United States Patent

[11] 3,583,502

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[54] **AXIAL FLOW TURBINE DRILL FOR EARTH BORING**
4 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** **175/107,** 175/215, 175/60
[51] **Int. Cl.** **E21b 308**
[50] **Field of Search** 175/60, 107, 215, 325

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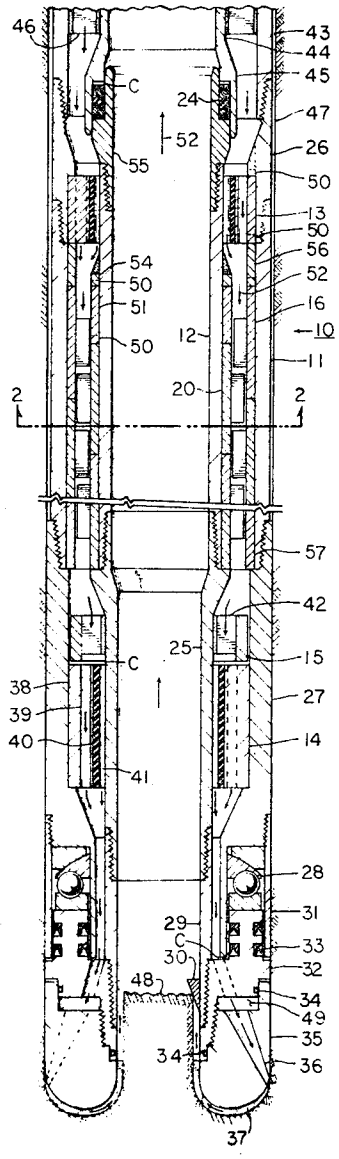
ABSTRACT: A downhole axial flow turbine to rotate the drilling bit in earth boring, the turbine actuated by drilling fluid flow.

The turbine operates in conjunction with dual-tube drill pipe. The drilling fluid flows downward in the annulus of the dual-tube drill pipe, through the annulus of the turbine, actuating the turbine, thence through the bit, thence ascending through the hollow spindle of the turbine, thence through the core tube of the dual-tube drill pipe to the earth's surface carrying bit cuttings and core segments therewith.

The turbine blades are smoothly curved to minimize fluid turbulence, and maximize power generation.

The drill pipe weight imposed on the bit is independent of the turbine spindle, being imposed by the drill pipe onto the turbine barrel, thence through a thrust bearing, to the bit.

The bit's shank, and/or structure above the bit, is preferably made full-hole size to form a barrier to prevent drilling fluid flowing upward in the borehole annulus.



