

May 17, 1960

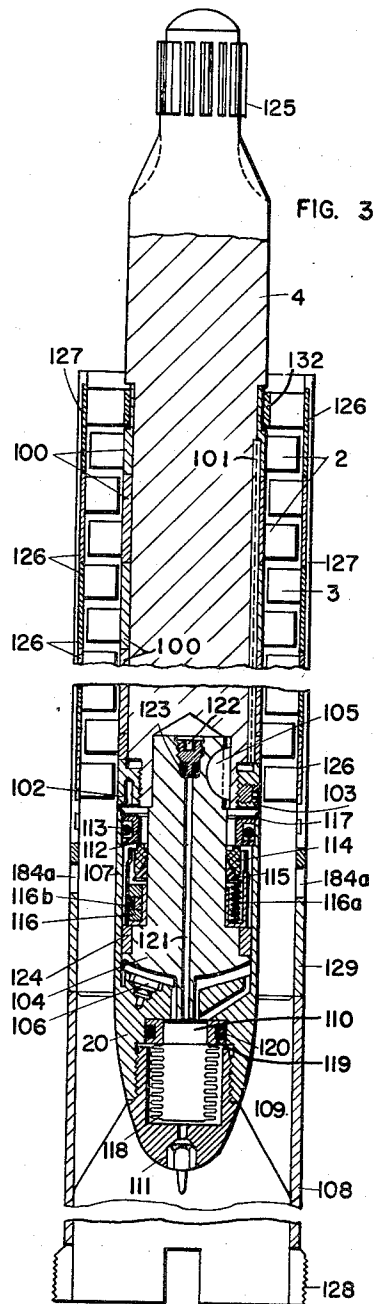
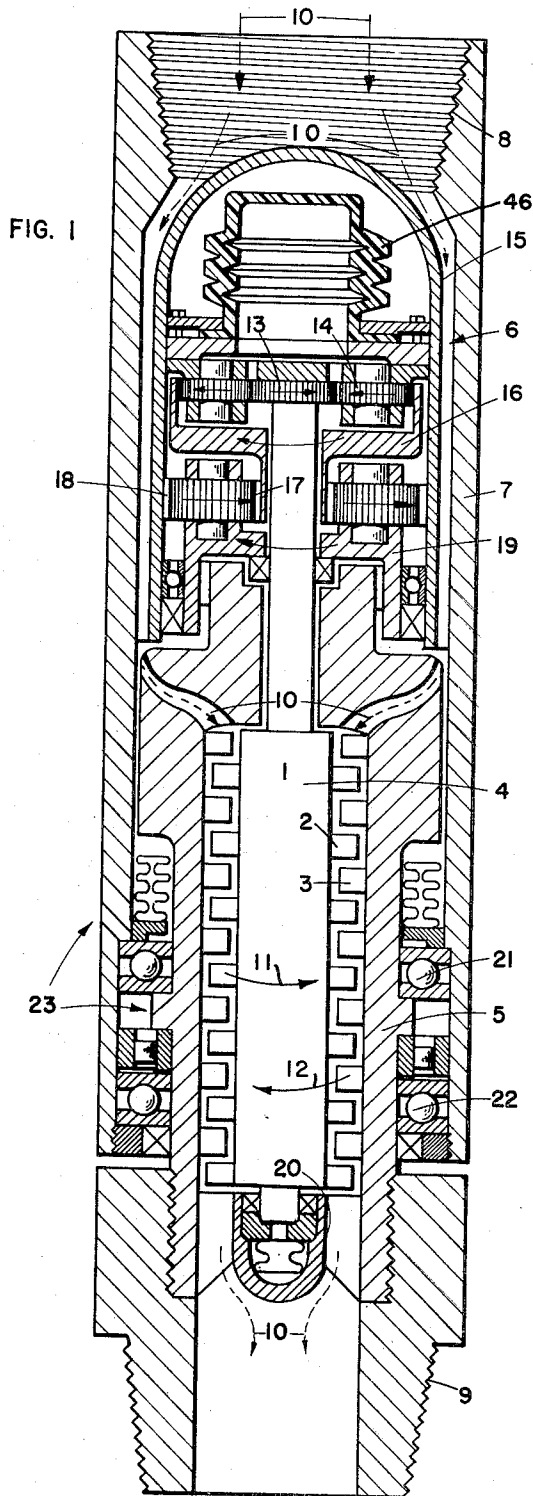
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2,937,008

