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(54) Axial balancing device for downhole drilling motors.

(57) A downhole drilling motor is described which has an outer drill casing (11), a shaft (12) for driving a drill bit connected thereto, and the shaft (12) being rotatable relative to the casing (11). A turbine (15) is disposed between the casing (11) and the shaft (12) to permit the shaft (12) to be rotated. A pressurised fluid can be admitted via an inlet (13) and is transmitted to the turbine (15) via a passage (20) to effect operation. The shaft is provided with reaction means which includes a sleeve (17) mounted on the shaft (12) and which sleeve and shaft have pressure surfaces (23, 24) which can be acted on by the pressure fluid to produce a force acting counter to the normal hydraulic thrust on the shaft (12) to produce a reduced resultant hydraulic thrust on the shaft (12). In a preferred arrangement, the reaction member and thrust bearing is located above the turbine (15) so that the unit can be replaced as a whole.

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AXIAL BALANCING DEVICE FOR DOWNHOLE DRILLING MOTORS

This invention relates to an axial balancing device for downhole drilling motors, in particular turbodrills.

As is well known in the art, a turbodrill is a downhole drilling tool for drilling of oil wells or the like and essentially consists of an outer casing within which is mounted a rotatable shaft carrying at its lower end a drill bit for drilling of the well. Drilling mud is arranged to be fed at pressure into the area between the casing and the shaft, the drilling mud passing down the drilling motor through suitable passageways to the drill bit where it serves to lubricate and clean the drill bit before being fed upwardly between the outside of the casing and the well bore to the surface where it can be cleaned and recycled.

The shaft is rotatably driven within the casing by a turbine section consisting of a plurality of annular turbine stages. Each turbine unit comprises a stator and a rotor having a plurality of blades or vanes of curved profile disposed annularly about the axis of rotation of the shaft. The stator normally is fixedly located in the bore of the casing and the rotor is fixedly attached to the rotatable shaft. On passage of drilling mud, the mud interacts with the co-operating blades of the stator and rotor of each turbine unit in order to cause rotation of the shaft relative to the casing and apply a torque to the drill bit connected thereto.

It will be appreciated by those skilled in the art that when the pressurised drilling mud is supplied to the turbine section of the turbodrill, a hydraulic downward axial thrust load is applied to the drilling motor shaft which is counteracted by the sum of the upward load on the bit and the upward thrust from the casing. In order to accommodate such axial forces it is necessary to provide axial thrust bearings and if the resultant axial forces on the thrust bearings are large, excessive wear of the axial thrust bearings is likely to occur.

Existing known designs of turbine have an optimum efficiency at comparatively high rotational speeds, typically 700-800 RPM and furthermore these turbines carry a large number of stages, typically over 250, with up to three separate turbine sections, when large bit torques are required. The comparatively high rotational speed of these turbines proved to be well matched to the characteristics required by natural diamond drill bits and these turbines have been very successfully used for deep hole and deviated drilling work, particularly in offshore oilfields. When such turbines are used with natural diamond bits, the downward hydraulic thrust on the rotor resulting from the pressure in the drill casing or pipe, is to a large extent balanced by the similarly large upward thrust on the drill bit resulting from the high bit loads required on diamond bits to achieve good penetration rates. This leaves a comparatively small axial load for the axial thrust bearing to carry.

During the last five years, polycrystalline diamond (PCD) drilling bits have been rapidly introduced into the drilling market and in many drilling situations have replaced the more expensive natural diamond bits. A feature of these PCD bits is that they require much less weight on the bit and a lower rotational speed if effective drilling with extended bit life in the well is to be achieved.

The advent of the PCD bit has led to a decline in the economic attractiveness of existing turbodrill for the operator since drills currently available run efficiently at too high a speed and too high an hydraulic thrust for the PCD bit weight-on-bit requirements, leaving a large residual axial thrust to be carried by the turbodrill thrust-bearing module, with resulting high bearing cost, large friction losses, and short bearing life. For this reason, PCD bits have found application with rotary drilling and with positive displacement downhole mud motors. In the case of rotary drilling, drilling speeds are very low, typically less than 100 RPM and furthermore for deep and deviated wells a significant proportion of the power put into the drill string at the surface is lost in friction resulting in a comparatively low net torque at the bit. Mud motors, particularly in the larger sizes, are also restricted to comparatively low rotational speeds and limitations on supply pressure and torque, and also suffer from higher wear rates than turbodrills and therefore have their own limitations despite being better matched to the requirements of PCD bits.

An object of the present invention is to provide an axial thrust arrangement for a turbodrill and which will assist the turbodrill in efficient operation when used with bits having the drilling characteristics of PCD bits.

According to the present invention there is provided a downhole drilling motor comprising an outer drill casing, a shaft for driving a drill bit connected thereto and said shaft being rotatable relative to said casing, turbine means extending between said casing and shaft for enabling rotation of said shaft, an inlet for admitting fluid under pressure, and passage means interconnecting said inlet and turbine means whereby pressurised fluid can be transmitted to the turbine means to effect operation thereof, characterised in that the shaft is provided with reaction means accessible to the pressure fluid in said passage means, said reaction means having surfaces which can be acted upon by the pressure fluid to produce a force acting counter to the normal hydraulic thrust on the shaft thereby producing a reduced resultant hydraulic thrust on the shaft.

Preferably, the reaction means comprises sleeve means fixedly mounted on the shaft, said sleeve and shaft having pressure surfaces which can be acted upon by unequal pressures from the pressure fluid to induce a force on the shaft counter to the normal direction of flow of the pressure fluid along the drill.