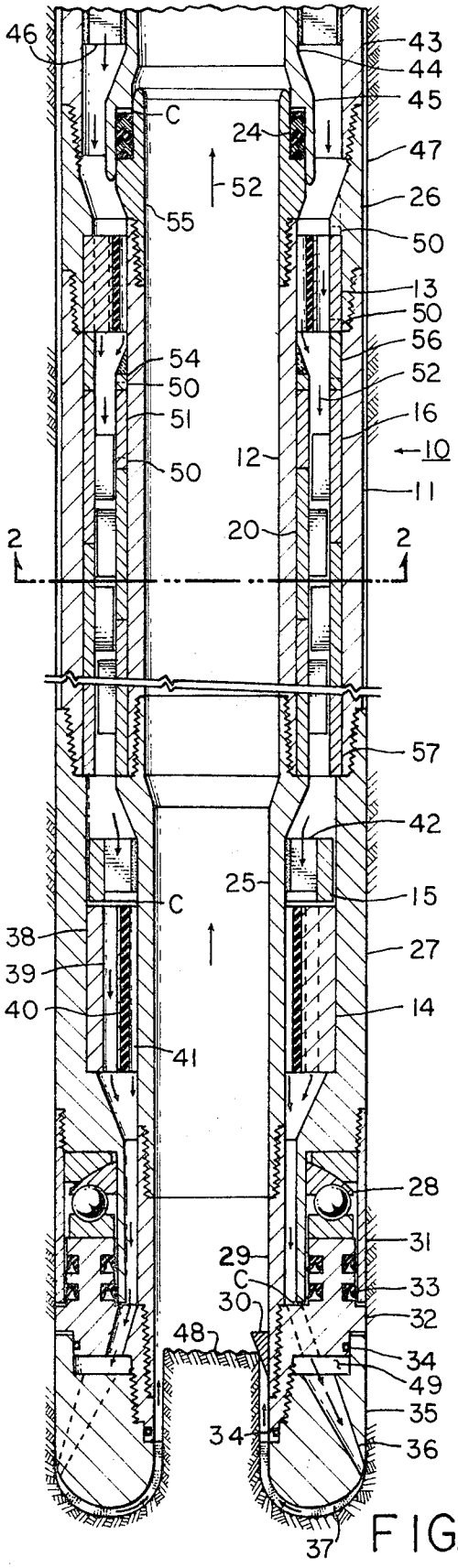


FIG. 1

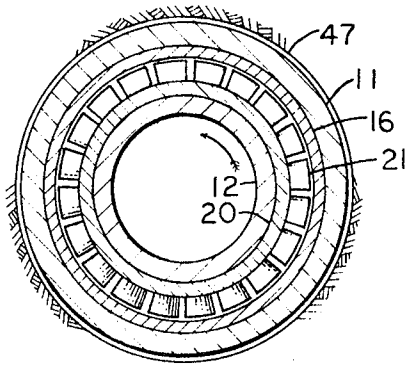


FIG. 2

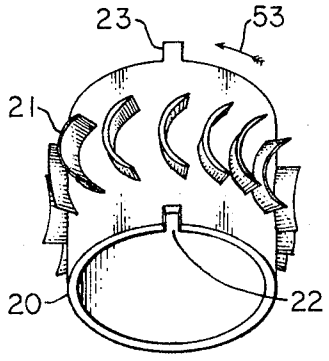


FIG. 3

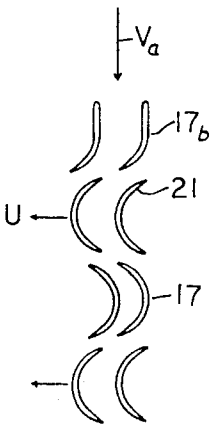


FIG. 5

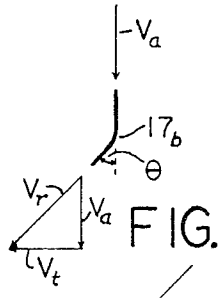


FIG. 6

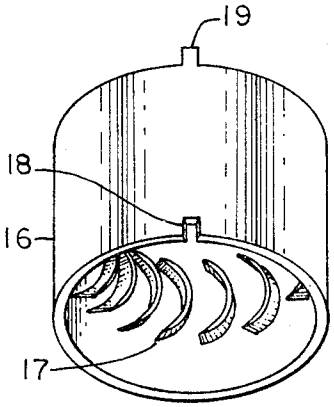


FIG. 4

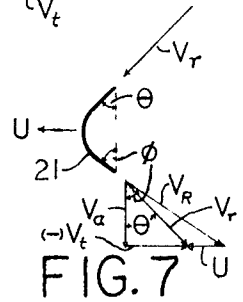


FIG. 7

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AXIAL FLOW TURBINE DRILL FOR EARTH BORING

Experimentation with axial flow turbine earth-boring drills began about one-half century ago, and they have been used quite extensively during the past one-fourth century. Still they have several deficiencies: 1) the hydraulic mud pressure is high, causing sealing problems; 2) they are not able to take cores; 3) the mud ascends in the borehole annulus, and the ascending velocity is high causing erosion of the hole walls; 4) the bottom hole pressure is high causing mud invasion of "pay" formations, as well as decreased drilling rates; 5) the high rotational speed causes early failure of roller bit bearings; 6) the high rotational speed, coupled with the necessity for a full-hole bit (i.e. no core) results in diamond bits experiencing "center burn out"; 7) it has not been practical to aerate the drilling mud to relieve high bottom hole pressure because it results in excessively high ascending velocity of the mud in the hole annulus which is destructive to hole walls; 8) Due to the large outside diameter of the turbine, and the need for ascending mud in the hole annulus, it has not been practical to drill small economical diameter holes; 9) the large amount of weight required for large diameter holes necessitates an excessively large load on the spindle thrust bearing, hence early failure; 10) the large hole diameter requires a high-power turbine, hence a large quantity of mud flow and high pressure.