HIGH-SPEED TURBO-DRILL WITH REDUCTION GEARING

Filed Sept. 24, 1956

6 Sheets-Sheet 1



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6 Sheets-Sheet 2

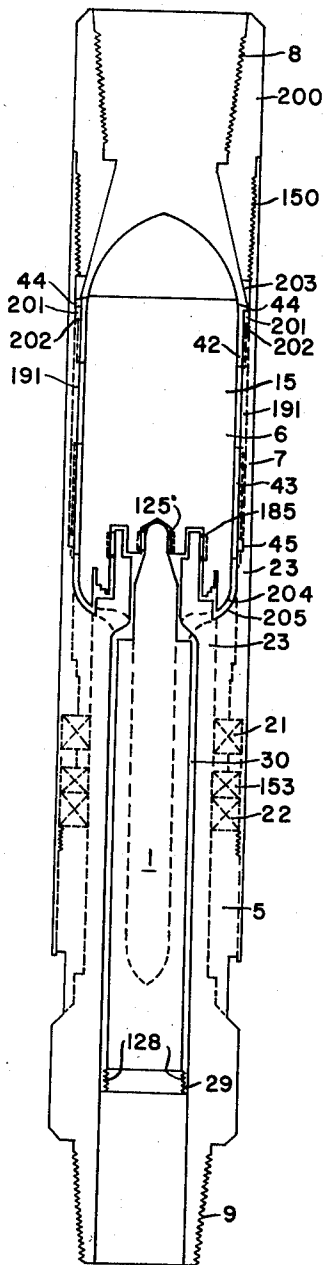


FIG. 8

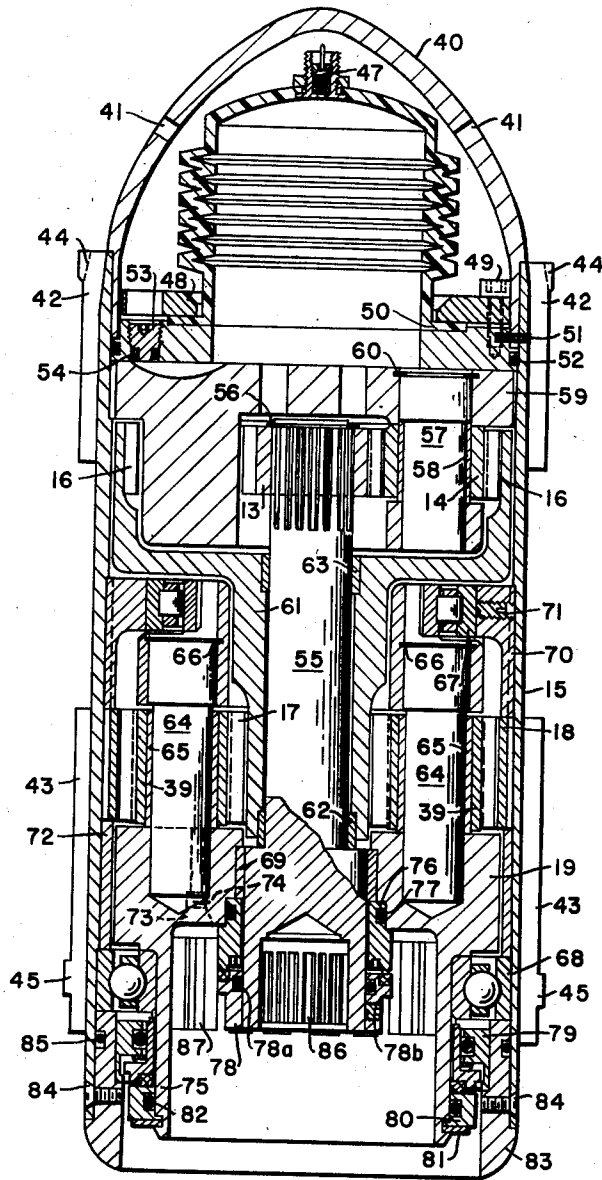


FIG. 2

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6 Sheets-Sheet 3

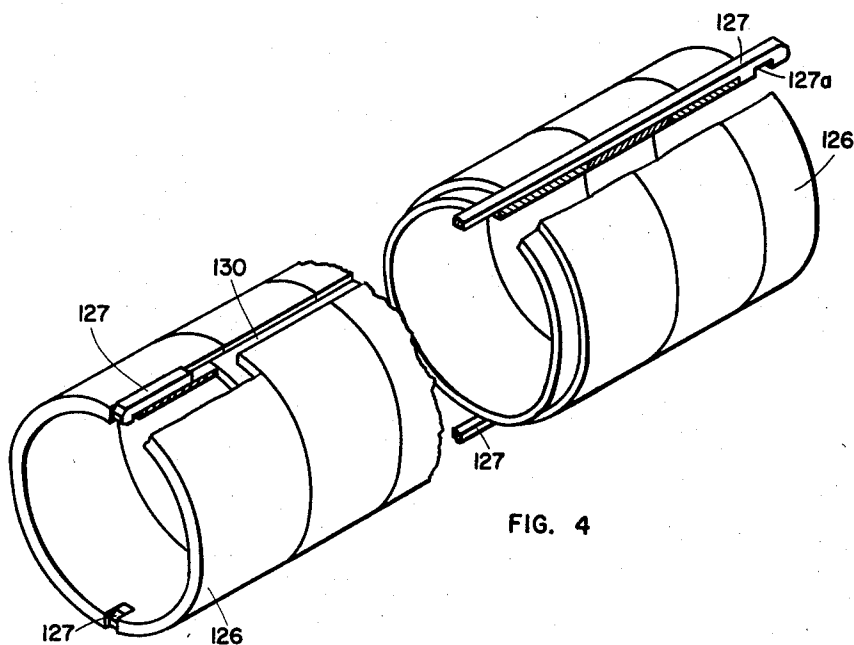


FIG. 4

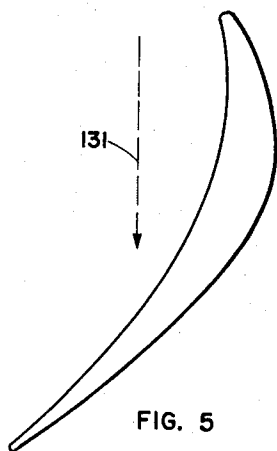


FIG. 5

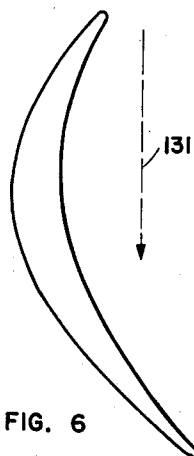


FIG. 6

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6 Sheets-Sheet 4

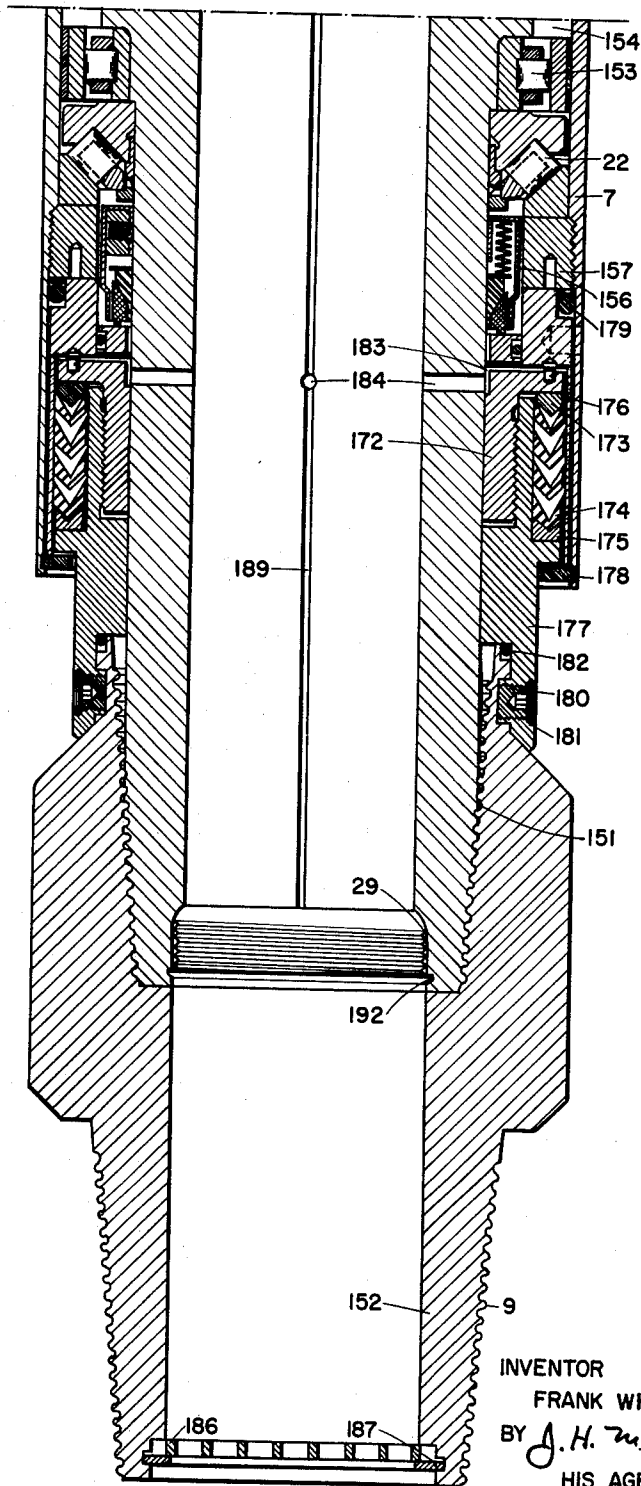


FIG. 7B

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6 Sheets-Sheet 5

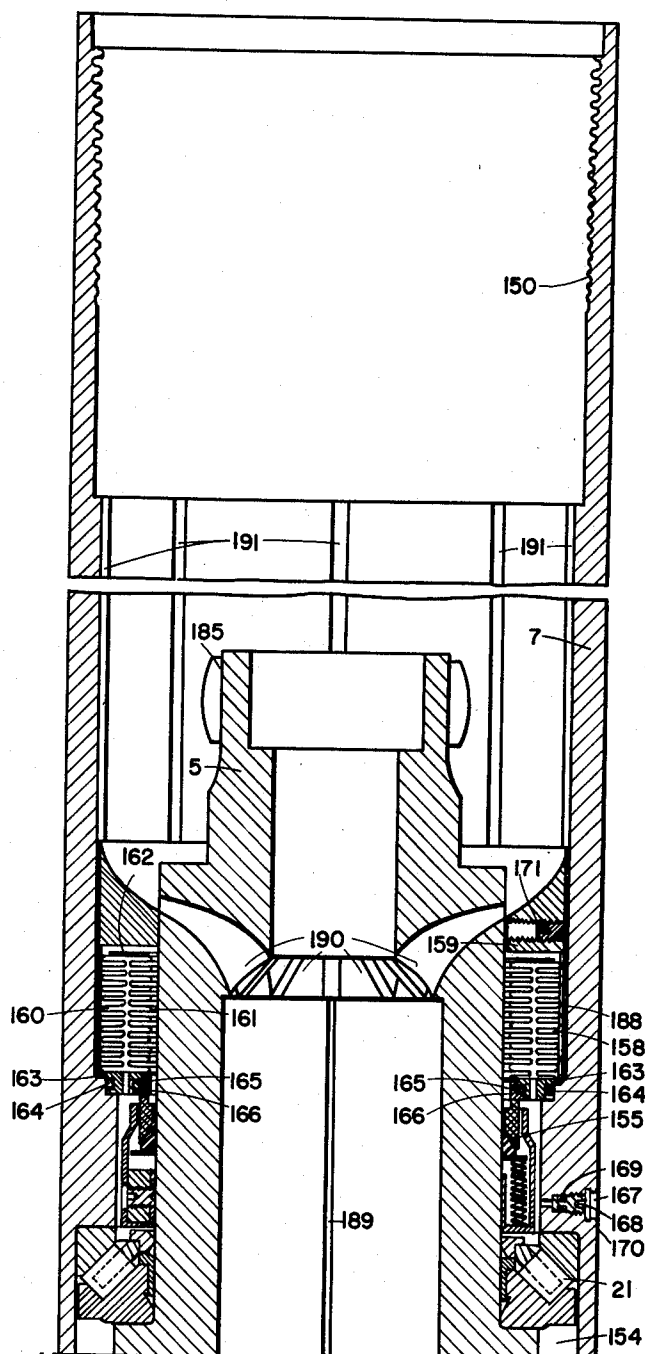


FIG. 7A

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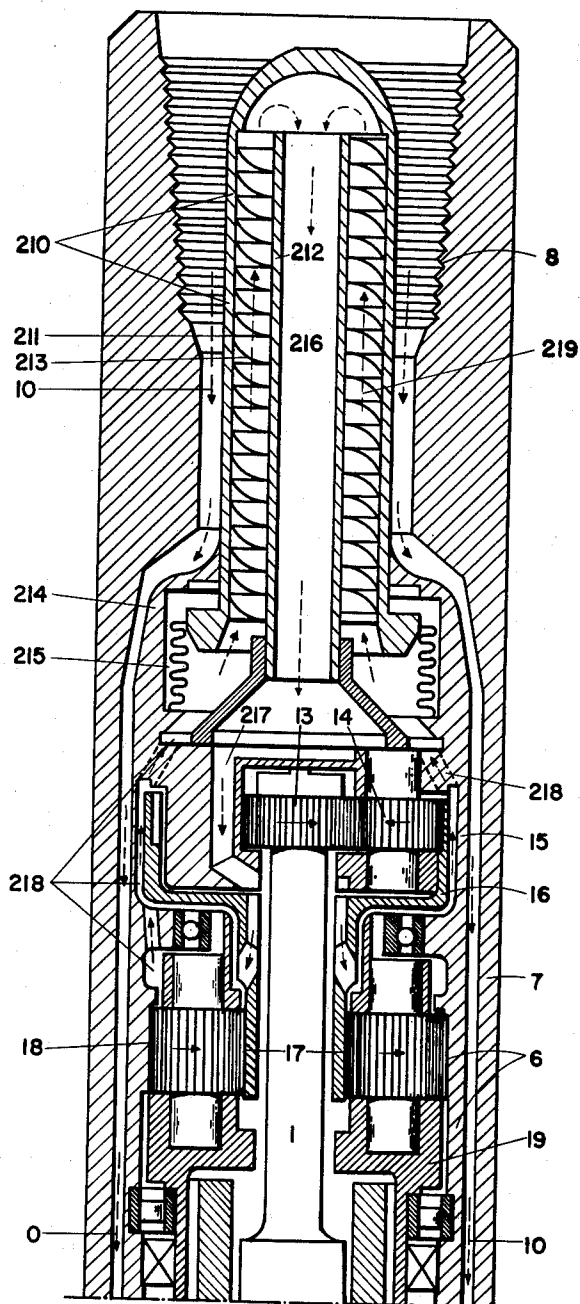


FIG. 9

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2,937,008

HIGH-SPEED TURBO-DRILL WITH REDUCTION GEARING

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Application September 24, 1956, Serial No. 611,639

Claims priority, application Great Britain
September 30, 1955

12 Claims. (Cl. 255—4)

The present invention relates to turbine units for turbine drilling systems used in well-drilling operations. A turbine drilling system is one in which there is provided a rotary drill bit and a hydraulic turbine, which in operation is located close to the drill bit at the bottom of the bore-hole being drilled, and is suitably joined to the bit to drive it. The turbine is actuated in operation by a stream of liquid delivered under pressure to its inlet. For this purpose, use may be made of the drilling mud flush circulation, which is used in conventional drilling systems and may also be used in turbine drilling systems. The turbine is joined to the lower end of the drill string, and the mud flush flows down the drill string, through the turbine unit and drill bit, out of openings in the drill bit, into the bore-hole and back towards the surface outside the drill string.

The present invention is particularly concerned with turbine units which incorporate or are combined with a speed reducing coupling, so that the turbine can operate at a higher speed of rotation than the bit. At present, bit speeds much in excess of 500 r.p.m. cannot be tolerated if a reasonable bit life is to be obtained, and there are considerable advantages (for example, a considerable reduction in the number of turbine stages required) to be obtained in employing a higher speed for the turbine, for example 5,000 to 10,000 r.p.m. and driving the bit through a speed reducing transmission.

Various turbine drilling systems incorporating speed-reducing transmissions have been proposed, but, as far as is known, these have failed for various reasons to become operational systems.

It is an object of the present invention to provide a turbine unit for a turbine-drilling system, the unit including a speed-reducing transmission through which the bit is driven in operation, and being arranged in novel manner to provide a relatively compact and robust well-drilling system when combined with a drill string and a rotary drill bit.