Preferably, the reaction means is located in the drilling tool above the turbine means.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

Figs. 1A-1E illustrate partly in cross-section a first embodiment of downhole drilling tool in accordance with the present invention, the views showing sequential sections of the tool from the upper end (Fig. 1A) to the lower end (Fig. 1E);

Fig. 2 illustrates a partial plan view of an axial thrust bearing as utilised in the embodiment of Figs. 1A-1E;

Fig. 3 is a sectional view on the line X-X of Fig. 2; and

Figs. 4A-4D illustrate, partly in cross-section, a second embodiment of downhole drilling tool in accordance with the present invention, the views showing sequential sections of the tool from the upper end (Fig. 4A) to the lower end (Fig. 4D).

Referring to Figs. 1 to 3 of the drawing, a downhole drilling tool or turbodrill comprises a connector 10 for connecting the drill tool to a supply of drilling fluid or mud under pressure. The connector 10 is fitted to a casing 11 of a drill string which is substantially non-rotatable within a well bore or may be rotated at low speed. Carried within the casing 11 is a rotatable shaft 12, the outer diameter of which is radially spaced from the internal diameter of the casing 11.

The connector 10 has a central passage 13 through which drilling mud under pressure can be supplied to a turbine section 14 for driving the shaft 12, the turbine section 14 (Fig. 1B) comprising a plurality of co-operating turbine units 15.

Extending across the passage 13 is a transverse face 16 of a cover 17 which seals, by means of O-rings 18, against the inside surface of the casing 11. The cover 17 has extending therefrom, in an axial direction, an integral cylindrical wall or skirt 19 which defines an annular pressure chamber 20 between the outer circumference of the wall 19 and the inner circumference of the casing 11. Ports 21 in the cover 17 interconnect the passage 13 and the chamber 20.

The lower end of the chamber 20 opens into a turbine pressure supply chamber 22. Pressurised fluid at a given pressure passing into the chamber 22 for driving the turbine section 14 automatically causes that pressure to be applied to an axial thrust balancing device having lower end faces 23 and 24 on a cylindrical sleeve 25 and associated fixed bush 26 respectively. The sleeve 25 is fixed to the outside of the shaft 12 and is provided on its external surface with a series of circumferential grooves 27. The bush 26 closely surrounds the external surface of the sleeve 25 but is spaced therefrom by a small clearance gap 28 sufficient to permit a small supply of pressurised fluid to pass between the sleeve 25 and bush 26 to act on the radial surfaces of the grooves 27 before leaking in controlled manner with a corresponding reduction of pressure into chamber 29 from where the fluid passes freely out of the drilling tool through radial holes 30 without communication with ports 21 to the annulus between the outside of the casing 11 and the wall of the borehole. It will be noted that, at its upper end, the bush 26 abuts against a shoulder formed on the inside of wall 19.

After passing through the turbine section 14, the main flow of pressure fluid passes through ports 31 in radial journal bearings 32 and thence into annular pressure chamber 33.

As shown in Fig. 1C, the drilling tool is broken into upper and lower portions interconnected by a coupling designated generally by the reference numeral 34. The coupling 34 comprises an outer sleeve 35 which is provided with screw-threads 35a and 35b whereby the sleeve 35 can be releasably connected to the upper and lower portions of the drill casing 11. The coupling 34 also includes male and female screw-threaded junction pieces 36,37 fixed to the lower end of the upper portion of shaft 12 and the upper end of the lower portion of shaft 12 respectively. By virtue of the coupling 34, the lower portion of the drilling tool can be removed for maintenance, repair or replacement without disturbing the upper portion which houses the turbine section 14. It will be seen that when the coupling 34 is fitted to connect the upper and lower portions of the drilling tool, the pressure chamber 33 extends through the coupling 34 into the lower portion of the tool.

In said lower portion of the tool, the pressure fluid passes through ports 38 in a second radial journal bearing 39 before passing through ports 40 in a plurality of axial thrust bearings 41 (Fig. 1D and Figs. 2 and 3). Each thrust bearing 41 consists of an annular metal ring 42 formed with a radially-extending web 43 to the upper and lower surfaces of which are moulded, at spaced intervals therearound, a plurality of thrust pads 44 of rubber or similar elastomeric resilient, wear-resistant material. Each ring 42 is formed radially outwardly of the pads 44 with the ports 40 which permit pressure fluid to flow longitudinally past the thrust bearings. As shown in Fig. 1D, each thrust pad 44 is operatively disposed in frictional engagement between a pair of co-operating thrust collars 45 secured to the shaft 12. Residual axial thrust is accommodated by the axial thrust bearings 41.

As shown best in Fig. 3, each thrust pad 44 is formed with radial grooves 46 and its surface which engages an adjacent thrust collar 45 is profiled by being tapered upwards towards its circumferential trailing edge. The combination of the profiled rubber thrust pads 44 and their grooves 46 result in the formation of a lubricating film which provides the bearings with a substantially lower co-efficient of friction and therefore lower wear rates than bearings of previously proposed types of drilling tool.

After the pressure fluid passes through the axial thrust bearings 41 located below the turbine section 14, the fluid flows downwardly into annular passage 47, angled port 48 and into an axial passage 49 for transmission to a drill bit secured to connector 50 at the lower end of the drilling tool.

A labyrinth seal 51 of known construction and radial journal bearing 52 which absorbs mechanical vibration forces during operation of the drill bit are provided at the lower end of the tool (Fig. 1E).

