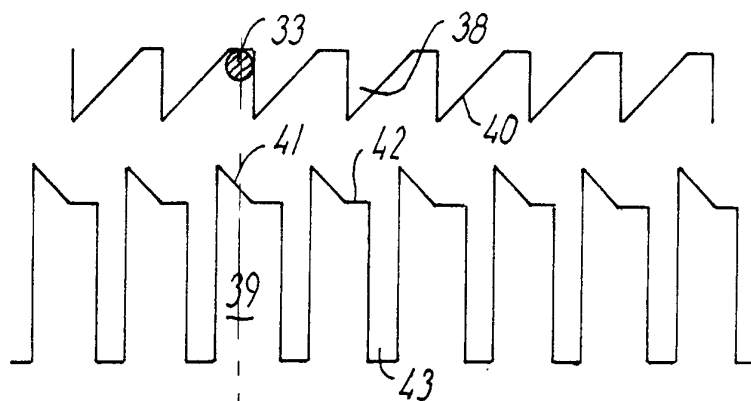


FIG. 8b

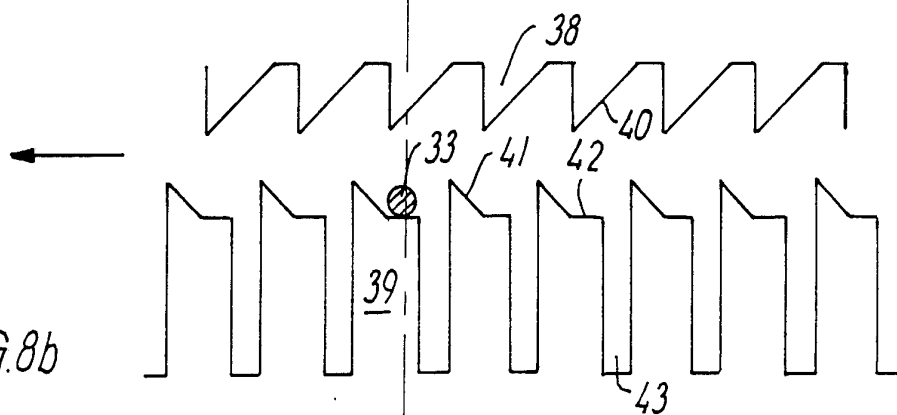


FIG. 8c

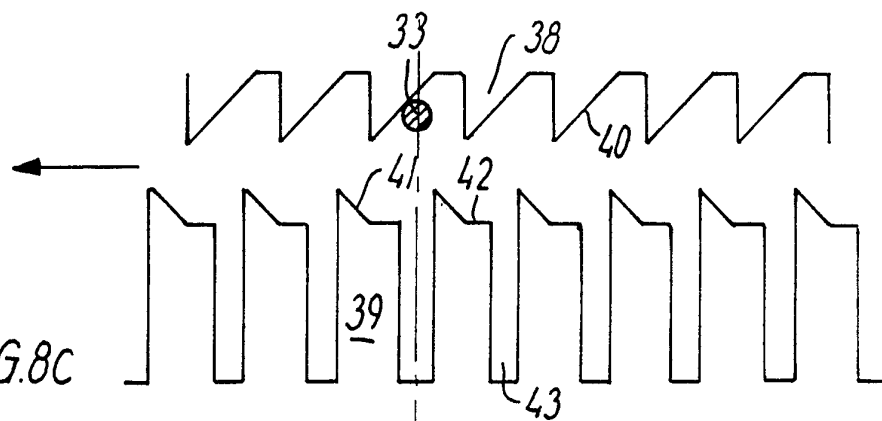
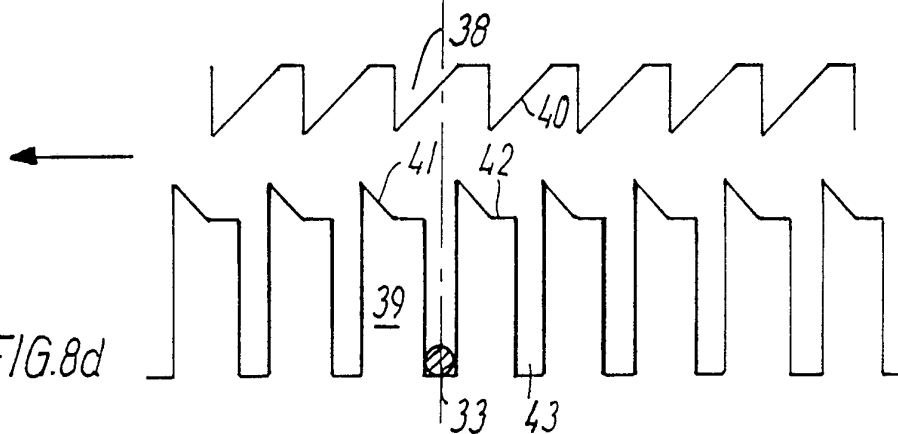