According to the present invention a turbine unit for a turbine drilling system is adapted to be joined at one end to a drill string or the like and at the opposite end to a drill bit, and includes an outer housing, a stator and a rotor, which are all rotatable relative to one another and are coupled by a speed reducing transmission arranged so that, in operation in a system, the speed of rotation of the bit is less than that of the rotor relative to the stator. It will be appreciated that the term "stator" is here used to mean the turbine blade system complementary to the rotor blade system, even though the former may, in some cases, rotate in operation as well as the latter. Where, in this specification, the terms "stator" and "rotor" are used in respect to a counter-rotating turbine, they are to be understood to mean the outer and inner blade systems respectively.

In a convenient arrangement of a turbine unit according to the present invention, it is the outer housing that is adapted to be joined to a drill string and the stator that is adapted to be joined to a drill bit. The speed reducing

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transmission is located between the said one end of the unit and the rotor and the stator. The stator, being rotatable relative to the housing, rotates due to the turbine reaction forces in the opposite direction to the rotor, and is also driven by the rotor through the speed-reducing transmission.

With this arrangement of the turbine unit, a number of advantages are obtained as compared with a more straightforward arrangement (not within the scope of the invention) in which the stator is rigidly mounted with respect to the housing, and the member (hereinafter referred to as "the bit shaft") to which the drill bit is joined is driven by the rotor through a speed reducing transmission located between the rotor and the bit shaft. One advantage of the unit in accordance with the invention is that the power loading of the speed-reducing transmission is reduced by the amount of the power directly produced by the torque reaction on the stator. Again in all drilling systems it is necessary to transfer an axial thrust to the drill bit, this thrust being commonly referred to as the bit weight. In the straightforward arrangement referred to above, this thrust, apart from any resultant hydraulic force which may act on the bit for example due to the pressure drop across the jet openings, has to be transmitted by a main thrust-bearing mounted on or attached to the housing and carrying the bit shaft. Using the arrangement in accordance with the invention as set out above, whilst a similar thrust bearing has to be provided, the thrust it has to transmit is reduced by the amount transferred hydraulically to the bit shaft, principally due to the fact that the turbine itself acts in effect as a piston on which there is a pressure equal to the pressure drop across the turbine. This pressure acts both on the stator and the rotor, and the hydraulic thrust transference is increased if the rotor thrust is transmitted to the stator through an axial thrust-bearing rigidly mounted with respect to the stator. Finally it is possible with this arrangement in accordance with the invention to mount the main thrust bearing around the stator and the rotor, so that the length of the unit is not increased by the length of the thrust bearing. This enables the unit to be made much shorter, which is an important factor from the point of view of operational convenience and manufacture, and also of designing the unit to avoid the undesirable effects of eccentric loading on a bit which can occur in operation when it comes into contact, for example, with the surface of a hard, inclined formation.