One object of this invention is to provide an axial flow turbine drill that can take cores as well as drill full hole, and is adapted for small diameter holes.

Another object of this invention is to provide a turbine drill adapted for use with the relatively new dual-conduit drill pipe, wherein the mud descends in an annulus between two unitized concentric tubes and ascends in the bore of the inner tube, carrying cuttings and core segments therewith.

Another object of this invention is to provide a turbine drill in which there is a barrier in the hole annulus above the bit to restrict fluid flow from under the bit upwardly in the hole annulus. This barrier requires the drilling fluid to ascend in the central tube ("core tube") as desired.

Another object of this invention is to provide a turbine drill with no flow in the hole annulus, thereby making it feasible to use aerated mud to reduce bottom hole pressure, reduce "pay" invasion, and increase rate of penetration.

Still another object is to provide a turbine drill that is less expensive to build, and to maintain, because of integral cast rotor units, and stator units, that are quickly assembled and/or replaced.

A further object is to provide an efficient turbine blade system wherein the fluid flow is smoothly changed from stator, to rotor, to stator units and the tangential velocity change per rotor state is at least double the tangential velocity entering the rotor stage.

Another object of this invention is to provide a turbine drill wherein the drill pipe weight required for the bit is not imposed on the turbine spindle but is transmitted by the drill collars, to the nonrotating turbine barrel, thence to a low-friction thrust bearing and thence to the bit.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a vertical section of this invention showing the turbine on the lower end of a drill collar, within a borehole, and having a coring bit on its lower end.

FIG. 2 is a cross-sectional view taken on the cutting plane 2–2 of FIG. 1.

FIG. 3 is an isometric view of a turbine rotor unit.

FIG. 4 is an isometric view of a turbine stator unit.

FIG. 5 is a stretch-out of the turbine blades to show the relationship of stator to rotor blades, and the smooth fluid flow.

FIG. 6 is a diagrammatic sketch showing the mud velocity changes at the initial stator unit.

FIG. 7 is a diagrammatic sketch showing the mud velocity changes at a rotor unit.

Referring to FIG. 1, the turbine is designated generally as **10** and comprises an outer barrel **11** and a spindle **12**. The spindle

is mounted in two or more radial bearings **13** and **14**. The spindle at its upper end has a seal segment **55** having a seat for the fluid seal **24**. At the spindle's lower end is the spindle lower member **25**, to which is secured, as by welding, the spindle thrust bearing **15**. To the lower end of member **25** is threadedly secured the core breaker segment **29**, which segment carries the core breaker cam **30**.

The turbine barrel **11** is threadedly secured to the barrel's head member **26**, which said head member is threadedly secured to the lowermost length of the unitized dual-conduit drill collar (or drill pipe) **43**, having a core tube **44** and a unitizing welded web **46**. This assembly is shown in the bore hole **47**.

FIG. **3** shows a rotor turbine unit **20** having blades **21**. The internal diameter of the shell **20** is such as to slide freely over the spindle **12**. The upper end of this unit has a projection, or lug **23**, while the lower end of this unit has a slot **22**. The purpose of the lug and slot on the rotor units is to provide a locking system whereby the individual units are locked to adjacent units and to the spindle to prevent relative rotation, one to another. These units and the stator units may be precision cast of hard metal to minimize cost and fluid erosion. The tailed arrow **53** shows the direction of rotor rotation.

FIG. **4** shows a stator unit **16** having blades **17**. The external diameter of the shell **16** is such as to slide freely in the barrel **11**. It has a lug **19** at the upper end and a slot **18** at the lower end for the purpose of locking individual units to each other and to the barrel **11** to prevent relative rotation.