In operation, pressurised drilling mud at high pressure is supplied into passage 13 and acts on the upper face 16 of cover 17 to tend to urge the drilling tool downwardly. The pressurised inlet fluid then flows from passage 13 through ports 19, pressure chamber 20 and turbine pressure supply chamber 22 to the turbine section 14. When the pressure fluid is present in the chamber 22, the pressure acts on the lower faces (23,24) of sleeve 25 and bush 26 respectively and a small proportion, say 5%, flows upwardly through clearance gap 28, into chamber 29 and out of the drilling tool through holes 30. Due to the reduction of fluid pressure as it passes upwards through clearance gap 28, the pressure of the fluid in chamber 29 is substantially lower than that on faces 23,24 and serves to reduce and tends to balance the downward hydraulic thrust on the drilling tool to a level such that when operating with weight on the bit, the residual load on the axial thrust bearings of the drilling tool is minimal.

As a result of the axial thrust balancing devices of the invention, drill tools incorporating such a device operate more efficiently and are subject to lower bearing wear rates than conventional drilling tools. In particular, the drilling tool as described above is suitable for use with PCD bits which operate at low weights on the bit due to the fact that the downward hydraulic axial thrust on the drill tool is balanced to a significant extent.

In the embodiment shown in Figs. 4A-4D, a drilling tool is shown in which the axial thrust bearing, axial thrust balancing device and turbine section are disposed differently relative to each other in the body of the drilling tool as compared with the embodiment of Figs. 1 to 3. In Figs.4A-4D like parts will be given the same reference numerals as in Figs. 1 to 3.

Referring to Figs. 4A-4D, a downhole drilling tool comprises a connector 10 for connection to a supply of drilling fluid or mud under pressure, the connector being fitted to casing 11 as in the previous embodiment. The central passage 13 of the connector 10 allows pressurised fluid to be fed axially past the outside wall of an axial thrust bearing containment wall or casing 19 located at the top end of the drilling tool above turbine section 14(Fig. 4C).

Internally of the connector 10 and integral therewith, a body portion 61 defines a cylinder 62 within which a flexible wall in the form of a piston 63 is slidable. Alternatively the flexible wall may be provided by a bellows. From the body portion 61 the cylindrical wall or skirt 19 extends downwardly in an axial direction substantially as in the embodiment of Figs. 1A-1E. Ports 64 extend through the body portion 61 to interconnect the passage 13 with annular pressure chamber 20 between the outer circumference of wall 19 and the inner circumference of casing 11.

The axial thrust bearing comprises a sealed chamber

65 filled or partially filled with a lubricating fluid such as oil and within which is housed a rotating bearing sleeve 66a mounted on a bearing shaft 66, the upper wall of the chamber 65 being defined by the piston 63 which allows for expansion or contraction of the sealed fluid as downhole pressure and temperatures vary. Furthermore, it allows for equalisation of the fluid pressure within the chamber 65 to that of the surrounding drilling mud. Within the cylindrical space 67 between the bearing shaft 66 and the wall 19 there is provided a plurality of bearings 68, for example ball or roller bearings, dynamically protected from drill bit dynamic loads by means of resilient mountings 68a. The upper end of the sealed chamber is closed by the piston 63 having a peripheral sealing ring 69 sealing against the inner surface of cylinder 62. The lower end of the bearing chamber 65 is sealed at its lower end by a shaft sealing system which is typically one or more rotary face-type seals 70 in combination with stationary lip-type shaft seals 71. The stationary lip seals 71 act as a barrier to prevent abrasive particles contained in drilling mud admitted to chamber 72 gaining access to the face seals 70. Drilling mud passing through the gap between rotary sleeve 25 and stationary bush 26 then passes to the annulus around casing 11 of the drill *via* drilled radial holes 73 without communication with chamber 20. Radial holes 74 allow annular pressure from the outside of casing 11 to be fed to the top side of piston 63 without communication with passage 13.

Below the axial thrust bearings 68 and carried on bearing shaft 66 is located an axial thrust balancing device of the type described in the embodiment of Figs. 1 to 3 and having associated sleeve 25 and bush 26 constructed and operating as described hereinabove.

The annular pressure chamber 20 extends past the axial thrust balancing device and through a coupling indicated generally by the reference numberal 75 (Fig. 4B).

The coupling 75, which is only one form of coupling found to be suitable for the purpose, connects bearing shaft 66 with turbine and drill bit shaft 76. The coupling 75 incorporates an upper female connector 77 which is screw-threadedly mounted on the lower end of bearing shaft 66. A male connector 78 adapted to interengage by means of splines 79 with female connector 77 is screw-threadedly mounted on the upper end of turbine shaft 76. A shear ring 80 is located in registering apertures in male and female connectors 77,78 to prevent relative axial displacement therebetween. The shear ring 80 is provided with a radial screw adjustment 81 whereby the ring 80 can be urged radially inwardly to interconnect connectors 77,78 and released radially outwardly to allow the connectors 77,78 to be moved axially into or out of engagement with each other. The casing 11 is interrupted into upper and lower portions which are screw-threadedly interconnected by coupling sleeve 82.

Access apertures 83 allow access to the screw adjustments 81.

As shown in Fig. 4C, and after passing through the coupling 75, annular pressure chamber 20 leads through radial journal bearing 84 to enable pressure fluid to be supplied to turbine section 85 which drives turbine shaft 76. After leaving the turbine section 85, pressure fluid is fed through a further radial journal bearing 86 and, as shown in Fig. 4D, thence through angled passage 87 and central bore 88 to drill bit connector 89. At the lower end of the casing 11 adjacent the drill bit connector 89 a radial journal bearing 90 is provided to assist in absorbing the dynamic forces generated on operation of the drill bit.

The operation of the drilling tool as shown in Figs. 4A-4D is similar to that described in Figs. 1 to 3. It will be noted, however, that in the second embodiment, the axial thrust bearing and axial thrust balancing device are located above the turbine section. This arrangement permits the thrust bearing to operate in a lubricant such as grease or oil, sealed from the drilling mud and thereby reduces bearing friction losses and prolongs bearing life. The arrangement has the further advantage that the axial thrust bearing and its associated seals are remote from the drill bit connection and from the highly dynamic radial action associated with that area. Furthermore, since there is no sliding seal above the thrust bearing, the lubricant which has a lower specific gravity than the mud is effectively trapped within the bearing chamber.