In U.S. patent application Serial No. 548,048, filed November 21, 1955, an explanation is given of the "control problem" in turbine drilling systems, which resolves itself into the necessity of obtaining the widest possible variation of the ratio bit torque/bit weight within a limited range of turbine speed if the turbine is not to stall in soft formations or overspeed in hard formations. With variation of bit weight, for example manually or automatically by means of a ram device as described in the said application, closer control is possible, but in all cases it is desirable that the turbine torque/speed characteristic should have the steepest possible negative slope.

According to a feature of the present invention the blading of the turbine is what will be known as "super-reaction" blading, that is to say it is designed so that the whirl velocity of the liquid leaving each ring of stator blades is less than the rotational velocity of the rotor blades at the design speed (by design speed is to be understood the desired operating speed on which the design of the turbine is based). Preferably the turbine has from four to eight stages of such blading. To prevent a loss of torque at low speeds due to flow break-away, various measures are possible:

(1) The pitch of the blading is less than that necessary to obtain optimum efficiency at the design speed,

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(2) A high axial liquid flow velocity if employed, lying, at the design speed in the range 0.6–0.9 times the rotor blade speed relative to the bit shaft at the mean blades diameter, and

(3) The profiles of the blades are based on the velocity vector diagrams for half the design speed.

The third measure also contributes to a rapid fall-off of torque above the design speed, which is again desirable. Whilst these measures detract from the efficiency of the turbine at the design speed, it is thought that this sacrifice is worth while to obtain a favorable torque/speed characteristic. Indeed the seven stage super-reaction turbine described with reference to the drawings, is thought to have a characteristic such that under most conditions it could operate in a turbine drilling system without variation of the bit weight either manually or automatically as for example by the use of a ram device.

Further, according to the present invention there is provided a turbine drilling system including a turbine unit as set out above, a drill string to the lower end of which the said one end of the unit is joined so that liquid can flow from the drill string to the unit, a drill bit joined to the said opposite end of the unit, and means for supplying liquid under pressure to the upper end of the drill string. Where reference is made to joining a turbine unit to a drill bit or a drill string, it will be appreciated that this may be effected either directly or by one or more intermediate elements such as drill collars, and in particular the joint with a drill string may incorporate a ram device as described and claimed in U.S. patent application Serial No. 548,048, filed November 21, 1955. In particular the bit weight, which may be of the order of 40,000 lbs., may be provided by including a suitable number of drill collars in the drill string above the turbine unit. The weight of the collars is preferably at least equal to the bit weight, although in the turbine unit, the advantages of which have been discussed above, only part of this weight (approximately one third) has to be transmitted to the bit by the main thrust bearing, the remainder being transmitted hydraulically.

Preferably the speed reducing transmission is epicyclic speed-reducing gearing, which may be in two stages. The driving member of the gearing will be driven by the rotor, the driven member will drive the stator (or the bit shaft, to which the stator is rigidly connected), and the fixed members will be rigidly connected to the housing. Preferably the gearing will be enclosed within a single casing, which is lubricant-filled in operation, and incorporates a flexible bellows or the like for substantially equalising the fluid pressures inside and outside the casing, and thus preventing or minimising the penetration of mud flush through the bearing seals of the casing in operation.

To provide sufficient cooling of the speed-reducing transmission, it may be provided with a heat exchanger through which heat generated in the speed-reducing transmission can be transmitted to the fluid which in operation flows through the turbine. Where the transmission includes gearing, the arrangement may be such that in operation the gearing lubricant is pumped by the action of the gearing through the heat exchanger where it is cooled by thermal contact with said fluid before returning to the gearing.

The various constituent sections of the turbine unit may, for convenience, be unitised, the arrangement of the unit being such that the unitised sections can be fitted together or dismantled by a few simple operations. This enables delays in operation for maintenance purposes to be reduced to a minimum, since any one of the unitised sections can be replaced rapidly by a spare, pending investigation and/or repair of the old one. This applies in particular to the speed reducing gearing, but in an embodiment of the invention to be described, the turbine itself is unitised and can be readily withdrawn from a

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unitised assemblage including the outer housing of the unit, the bit shaft and associated bearings.

An example of a turbine unit in accordance with the present invention is now described with reference to the drawings of which,

Figure 1 is a schematic diagram showing the layout of the turbine unit and illustrating in particular its action in operation,

Figure 2 shows a longitudinal section of the reduction gearing,

Figure 3 shows a longitudinal section of the turbine itself,

Figure 4 shows a perspective view of the assembled stator-blade rings of the turbine,

Figures 5 and 6 show profiles of a rotor blade and a stator blade respectively,

Figure 7 shows in two parts, Figures 7A and 7B, a longitudinal section of a constituent assemblage including the outer housing of the turbine unit, the bit shaft and associated bearings,

Figure 8 shows in outline the various constituent sections of the turbine unit which are shown in Figures 2, 3 and 7, when assembled together, and

Figure 9 is a longitudinal section showing the layout of a modified form of the reduction gearing.

Figure 1 shows schematically only the general layout of the turbine unit, disposed as it would be in operation in a vertical borehole. The turbine, indicated generally by the reference 1, includes a rotor blade system 2 (which will be referred to as "the rotor 2") and a complementary blade system 3 (which will be referred to as "the stator 3"). The rotor 2 is mounted on a rotor shaft 4, whilst the stator 3 is keyed to the inside of a bit shaft 5. The rotor shaft 4 and the bit shaft 5 are coupled by a two-stage epicyclic reduction gearing 6, the casing of which is mounted in the outer housing 7. At its upper end the housing 7 is provided with a screw thread 8 for joining the unit to the lower end of a drill string (not shown) and, at the lower end of the turbine unit, there is provided a screw thread 9 for joining the unit to a drill bit (not shown). The turbine is actuated by drilling fluid, pumped down through the drill string and passing through the unit as indicated by the dotted arrows 10. (It should be noted that details of many seals and other items to be later described have been omitted from Figure 1, and that the fluid flow is in fact confined to the path indicated.) The drilling fluid, passing through the turbine, causes the rotor 2 and the rotor shaft 4 to rotate in the direction indicated by the full line arrow 11, whilst the stator 3 rotates in the opposite direction indicated by the full line arrow 12. As the stator 3 is keyed to the inside of the bit shaft 5, the arrow 12 also indicates the direction of rotation of the bit shaft 5.

The rotor shaft 4 drives a sun wheel 13 of the first stage of the reduction gearing 6, the direction of rotation of which, together with that of the other elements of the reduction gearing 6, are indicated on Figure 1 by full line arrows on the elements concerned. The planet pinions 14 of the first stage are rotatably mounted in a cage fixed to the casing 15 of the reduction gearing 6, the casing 15 itself being secured to the housing 7, so that the planet pinion cage of the first stage of the reduction gearing is stationary relative to the housing 7. Consequently, the ring gear 16 of the first stage is driven in a direction opposite to that of the sun wheel 13. The ring gear 16 is connected to the sun wheel 17 of the second stage, the ring gear 18 of which is connected to the casing 15 and thus is stationary relative to the housing 7. The planet pinion cage 19 of the second stage of the gearing 6 is connected to the bit shaft 5 and causes it to rotate in the same direction as the sun wheel 17. Thus, with drilling fluid being pumped through the device, the bit shaft 5 will rotate, the torque being derived in part directly from the turbine torque reaction on the stator 3 and, in part, in-

directly by the drive from the rotor 2 through the gearing 6.