FIG. 8d



8/10

FIG. 9a

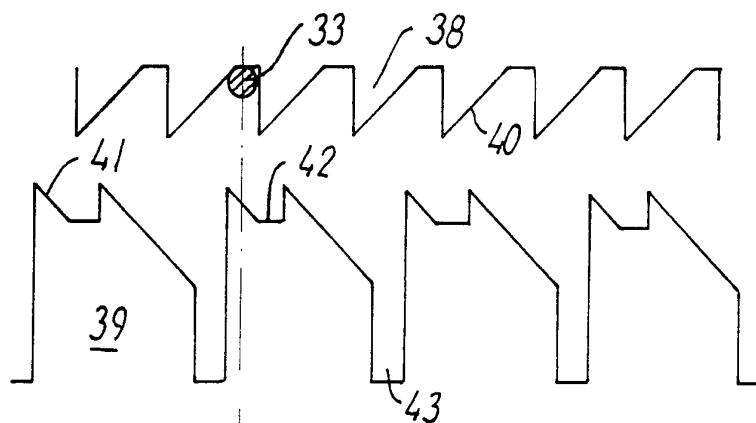


FIG. 9b

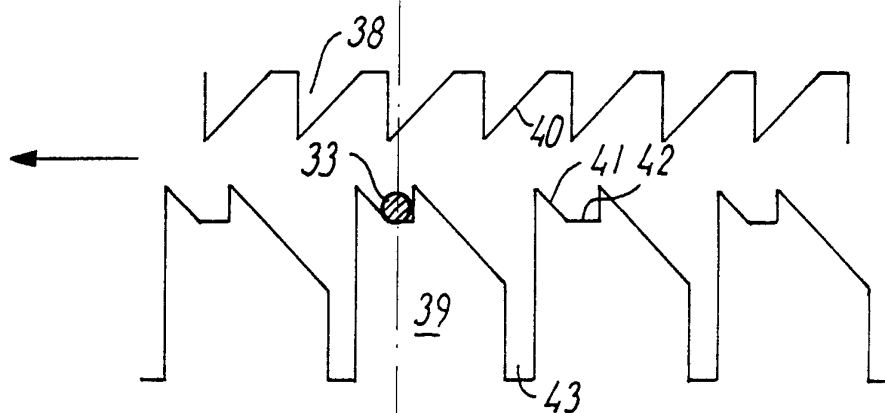


FIG. 9c

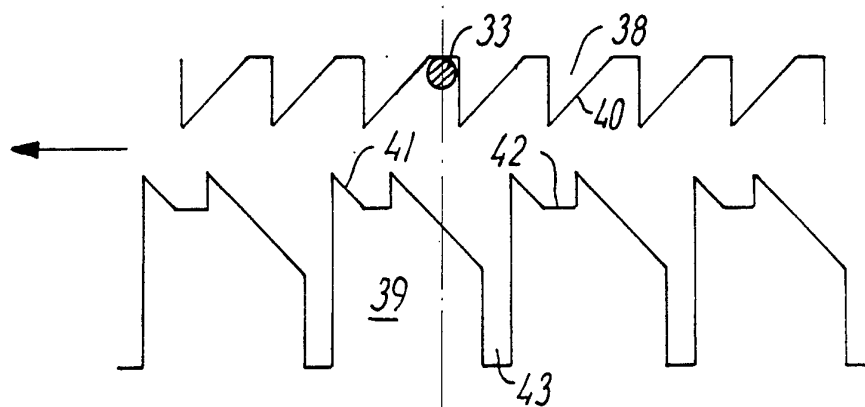
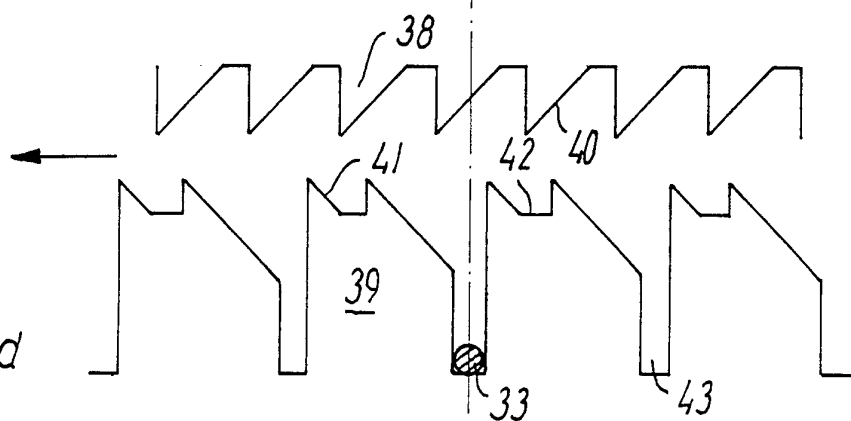