It will be further appreciated that by providing coupling 75 between the sealed axial thrust bearing assembly and axial balancing device on the one hand and the turbine section on the other hand, the bearing assembly and balancing device form an integral replaceable module.

If desired, the lubricating fluid in the sealed bearing chamber can be circulated round the chamber and through a heat exchanger in order to transfer heat from the lubricant to the drilling mud.

CLAIMS

1. A downhole drilling motor comprising an outer drill casing (11), a shaft (12) for driving a drill bit connected thereto and said shaft (12) being rotatable relative to said casing (11), turbine means (15) extending between said casing (11) and shaft (12) for enabling rotation of said shaft (12), an inlet (13) for admitting fluid under pressure, and passage means (20) interconnecting said inlet (13) and turbine means (15) whereby pressurised fluid can be transmitted to the turbine means (15) to effect operation thereof, characterised in that the shaft (12) is provided with reaction means (17) accessible to the pressure fluid in said passage means (20), said reaction means (17) having surface (23, 24) which can be acted upon by the pressure fluid to produce a force acting counter to the normal hydraulic thrust on the shaft (12) thereby producing a reduced resultant hydraulic thrust on the shaft (12).

2. A downhole drilling motor as claimed in claim 1 wherein the reaction means comprises a sleeve (25) fixedly mounted on the shaft (12), said sleeve (25) and shaft (12) having pressure surfaces (23,24) which can be acted upon by unequal pressures from the pressure fluid to induce a force on the shaft counter to the normal direction of flow of the pressure fluid along the drill.

3. A downhole drilling motor as claimed in claim 2, in which the sleeve (25) defines a fluid passage to permit leakage of pressurised fluid in a controlled manner with corresponding reduction of pressure into said chamber (29), and an outlet (30) for permitting the fluid to pass freely out of the drilling tool.

4. A downhole drilling motor as claimed in claim 3, in which bush means (26) surround said sleeve (25) to define a clearance gap (28) for said leakage of pressurised fluid.

5. A downhole drilling motor as claimed in any of claims 1 to 4, wherein the reaction means is located in the drilling tool above the turbine means (15).

6. A downhole drilling motor as claimed in any preceding claim, including a thrust bearing (41), said thrust bearing being disposed below said turbine means (51).

7. A downhole drilling motor as claimed in any of claims 1 to 5, wherein said downhole motor includes a thrust bearing (68), said thrust bearing (68) being disposed above said turbine means (15).

8. A downhole drilling motor as claimed in claim 7, in which the thrust bearing (68) is disposed above the reaction means (17).

9. A downhole drilling motor as claimed in claim 7 or 8, in which sealing means is provided between the reaction means (17) and the thrust bearing (68), said thrust bearing (68) having a sealed chamber (65) at least partially filled with a lubricating fluid.

10. A downhole drilling motor as claimed in claim 9, in which the sealed chamber (65) has an adjustable wall member (63) for permitting expansion or contraction of the lubricant fluid as downhole pressures or temperatures vary.

11. A downhole drilling motor as claimed in any of claims 9 or 10, in which the chamber (65) is provided with sealing means (70,71) at the lower end of the chamber (65) only, the chamber (65) being located at the upper end of the rotating assembly.

12. A downhole drilling motor as claimed in any of claims 9 to 11, in which there is provided means for circulating the lubricating fluid within the chamber (65) and cooling means for said lubricant fluid.

13. A downhole drilling motor as claimed in any of claims 6 to 12, in which the thrust bearing comprises at least one resiliently mounted rolling element (68).

14. A downhole drilling motor as claimed in claims 5 to 13, in which said thrust bearing comprises one or more face to face bearing elements (41).

15. A downhole drilling motor as claimed in claim 14, in which each bearing element comprises a thrust collar (45) secured to shaft (12) and a thrust bearing ring (42) operatively associated therewith, said ring (42) having a pad or pads (44) of elastomeric material in contact with said thrust collar (45).

16. A downhole drilling motor as claimed in claim 15, in which each pad (44) is provided with a lubrication groove or grooves (46) therein.

17. A downhole drilling motor as claimed in claim 15 or 16, in which the surface of each thrust pad (44) which engages an adjacent thrust collar (45) is profiled by being tapered upwards towards its circumferential trailing edge.

18. A downhole drilling motor as claimed in any preceding claim, including coupling means (75) disposed between said turbine means (15) and said reaction means (17) and said thrust bearing (68), the reaction means (17) and thrust bearing (68) forming an integral module adapted to be replaceable as a unit.