A thrust bearing 20 of the Kingsbury type, carrying the lower end of the rotor shaft 4, is mounted on the bit shaft 5 and transmits to the latter the downwards thrust on the rotor shaft 4 caused by the resultant hydraulic pressure acting on the rotor 3 and the rotor shaft 4.

Further thrust bearings 21 and 22 are provided between the bit shaft 5 and the housing 7. The bearing 21 transmits downwards thrust from the housing 7 to the bit shaft 5 and hence the bit, but in operation under drilling conditions, this thrust is not equal to the entire bit weight as part of the latter is provided by the thrust on the bit shaft 5 due to the resultant hydraulic pressure acting on the turbine 1 and the bit shaft 5. Under drilling conditions, the load on the bearing 21 may be a relatively small part of the bit weight, being for example under the design conditions given below for this particular turbine unit about one-third of the total bit weight and under some circumstances considerably less. The bearing 22 is provided to complete the location of the bit shaft 5 with respect to the housing, and is employed to transmit upwardly directed pull from the housing 7 to the bit shaft 5, as required for example when the bit is not in contact with the bottom of a borehole, or when pulling upwards on the drill string to free a drill bit that has become stuck.

One advantage of the arrangement of the unit shown in Figure 1 is that only part of power generated is transmitted to the bit through the reduction gearing 6, since the stator 3 is directly coupled to the bit shaft 5, and part of the power is generated by the torque reaction on the stator 3. In fact, the power transmitted by the reduction gearing 6 in the unit being described is about 90% of the total power and the percentage may be even lower in some cases. Another advantage is that the thrust bearings 21 and 22 are located around the turbine blading, and therefore do not add to the length of the unit which is therefore considerably shorter than a presently-known similar unit in which the stator is still and the rotor drives the bit through a reduction gearing located between the rotor and the bit. In that case, the thrust bearing has to be located below the gearing and adds to the length of the unit. The turbine of the present invention is also shorter than a unit employing a multi-stage turbine and a direct drive from the rotor to the drill bit. Further, it is possible, in the present device, to unitise the gearing 6 so that it may be readily withdrawn and assembled as a unit. The input and output shafts are coaxial with one another at the same end of the housing 15, the other end being sealed off and including a pressure-balancing device of generous capacity for maintaining the pressure of the lubricant within substantially equal to that of the drilling fluid outside and thus preventing penetration of the latter into the gearing 6.

The turbine unit being described is designed to develop 100 H.P. at a bit speed of 500 r.p.m. with a circulation rate of 600 U.S. g.p.m. of water and to operate with a bit weight of the order of 40,000 lbs. Figures 2-8 show the construction of the unit in more detail. Of these, Figures 2, 3 and 7 show three sections of the unit which may be fitted together. The outer diameter of the particular unit which is described, is 7 3/4 inches and its length from shoulder to shoulder is 47 inches. It will be understood though, that these design conditions are more or less arbitrary and that the details of the design must be varied to suit any given set of conditions. In this respect it may be well to point out, that the design conditions are to a great extent governed by the quality of the drill bits which are available. As it may be expected that this quality will be improved constantly, for instance so as to allow higher rotational bit speeds, the design conditions may be drastically changed. Thus, it may be possible to have only a single stage reduction gearing and/or to use another turbine than the one which is chosen in the present device.

Although the whole unit is of considerable complexity, the assembly of it is relatively simple, as the gearing 6 (shown in detail in Figure 2), the turbine 1 (shown in detail in Figure 3) and the assemblage 23 (shown in detail in Figure 7) which includes the housing 7, the bit shaft 5 and the bearings 21 and 22, have each been unitised, so that the turbine unit as a whole can readily be broken down into three sections for maintenance or replacement purposes.

Figure 8 shows the three sections in outline when assembled together.

The speed reducing gearing 6 is a two-stage epicyclic gearing giving a reduction of 10.55:1 and is shown in detail in Figure 2, in section, in a plane containing its longitudinal axis. It is shown in Figure 2 in its position when the turbine unit is in operation in a vertical borehole and is designed as a self-contained unit which can be easily placed in or taken out of the housing 7 of the turbine unit for maintenance and replacement purposes. The gearing 6 is provided with a case 15 having eight axial ribs 42 and 43 spaced around its external surface (only some of which are visible in Figure 2) and a nose cover 40. The ribs 42 and 43 are provided with feet 44 and 45 and are designed to fit in keyways (see the description of Figures 7 and 8) broached in the housing 7 of the turbine unit. The case 15 is supported against radial movement in the housing 7 only towards its ends by means of the feet 44 and 45, so that it is not subjected to any bending moments which may be applied to the drill bit due to eccentric loads. As far as torque is concerned, however, the case 15 is supported along the entire length of the ribs 42 and 43.

In the nose cover 40 there are some openings 41 for the passage of drilling mud into the interior of the cover 40 to a space surrounding the exterior of a pressure-balancing bellows 46 of a suitable plastic material such as polytetrafluoroethylene which, as described below, is provided substantially to equalise the fluid pressures inside and outside the gear cavity and thus to minimise the penetration of drilling fluid into the lubricant in the cavity. An air bleed valve 47 is mounted in the upper end of the bellows 46 to permit the expulsion of air when filling the gear cavity with lubricant. The foot of the bellows 46 is secured by clamping it between the bellows flange plate 48 and the bellows flange 50, the former being secured to the latter by twelve bolts 49 of which only one is shown in Figure 2. The bellows flange 50 is held in the case 15 by four bellows flange pins 51 of which again only one is shown in Figure 2. An O-ring seal 52 is mounted in a groove in the periphery of the flange 50 to prevent the passage of fluid between the inner surface of the case 15 and the outer surface of the flange 50, compression of the bellows 46 by the drilling fluid raising the pressure of the lubricant within the cavity so that the pressure drop across the seal is negligible. A lubricating port in the bellows flange 50, normally closed by the plug 53, is provided to enable the gear cavity to be filled or topped up with lubricant. The plug 53 is provided with an O-ring seal 54.

A shaft 55, which is the driving shaft of the first stage of the speed-reducing gearing 6, has a sun wheel 13 and a gear retaining ring 56 secured to its upper end. The sun-wheel 13 meshes with three planet pinions 14 only one of which is shown in Figure 2 and which are rotatably mounted on pinion pins 57, pinion bearings 58, preferably of tungsten carbide, being provided between the pins 57 and the pinions 14. The pinion pins 57 are fixed to a planet pinion cage 59 which is itself keyed to the case 15. Pinion pin retaining rings 60, which snap into position in grooves in the pinion cage 59, prevent axial movement of the pinion pins 57. A ring gear 16 meshes with and is driven by the planet pinions 14, and is integral with a cylindrical member 61 which is in effect both the driven shaft of the first stage and the driving shaft of the second stage and is mounted coaxially around the

shaft 55, bushings 62 and 63 being provided to prevent galling in the event of contact with the shaft 55 due to gear wear. The sun wheel 17 of the second stage is mounted on the lower end of the member 61 and meshes with four planet pinions 39 of which only two are visible in Figure 2. The planet pinions 39 are carried in the cage 19 by planet pinion pins 64, pinion bearings 65, again preferably of tungsten carbide, and retaining rings 66 being provided as in the first stage. The planet pinions 39 mesh with the stationary ring gear 18, which is keyed to the case 15. The pinion cage 19 is rotatably supported in the case 15 by upper and lower cage bearings 67 and 68, whilst the shaft 55 is rotatably supported in the cage 19 by a sleeve bearing 69.

The upper cage bearing 67 is mounted in the bearing support spacer ring 70, which itself is keyed to the case 15, a set screw 71 being screwed into the spacer ring 70 to position the bearing 67. The spacer ring 70 is held between the upper ends of the keyways in the case 15 and the upper end of the ring gear 18, whilst a further spacer ring 72 is interposed between the gear 18 and the lower cage bearing 68, which is held in position against a shoulder on the case 15. Lubricating ports, normally closed by plugs 73 and passing through the cage 19 at points spaced between the pinion pins 64, are provided for use in supplying lubricant to the gear cavity. The plugs 73 are provided with O-ring seals 74.