The number of turbine stages required will depend upon the horsepower required, the volume of fluid pumped, and the fluid velocity in the turbine annulus. A reasonable number for average drilling is 70 stages; which, at 2⅛ inches per stage is a turbine length slightly greater than 13 feet. This can be operated with radial bearings at each end, **13** and **14**, as shown. Longer units may require intermediate radial bearings. The rotor blades **21** and the stator blades **17** are of a radial width just slightly shorter than the annulus width between the rotor shell **20** and the stator shell **16**. The blades are ground to close tolerance and to smoothness. Relative lateral vibration between the spindle and the barrel may cause blade-to-shell contact but the friction will be low due to hard, smooth surfaces, and the ensuing damping will minimize vibration. The full-hole diameter of the lower assembly minimizes lateral vibration. The total length of the turbine can be made full-hole diameter, if desired.

To the spindle **12** is welded a positioning ring **54**, having a slot **50** to receive the lug **23**.

To assemble the device, the spindle **12** is positioned, preferably in a pipe cradle of special design, in a near horizontal position with the upper end slightly lower than the lower end. The bearing **13** is put in its proper place and the seal segment **55** is screwed in tightly. The rotor spacer ring **51**, which has a lug **23** and a slot **22**, is mated to the positioning ring **54**. The stator spacer ring **56** is slipped over the spindle and its lug **19** is mated to the slot **50** in the bearing **13**. This is followed by the initial stator unit **16***b* of FIG. **5**, thence the first rotor unit **20**, then a stator unit **16**, then a rotor unit **20**, and so on until all of the rotor units are in place. The upper rotor spacer ring **51** is of such a length as to assure that the bottom stator unit will terminate flush with the end of the spindle. The bottom stator spacer ring **57** is of such a length as to assure that it too terminates flush with the bottom of the barrel **11**. Now the spindle lower member **25**, with the bearing **15**, having webs **42**, and being securely welded in place, is firmly screwed into the spindle. This locks the rotor elements in place. Now the barrel head member **26** is slipped over the bearing **13** making certain that the slot **50** in the member mates with the slug **19** of the bearing **13**. The member **26** is then positioned in its longitudinal place and clamped to hold it properly positioned. The barrel **11** is now slid over the assembly with the upper end of the barrel starting over the lower end of the spindle. When it reaches the head member **26** it is screwed thereto. Whereupon the column member **27**, with the bearing **14** in place, is

screwed onto the lower end of the barrel 11. The rest of the assembly will be obvious.

It will be seen that the weight of the drill collars which is imposed on the bit is via the head 26, the barrel 11, the column member 27, the thrust bearing 28, the thrust-sealing member 32, thence to the bit. This frees the spindle from carrying any of this load, a distinct advantage. When the bit is on hole bottom there is no weight on the spindle thrust bearing 15. The spindle is free to move longitudinally relative to the barrel, within limits, the limits being the clearance *c*. When the bit is above bottom, hanging free in the borehole, then the spindle is forced downward by its own weight, plus the differential fluid pressure in the turbine and the spindle moves downward relative to the barrel until the low-friction member of the bearing 15 bears against the steel body 38 of the bearing 14.

The tailless arrows 52 indicate the direction of fluid movement in the device. The radial bearings 13 and 14 may be conventional rubber bearings with a metal body 38, having holes 39 to conduct fluid as well as flutes 41 to conduct fluid. The thrust-sealing member 32 has seals 33 to protect the bearing 28 from fluid invasion of its lubricating grease. This member 32 also has O-rings 34 to form static seals between itself and the bit 35. The annular space 49 is provided to feed fluid to the nozzles of the bit.

The bit 35 is driven by the turbine spindle 12 through the spindle drive tube assembly, comprising the tubular spindle lower member 25, the tubular core breaker section mounting the core breaker 30, the hollow thrust-sealing member 32, to which last member the bit is threadedly engaged.

Although the bit shown is a diamond core bit, it will be obvious that a roller-type bit or drag-type bit could be used as well. Also, that it isn't necessary to core, and that a full-hole bit could be used if desired.