FIG. 9d



9/10

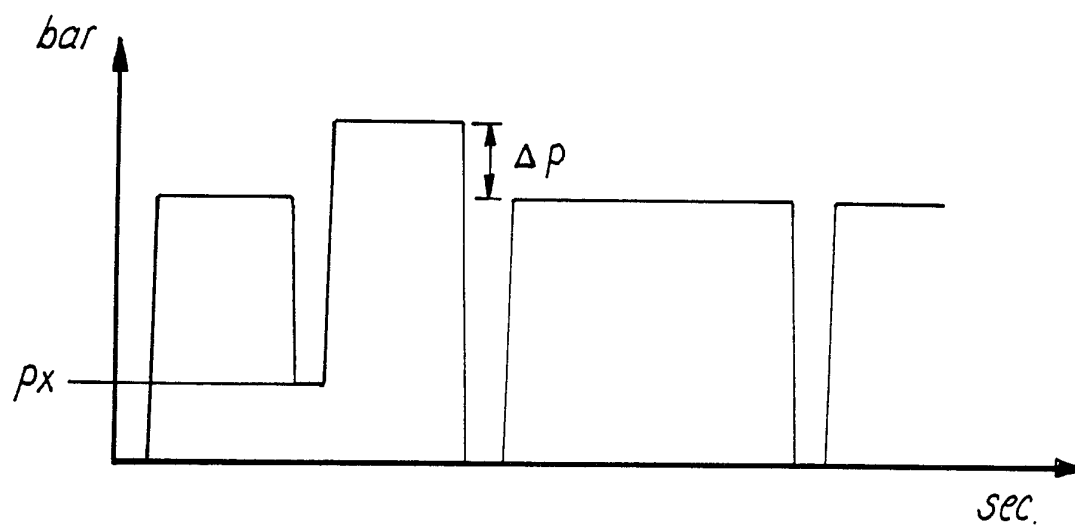


FIG. 10

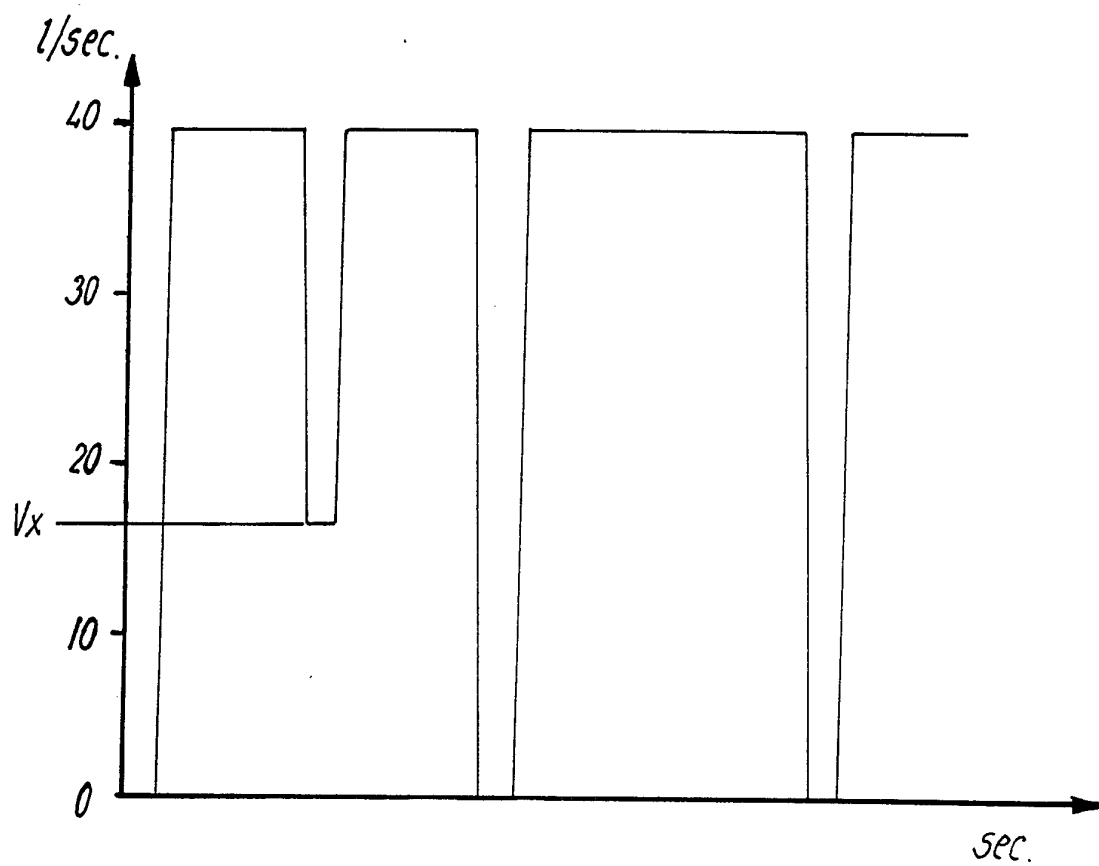


FIG. 11

10/10

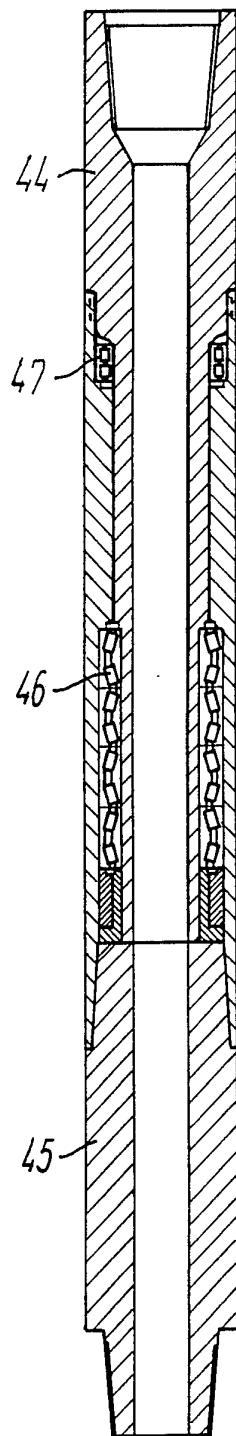


FIG. 12

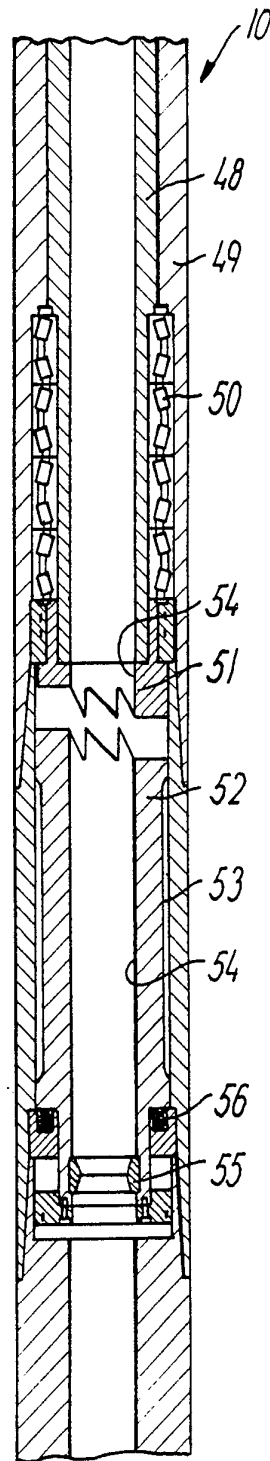


FIG. 13

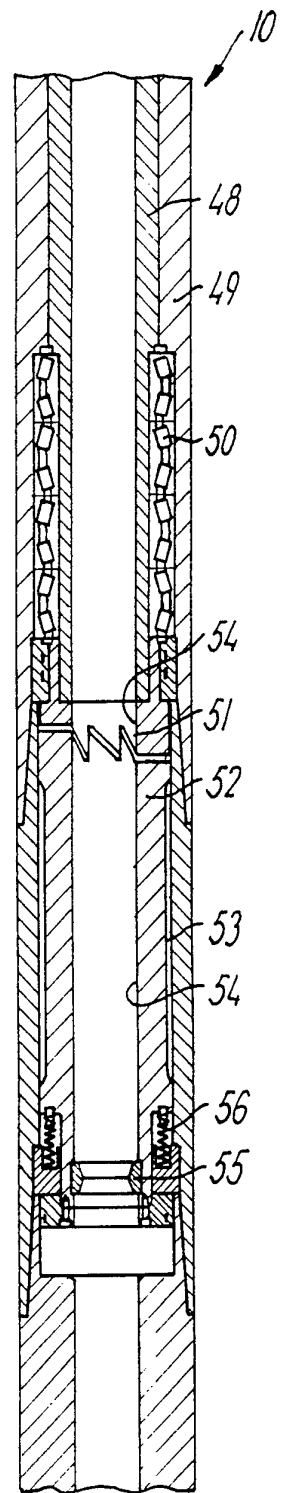


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 92/00341

A. CLASSIFICATION OF SUBJECT MATTER

IPC5: E21B 7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC5: E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DK, B, 157251 (SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.), 27 November 1989 (27.11.89), page 1 - page 2, figure 1, claim 1 --	1-13