The pinion cage 19 is provided with a cylindrical extension 75 serving as the driven shaft of the speed-reducing gearing 6. A sealing assembly, consisting of a magnetic seal wear ring 76, an O-ring seal 77 and a magnetic seal member 78, itself equipped with an O-ring seal 78a and a set screw 78b, is provided to prevent the penetration of drilling fluid between the cage 19 and the driving shaft 55 into the gear cavity. Similarly, a sealing assembly, consisting of a seal member 79, a seal wear ring 80, a retaining ring 81 which snaps into position in a groove in the extension 75, and an O-ring seal 82, is provided between the extension 75 and the case 15. The seal member 79 is fixed in position in the seal retaining block 83, which is itself secured in position in the case 15 by means of set screws 84, its upper end pressing against and locating the lower cage bearing 68. An O-ring seal 85 is mounted in a groove in the outer surface of the block 83 to act as a seal between that surface and the inner surface of the case 15.

Neither of these sealing assemblies which are provided to prevent drilling fluid from entering the gear cavity at the lower end has to withstand a pressure drop equal to the full hydrostatic pressure of the drilling fluid, as the pressure balancing bellows 46 is subjected externally to the pressure of the drilling fluid before it passes through the axial passages along the outside of the case 15 and consequently maintains in the lubricant inside the cavity a pressure which is in fact higher than that of the drilling fluid on the exterior of these sealing assemblies, owing to the slight pressure drop in the fluid in passing through the passages round the case 15. For this reason, there would tend to be, if anything, a leakage of lubricant out of the cavity through the seals, rather than a penetration of drilling fluid into the cavity.

Both the driving shaft 55 and the extension 75 of the pinion cage 19 are provided with spline fittings 86 and 87 respectively for coupling the rotor shaft 4 and the bit shaft 5 (see Figure 2) to the driving and to the driven shafts 55 and 75 respectively of the speed reducing gearing 6, in such a way that they can be easily uncoupled by a simple axial movement. By crowning the splines on the rotor shaft 4 and the bit shaft 5, that is by providing a slight longitudinal curvature on their outer edges a small amount of axial misalignment can be tolerated, so that bending moments due for example to eccentric bit loads are not transferred from the rotor shaft 4 or the bit shaft 5 to the speed-reducing gearing 6.

The cartridge-shaped turbine 1, consisting mainly of

the rotor 2 and the stator 3, is shown in detail in Figure 3, which like Figure 2 is a section in a plane containing the longitudinal axis and to the same scale as Figure 2. To shorten the length of Figure 3, however, a break has been made in the support ring 108, its overall length when complete being such that, as shown in Figure 8, the screw thread 128 can receive the screw thread 29 shown in Figure 7B. Seven rotor blade rings 100 are keyed to the rotor shaft 4 by means of two longitudinal keys 101 of which only one is visible in Figure 3. Axial movement of the rotor blade rings 100 is prevented by the retaining nut 102, which is provided with a set screw 103 and holds the rings 100 against a shoulder on the rotor shaft 4 at their upper end. The rotor blades are mounted on the rings 100 in a conventional manner. Details of the blade shape, etc., are given below.

Axial thrust on the rotor shaft 4 is transmitted to the bit shaft 5 through a rotor thrust bearing 20 which is preferably of the Kingsbury type and is located at the lower end of the rotor shaft 4. It is mounted on webs 109 secured to the support ring 108, which in its turn is screwed to the bit shaft 5 by means of the thread 128 at its lower end (see also Figure 8). In the bearing 20, a bearing block 104 is keyed to the rotor shaft 4 by means of a key 105. The lower surface of the block 104 engages the bearing pads 106 (of which only one is visible in Figure 3) which are supported by the bearing case 107, which is carried by the webs 109 fixing it to the support ring 108. The lower end of the bearing case 107 is closed by a bearing cap 111 which is screwed into position. A sealing assembly is provided in the space between the bearing block 104 and the bearing case 107 to prevent the flow of drilling fluid into the bearing cavity 110, the assembly consisting of a wear ring 112, an O-ring seal 113, a Teflon wedge ring 115, a carbon ring 114 and a number of springs 116a set in a seal member 116, held by a set screw 116b. A retaining ring 117, which is snap fitted, secures the wear ring 112 in position against the pressure of the springs 116a. The cavity 110 is closed at its lower end by a bellows 118 which is secured to the bearing case 107 by means of a bellows block 119, which carries an O-ring seal 120 to prevent drilling fluid from entering the cavity 110 around the block 119. The bellows 118 serves as a pressure-balancing device to render the fluid pressure within the cavity 110 substantially equal to that of the drilling fluid circulating without, which has access to the exterior of the bellows 118 through the axial channel 111a in the cap 111. The cavity 110 can be filled or replenished with lubricant through the channel 121, which is normally closed by a plug 122 provided with an O-ring seal 123. A radial bearing 124 supports the rotor shaft 4 radially in the bearing case 107.

The upper end of the rotor shaft 4 is provided with splines 125 for coupling the rotor shaft 4 to the driving shaft 55 of the speed reducing gear, the splines 125 being preferably crowned as previously mentioned.

The stator 3 consists of eight stator blade rings 126, carrying the stator blades. A perspective view, partly cut-away, of the assembled stator blade rings 126 is shown in Figure 4 (for clarity the stator blades are omitted from Figure 4). The rings 126 are stepped on their outer surfaces at one end and on their inner surfaces at the other end, so that they can be fitted together in the manner indicated in Figure 4. The stator rings 126 are provided with two diametrically opposed keyways 130, into which two gib-head keys 127 are sprung to clamp the rings together. These keys 127 project outwards from the outer surfaces of the rings 126 and serve also to key the stator to the bit shaft 5 as will be described (see Figure 2). At the right hand end in Figure 4 (which corresponds to the lower end in Figure 3), the keys 127 extend slightly beyond the end ring 126 and are provided with notches 127a for facilitating removal of the keys 127 when re-

quired. Referring again to Figure 3, it will be seen that the lower ends of the keys 127 are in contact with the spacer ring 129, the lower end of which is in contact with the support ring 108. The screw thread 128 on the support ring 108 screws into a co-operating thread on the bit shaft 5 and is held in position by a retaining ring which snaps into position. It clamps the stator rings 126, the spacer ring 129 and the support ring 108 against an internal shoulder on the bit shaft 5 (see Figure 2). When the present turbine is partially disassembled, as shown in Figure 3, the stator 3 is not fixedly positioned axially with respect to the rotor 2, and if it is desired to treat the turbine 1 as a separate unit before and during assembly, it may be convenient to set the stator 3 in position by pouring molten wax into the blade spaces and allowing it to solidify. This wax can readily be removed when required in any suitable manner, as by steaming. To prevent damage to the stator blades of the first stage in assembly or transit etc. they are provided with a shroud 132.