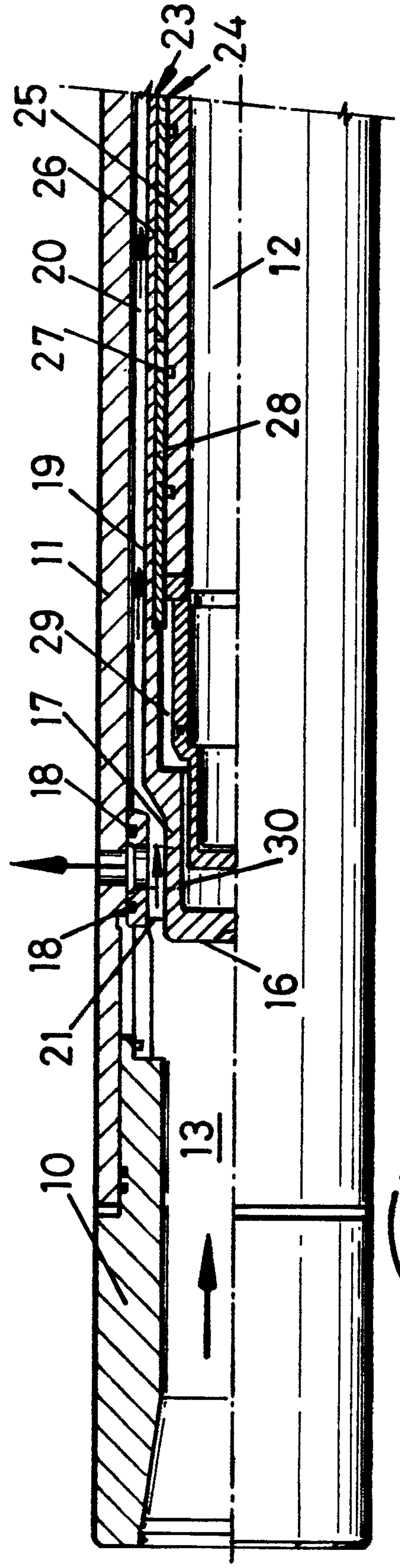

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FIG.1A

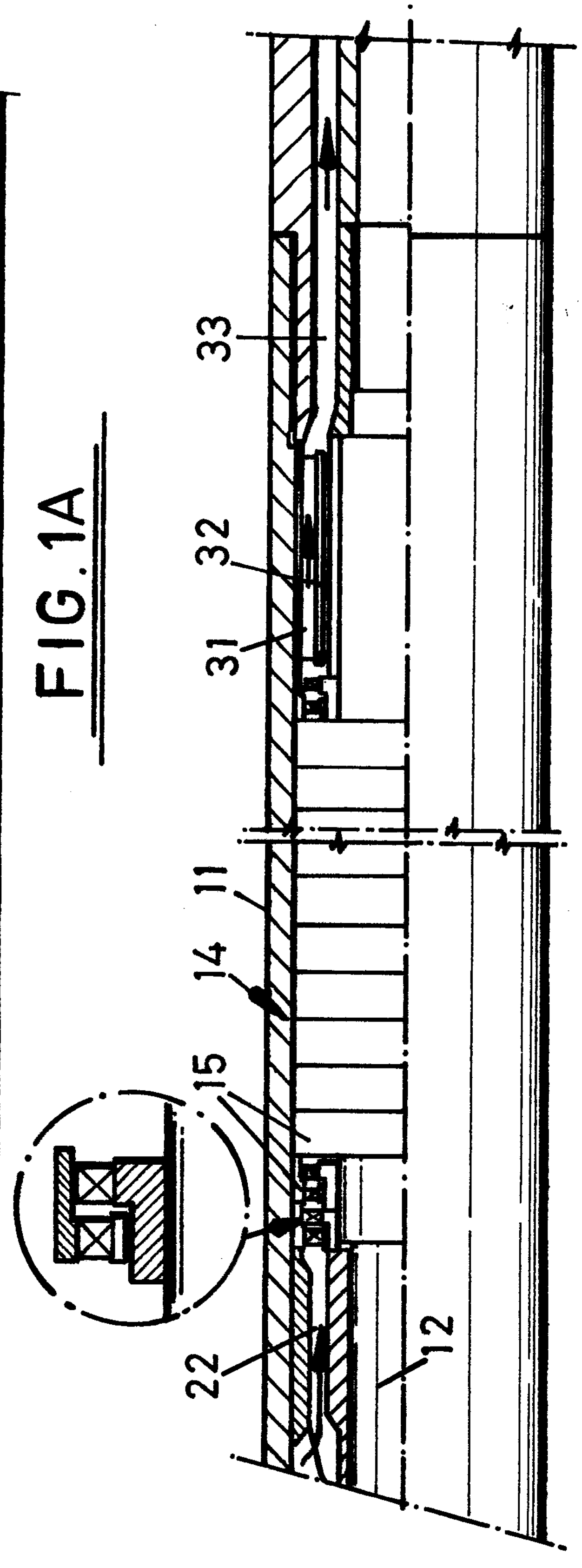

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FIG.1B

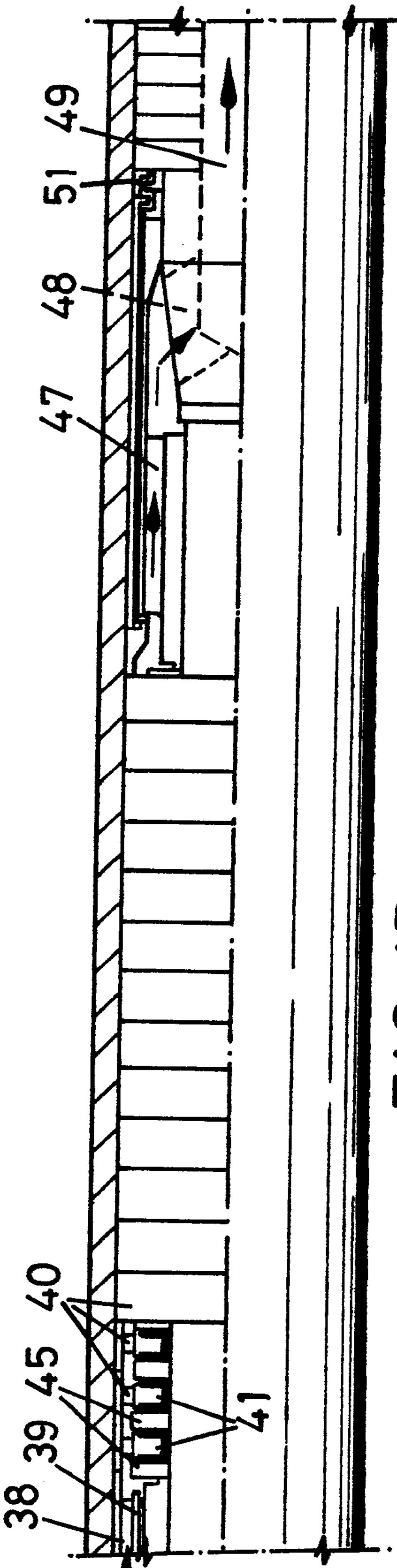