A	EP, A1, 0195559 (FLOWMOLE CORPORATION), 24 Sept 1986 (24.09.86), page 1 - page 2, claim 1 --	1-13

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15 February 1993

Date of mailing of the international search report

19 -02- 1993

Name and mailing address of the ISA/
Swedish Patent Office
Box 5055, S-102 42 STOCKHOLM
Facsimile No. +46 8 666 02 86

Authorized officer

Christer Bäcknert

Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 92/00341

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SE, B, 441291 (INSTITUT FRANCAIS DU PETROLE), 23 Sept 1985 (23.09.85), page 6 - page 7 --- -----	1-13

INTERNATIONAL SEARCH REPORT

Information on patent family members

29/01/93

International application No.

PCT/DK 92/00341

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
DK-B-	157251	27/11/89	NONE		
EP-A1-	0195559	24/09/86	AU-B-	585947	29/06/89
			AU-A-	3500789	14/09/89
			AU-A-	5434786	11/09/86
			JP-A-	61257501	15/11/86
			US-A-	4674579	23/06/87
			US-A-	4787463	29/11/88
SE-B-	441291	23/09/85	CA-A-	1128925	03/08/82
			CH-A-	630700	30/06/82
			DE-A, C-	2930014	07/02/80
			FR-A, B-	2432079	22/02/80
			FR-A, B-	2453268	31/10/80
			FR-A, B-	2519686	18/07/83
			GB-A, B-	2026063	30/01/80
			JP-C-	1375074	22/04/87
			JP-A-	55122989	22/09/80
			JP-B-	61044195	01/10/86
			NL-A-	7905667	28/01/80
			SE-A-	7906247	26/01/80
			US-A-	4286676	01/09/81
			US-A-	4374547	22/02/83
			FR-A, B-	2453269	31/10/80