The turbine 1 has seven stages of "super-reaction" blading. Each rotor blade ring 100 has thirty-two blades mounted on it, while each stator blade ring 126 has thirty-one blades. Figures 5 and 6 show respectively magnified profiles of a rotor blade and a stator blade, the axial component of the flow of the drilling fluid being indicated by the arrow 131 in each case. Further particulars of the blading of a typical unit are as follows:

Axial blade width	inches	0.5
Axial clearance between blade rows	do	0.1
Annular area	sq. inches	4.0
Width of annulus	inches	0.515
Blade height	do	0.495
Mean blade diameter	do	2.475
Mean pitch of rotor blades	do	0.243
Mean pitch of stator blades	do	0.251
Speed of the rotor 4 relative to the housing 7 at design operating speed	r.p.m.	5,275
Speed of the rotor 4 relative to the bit shaft 5 at design operating speed	r.p.m.	5,775
Mean Blade speed at design operating speed ft./sec.		62.6
Whirl velocity of fluid emerging from the stator at design operating speed	ft./sec.	50.1
Axial velocity of fluid, when flow is 600 g.p.m. ft./sec		48.2

It will be seen from the above figures that, under the design operating conditions, the whirl velocity of the fluid emerging from each ring of blades of the stator is less than the mean rotational velocity of the rotor, and that therefore the blading falls within the definition or super-reaction blading. The dimensions have been calculated to give satisfactory performance under varying operating conditions, but it will be appreciated that the dimensions will be subject to variations under differing design conditions or may indeed be varied with the same design conditions. While the so-called "super-reaction" blading is preferred, it is not essential, and a turbine having 6 or 7 stages of ordinary reaction blading could be used instead of the turbine described above. The super-reaction turbine, however, has a more suitable torque/speed characteristic, which renders the "control" problem, when drilling through formations of varying hardness, less severe.

Figure 7 shows a section of the bearing unit 23 (see also Figures 1 and 8) in a plane containing its longitudinal axis. It is in two parts, Figure 7A and Figure 7B, which are collectively referred to as Figure 7, the bottom of Figure 7A joining the top of Figure 7B to form the whole. Figure 7 is to the same scale as Figures 2 and 3, the part omitted at the break in Figure 7A being of a length such that the overall length of this particular complete turbine unit from shoulder to shoulder is 47 inches.

The assemblage 23 consists of two main parts, namely the bit shaft 5 and the housing 7. The upper end (the

unit 23 is shown in its position in a turbine unit operating in a vertical borehole) of the housing 7 is provided with a screw thread 150 for joining it in conventional manner to the lower end of drill string, a drill collar or a ram device, for example, as the case may be. The lower end of the bit shaft 5 is provided with a screw thread 151, for joining the bit shaft 5 to a tool joint 152.

The assemblage 23 also includes axial thrust bearings 21 and 22 and a radial bearing 153 of conventional construction which are located in the space between the housing 7 and the bit shaft 5. The bearings 21, 22 and 153 are held in an axial direction by means of a retaining nut 157, which screws into a thread provided on the internal surface of the housing 7.

Sealing assemblies 155 and 156 of the same construction as used for the sealing of the cavity of the axial thrust bearing 20 for the rotor shaft 4, are used for preventing drilling mud from entering the bearing cavity 154 containing the bearings 21, 22 and 153.

Above the sealing assembly 155, a further cavity 158 is formed between the streamline block 159, the housing 7 and the bit shaft 5. The streamline block 159, the upper curved surface of which forms part of the surface of the channels for the drilling fluid (as indicated in Figure 1), is secured to the housing 7 by set screws 171, a narrow radial clearance being left between the inner surface of the block 159 and the surface of the bit shaft 5 to permit drilling fluid to flow in operation into the cavity 158. The latter contains a pressure balancing device for the bearing cavity 154, in the form of two annular bellows 160 and 161, joined at their upper end by a sealing plate 162 and mounted on a block 163. The device is submitted externally to the hydrostatic pressure of the drilling fluid before it flows through the turbine 1, and serves to raise the pressure of lubricant within the bearing cavity 154 to a substantially equal value, thus minimising leakage of fluid through the sealing assemblies 155 and 156. There will however be a pressure differential across the sealing assembly 156 equal to the pressure drop in the turbine 1.

An O-ring seal 164 is located in a groove on the outer surface of the block 163 to act as a seal between the surfaces of the block 163 and the housing 7 and another O-ring seal 165 is located between the support block 163 and a seal wear ring 166. The block 163 is held against shoulders on the housing 7 and is spaced from the streamline block 159 by the spacer ring 188. Lubricant may be supplied to the cavity 154 when required through the lubricant port 167, normally closed by the plug 168, which is provided with an O-ring seal 169 and is fixed in the port 167 by means of a snap retaining ring 170.

A further sealing assembly consisting of an inner seal block 172, a packing filler 173, a chevron packing 174, a packing filler 175, a seal housing 176 and an outer seal block 177 are located below the sealing assembly 156 to seal the gap between the lower end of the housing 7 and the bit shaft 5. Ports 184 in the bit shaft 5 and corresponding ports 184a (see Figure 3) in the support ring 108 of the turbine 1, permit drilling fluid from the turbine exhaust space to enter the cavity 183 outside the sealing assembly 156. The pressure drop across the assembly 156 is then equal only to the pressure drop across the turbine 1, whilst the pressure drop across the said further sealing assembly is equal to the pressure drop from the turbine exhaust space to the borehole outside the housing 7. The housing 176 for the further sealing assembly is fixed in an axial direction by means of a snap retaining ring 178. An O-ring seal 179, located in a groove in the seal housing 176, is provided to act as a seal between the surfaces of the housings 176 and 7. The outer seal block 177, while always being retained loosely by the snap ring 178, is secured in operation to the tool joint 152 by means of a set screw 180, which is prevented from loosening by the snap ring 181. Another O-ring seal 182 is located in a groove in the tool joint 152.

The bearing unit 23 also incorporates various features concerned with the assembly of the turbine unit and its operation. These include splines 185 at the upper end of the bit shaft 5 for fitting into the corresponding keyways 185a on the extension 75 (see Figure 2), i.e. the driven shaft, of the gearing 6 (see also Figure 8). As with the splines 125 (Figure 3) on the rotor shaft 4, the edges of the splines 185 are crowned, i.e. given a slight longitudinal curvature, to permit axial misalignment under eccentric loads. In addition there are provided channels 190 through the upper end of the bit shaft 5, permitting the flow of drilling fluid from the space around the casing 15 of the gearing 6 to the inlet of the turbine 1 (see Figure 8). An internal screw thread 29 at the lower end of the bit shaft 5 is for receiving the screw thread 128 on the turbine 1, a groove 192 being provided also to receive a snap retaining ring, whilst a screen 186 held in position at the lower end of the tool joint 152 by a snap retaining ring 187 is provided to prevent coarse solid matter from reaching the turbine in the event of back flow. Keyways 191 on the inner surface of the housing 7 are provided to receive the ribs 42 and 43 on the casing 15 of the gearing 6.

Referring to Figure 8, which shows a longitudinal section of the complete turbine unit not to the same scale as Figures 2, 3 and 7, the assembly of the various constituent units may be seen. The gearing 6 is unitised and can be inserted in the housing 7 of the assemblage 23 from above, after removal of the tool joint 200 which is shown in Figure 8 screwed into the thread 150 at the upper end of the housing 7. On inserting the gearing 6 from above, the ribs 42 and 43 slide into the keyways 191 in the housing 7 until a support ring 201, which is a split ring that is snapped in position behind the feet 44 on the ribs 42, comes up against a shoulder 202 on the interior of the housing 7. Before screwing down the tool joint 200, a bevelled ring 203 is inserted which finally clamps the gearing 6 in position. When the gearing 6 is properly home the splines 185 on the bit shaft will engage with the spline fitting 87 (see Figure 2) on the extension 75 (see Figure 2) of the pinion cage 19, the orientation of the bit shaft 5 being adjusted from the lower end to obtain the initial engagement.

The turbine 1, with the stator 3 and the rotor 2 held relative to one another by solidified wax, is inserted in the bit shaft 5 from the bottom end, the tool joint 152 being first removed. The gib-head keys 127 on the stator 3 slide into the keys 189 in the bit shaft 5 and eventually the splines 125 at the upper end of the rotor shaft have to be engaged with the spline fitting 86 on the shaft 55 of the gearing 6, the turbine 1 being rotated gently relative to the housing 7 to obtain the initial engagement. The turbine 1 is finally secured by screwing up the threads 128 and 29 and inserting a snap retaining ring in the groove 192. Finally (see also Figure 7) the tool joint 152 is screwed on, the O-ring seal 182 being inserted first, and the seal block 177 is secured in position by screwing down the set screw 180 and fastening it in position with the snap ring 181.