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FIG.1D

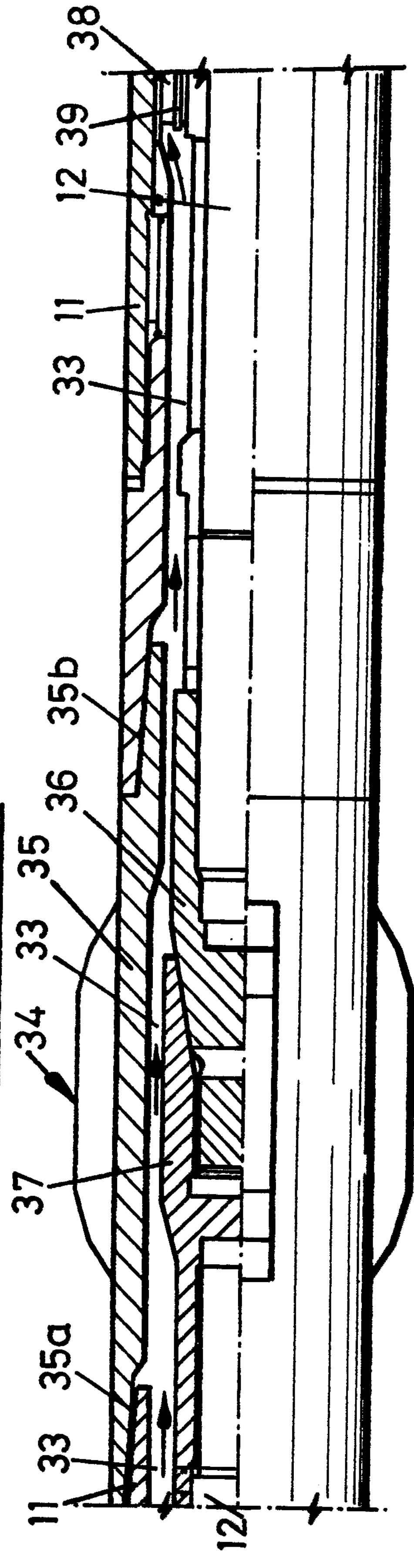

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FIG.1C

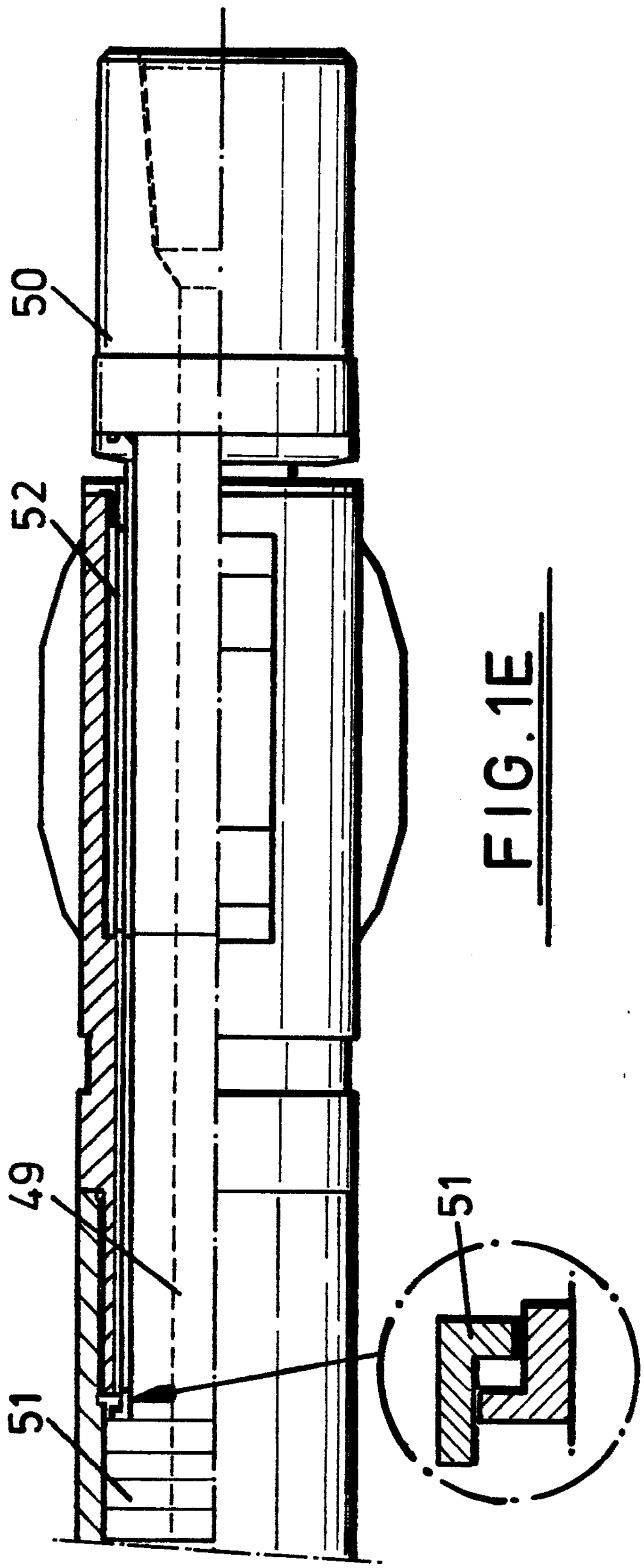

FIG.1E