From Figure 8 it can be seen that on emerging from the channels between the housing 7 and the case 15, the drilling fluid passes between the curved end surface 204 of the seal retaining block 83 (Figure 2) of the gearing 6 and the surface 205 opposite it on the upper end of the streamline block 159 (Figure 7) of the bearing unit 23, and finally through the channels 190 in the bit shaft to the turbine inlet.

In order to provide sufficient cooling of the speed-reducing transmission of a turbine unit according to the present invention, a heat exchanger may be incorporated in which the heat generated in the speed reducing transmission is transmitted to the fluid which flows through the turbine. Thus, in the turbine unit described with reference to Figures 1 to 8, a heat exchanger may be incorporated through which the gearing lubricant is cir-

culated and cooled by thermal contact with the drilling fluid.

An example of the layout of an assembly incorporating the gearing and a heat exchanger is shown in a longitudinal section in Figure 9. The gearing is substantially the same as that shown in Figures 1 and 2 and the same reference numerals are therefore used for the corresponding parts in Figure 9.

Referring now to Figure 9, it will be seen that the heat exchanger 210 consists of a cylindrical outer shell 211 and a coaxial cylindrical inner shell 212 within which is a central channel 216. A helically-wound metal strip 213 is secured in the space between the shells 211 and 212 in such a way that a helical channel 219 is formed. The outer shell 211 is slide fitted in an axial hole in the upper end 214 of the casing 15 of the gearing 6 and is thus able to move axially with respect to the casing 15. An extensible bellows 215 is secured across the gap between the lower end of the shell 211 and the casing 15. This bellows 215 acts to confine lubricant issuing in operation from the upper end of the channels 218 to flow into the channel 219 in the heat exchanger 210, whilst at the same time the outer shell 211 and the bellows 215 act together as a pressure balancing device, substantially to equalise the pressure of the lubricant within the heat exchanger 210 and the casing 15 with that of the drilling fluid in the channel 10 and thus to reduce the possibility of the drilling fluid penetrating the various seals. The channels 218 connect with the lubricant filled cavities within the casing 15, whilst the lower end of the central channel 216 is joined to those same cavities by channels 217.

When the turbine unit is in operation, the lubricant is circulated through the heat exchanger 210 by the pumping action of the gears. At each point where gears are in mesh, lubricant is drawn into the separating teeth and forced out from between the closing teeth; thus, for example, with a sun wheel, four planet pinions and a ring gear, there are eight possible points of suction and eight possible points of pressure. There are many ways of ducting the pumped fluid according to the volume of circulation desired. In the construction shown in Figure 9 it is assumed that the necessary circulation can be provided by the second stage only of the gearing 6, the lubricant being drawn from the heat exchanger 210 through the channels 217 and returned to the heat exchanger 210 through the channels 218. The pressure points due to the meshing of the sun wheel 17 and the planet pinions and those due to the meshing of the planet pinions and the ring gear 18 may be placed in parallel by connecting ducts in the cage 19 (not shown). In a similar manner the suction points can be connected in parallel. If the circulation thus provided is excessive, then it may be desirable to short-circuit part of it, for example, by providing ducts in the cage 19 to connect the pressure points round the sun wheel 17 to the suction points round the ring gear 18. It may further be desirable to arrange for some of the lubricant pumped to pass along grooves in the planet bearing pins, so as to ensure continuous exchange of oil in the bearings. If necessary, the first stage pinions may be used as pumps in a similar manner. As shown in Figure 9, the lubricant flows through the channels 218 into the helical channel 219 and thus comes into contact with the inner surface of the outer shell 211. The drilling fluid flowing through the channel 10 to the turbine 1 passes over the outer surface of the shell 211 and is normally at a lower temperature than the lubricant in the channel 219 so that the latter loses heat to the drilling fluid. After being cooled in the heat exchanger 210, the lubricant passes back to the gearing 6 through the central channel 216 and the channels 217. By this circulation of the lubricant, the heat generated in the gearing 6 is transferred to the drilling fluid and excessive heating of the gearing 6 is thus prevented.

It will be appreciated that many changes may be made in the details of the design of turbine units according to the present invention.

It will also be appreciated that the various dimension and operating conditions of the turbine unit described are given by way of example only and may be varied as required to suit the needs of individual cases.

I claim as my invention:

1. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried within said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway therethrough, connector means at the extending end of said stator for connecting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, and flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine.

2. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway therethrough, connector means at the extending end of said stator for connecting a drill bit thereto, said bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, said gear means forming a gear train such that the speed of rotation of the stator is less than that of the rotor relative to the stator when the turbine is in operation, and flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine.

3. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway therethrough, con-

necting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, super-reaction turbine blading carried by said rotor and said stator, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, and flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine.

4. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway therethrough, connector means at the extending end of said stator for connecting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, from four to eight stages of super-reaction turbine blading carried by said rotor and said stator, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, and flow passage means into the top of said stator for circulating fluid through said turbine.

5. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway therethrough, connector means at the extending end of said stator for connecting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, reaction turbine blading carried by said rotor and said stator, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, and flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine.

6. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill

string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway there-through, connector means at the extending end of said stator for connecting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, from four to eight stages of reaction turbine blading carried by said rotor and said stator, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, and flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine.

7. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway there-through, connector means at the extending end of said stator for connecting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, epicyclic-gear speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, and flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine.

8. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first thrust bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway there-through, connector means at the extending end of said stator for connecting a drill bit thereto, second thrust bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, a two-stage epicyclic-gear speed-reducing transmission carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, and flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine.

9. The apparatus according to claim 8 wherein the two-stage epicyclic-gear speed-reducing transmission

couples together the rotor and the stator at the upper ends thereof, each of said stages of said transmission having a sun gear, a ring gear and a planet pinion cage enclosed in a common casing, said rotor being coupled to the sun gear of the first stage of the transmission, said stator being coupled to the planet pinion cage of the second stage of the transmission, the planet pinion cage of the first stage and the ring gear of the second stage being secured to the transmission casing, and the ring gear of the first stage being coupled to the sun gear of the second stage and thrust bearing means carried within said housing around said stator for rotatably mounting said stator.

10. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway there-through, connector means at the extending end of said stator for connecting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, a casing enclosing said transmission means adapted to be filled by a lubricant, flexible bellows means in the wall of said casing for substantially equalizing the fluid pressures inside and outside of said casing, and flow passage means into the top of said housing around the transmission means casing positioned therein and through said stator for circulating fluid through said turbine.

11. A hydraulic turbine unit adapted to be secured to the lower end of a drill string for rotating a drill bit during well drilling operations, said turbine unit being actuated by a mud flush pumped down said drill string and through said turbine unit, said turbine unit comprising an outer housing, connector means at the top of said housing for fixedly securing said housing to a drill string, first bearing means fixedly carried near the lower end of said housing, a multi-stage stator rotatably mounted within said housing on said first bearing means with the lower end of said stator extending from said housing to form the power takeoff element of said turbine, said stator having an axial flow passageway there-through, connector means at the extending end of said stator for connecting a drill bit thereto, second bearing means fixedly secured within said stator, a multi-stage rotor rotatably mounted coaxially within said rotatable stator on said second bearing means, speed-reducing transmission means carried within said outer housing and fixedly anchored thereto, said transmission means including gear means meshing together to couple the upper end of said rotor to the upper end of said stator to drive said stator, flow passage means into the top of said housing around the transmission means positioned therein and through said stator for circulating fluid through said turbine, said transmission means being filled by a lubricant, and heat exchange means carried by said transmission means, said heat exchange means being arranged so that heat generated within the transmission means is dissipated by the flow of mud flush through the turbine unit outside said transmission means.

12. The hydraulic turbine unit of claim 11 wherein the

gears of the transmission means are arranged to pump the lubricant through said heat exchange means.

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