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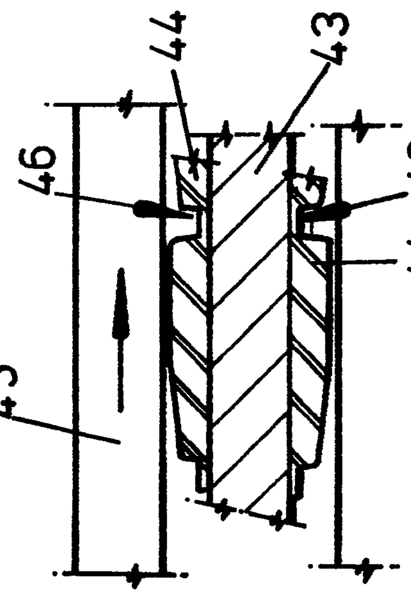

FIG. 3

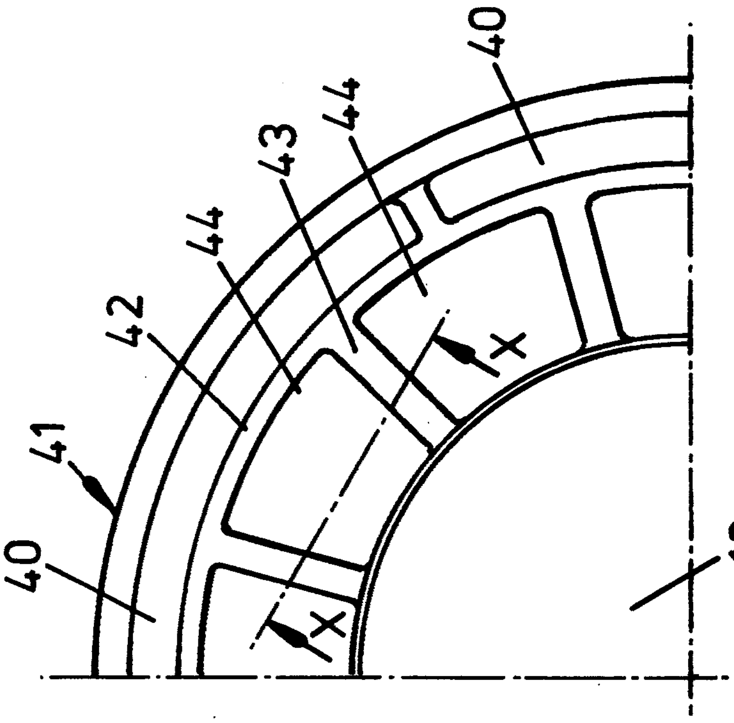

FIG. 2

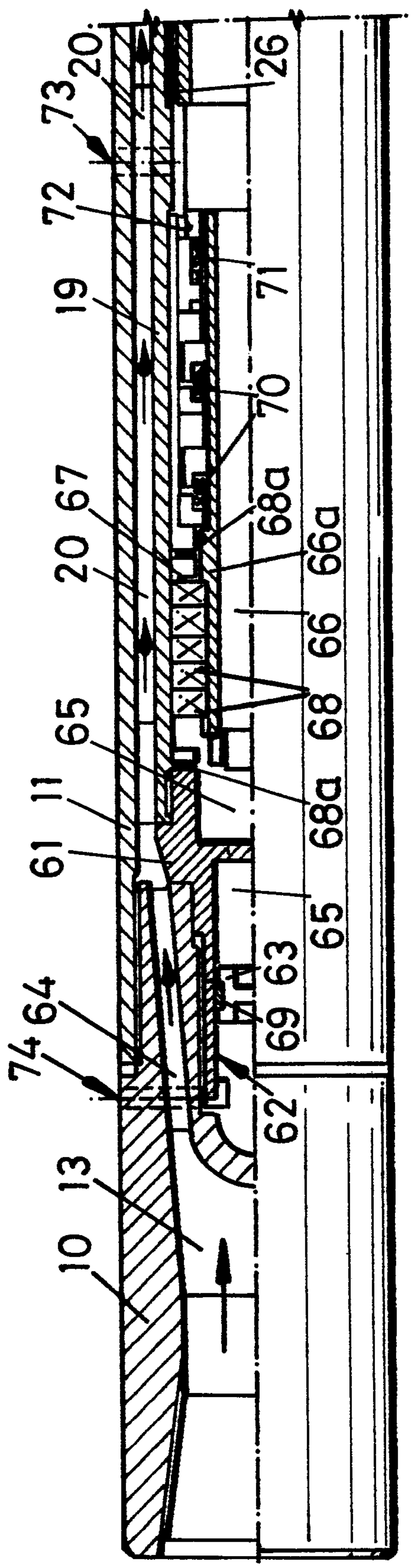
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FIG.4A

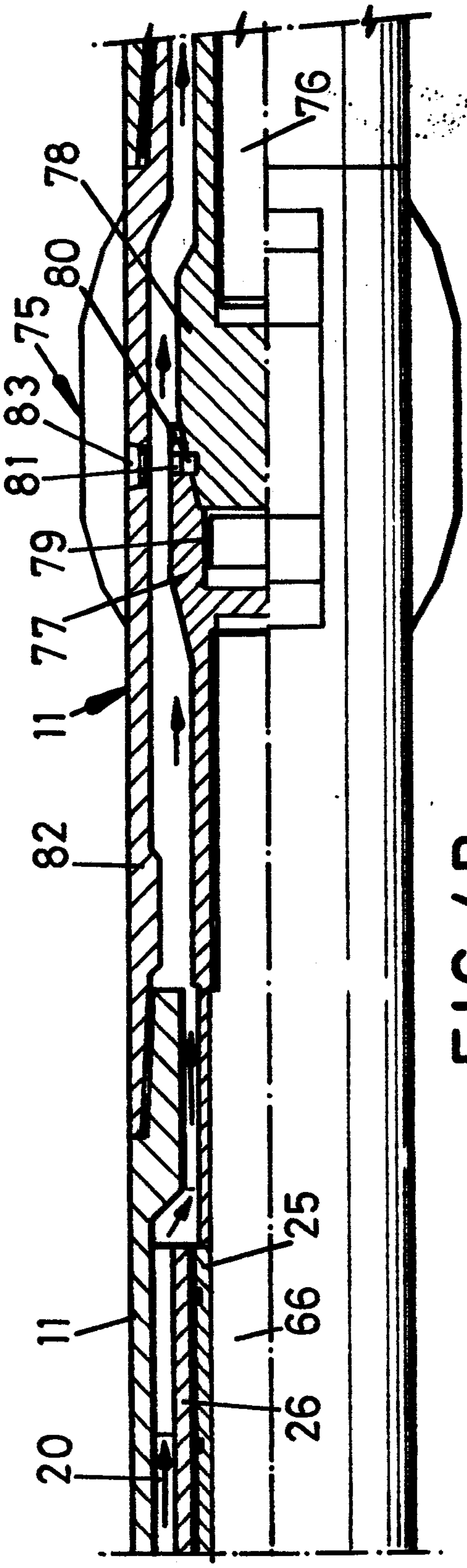
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FIG.4B

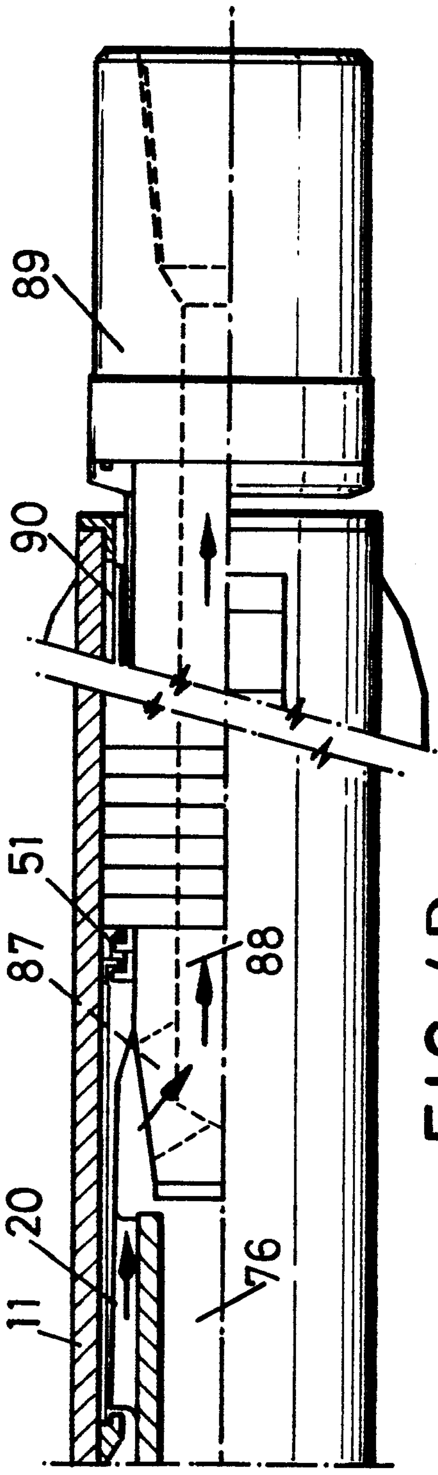

FIG.4D

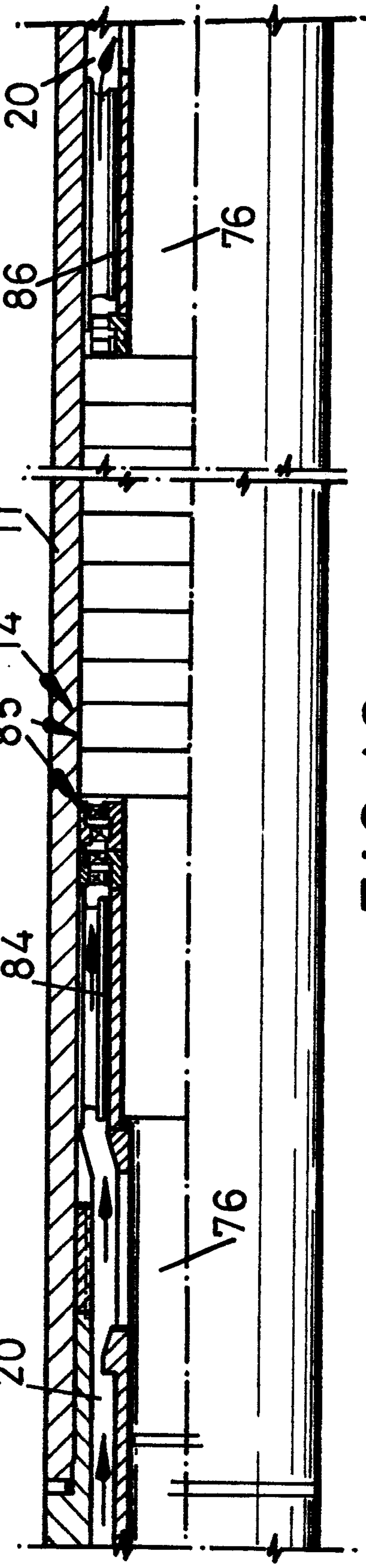

FIG.4C