FIG. 5 shows a diagrammatic stretch-out of the blade system of the rotor-stator assembly. The initial stator unit 16*b* is a modified version of the normal stator in that the first one-half of the blades 17*b* are parallel with the axis, while the later one-half of the blades are normal for these stators and smoothly curved to deflect the axial flow V_a to give the flow a considerable tangential component. The rotor blades 21 receive this flow, having a tangential component, and the rotor is urged in the direction of the tangential flow with a velocity U.

FIG. 6 is a schematic of the fluid velocities at the initial stator unit. The axial fluid flow, velocity V_a, meets the blade 17*b* and is smoothly deflected to discharge from the blade with an angle θ relative to the spindle axis. The vector diagram of the velocities relative to a fixed earth reference shows the axial velocity V_a, the tangential velocity V_t and the resultant velocity V_r.

FIG. 7 shows the vector diagram for a rotor unit. The blade 21 has an entrance angle θ relative to the axis, which is the same angle as the discharge from the preceding stator unit. The central curved portion of the blade is a sector of a circle, with a straight entrance segment having an angle θ tangent to the circle, and with a straight exit segment having an angle Φ being also tangent to the central circle. This configuration makes for a smooth flow with minimum turbulence. The velocity vector for the blade 21 is shown as U. FIG. 7 shows the vector diagram of the fluid velocities comprising the exit velocity from the blade. The velocity from the blade is V_R and is comprised of the axial velocity V_a the blade velocity U and the reversed direction tangential velocity $(-)V_t$.

The force exerted on the rotor blade is computed by the "impulse = momentum change" principle. Thus $Ft=\Delta(M+V_t)$ where *F* is force in pounds, *t* is time in seconds, *M* is the mass of fluid in slugs and V_t is the tangential velocity in f.p.s. If we let $t = 1$ sec., then the mass becomes the mass of fluid that flows in 1 second of time, and the *t*'s cancel. Assume that the angle θ is 45° and that the axial velocity V_a is maintained by the pump and is constant in the turbine annulus. In which case $V_t = V_a$ and the magnitude of the resultant velocity $V_r = 1.414 V_a$. The force generated on one rotor stage: $F=M(V_{t_1}-V_{t_2})$ where *M* is the fluid mass per second, V_{t_1} is the rotor entrance tangential velocity, and V_{t_2} is the rotor exit tangential velocity. It is desirable that $(V_{t_1}-V_{t_2})$ be as large as feasible with smooth fluid flow even to the point where V_{t_2} is negative and of the same magnitude as V_{t_1}. If we assume as is normal for loaded conditions that the rotor tangential velocity *U* is $\frac{1}{2} V_{t_1} = \frac{1}{2} Va$, then by the vector diagram of FIG. 7 it is apparent that, tangent

$$\phi=\frac{V_{t_2}+U}{V_a}=\frac{1+\frac{1}{2}}{1}=1.5$$

and $\Phi = 56°19'$ and

$$V_R=\frac{1.5}{\sin\phi}=\frac{1.5}{.832}=1.802(V_a).$$

If the exit angle of the rotor blade be made 56°19' then the force equation per stage becomes: $F=M[V_a(-)V_a]M(2V_a)$. The axial flow turbine units in use heretofore have employed flat blades in both the rotor and stator. In such a case the blades of rotor and stator are set substantially at right angle to each other and the fluid impact is abrupt, and is quite turbulent, spreading as a sheet in all directions and is wasteful of energy, in contrast to the smooth rhythmic flow to right and left of this invention.

Thus it is seen that the smoothly curved fluid path as shown in FIG. 5 is not only conducive to a minimum of turbulence, but it also permits the rotor force to be double the force derived by merely stopping the entering tangential velocity. The angle Φ can be made greater than 56°19' thereby increasing still more the force generated in the rotor, but turbulence is increased so that the gain is low. Also, it is to be noted that the rotor exit angle of FIG. 7 relative to a fixed reference is θ, or 45°,(the resultant of V_R and *U*) which is the entering angle of the next stator unit. It is desirable that all leaving and entering angles, stator to rotor and rotor to stator, have the same angle, this to minimize wasteful turbulence. This requires that it be designed around a known value for *U* when under working conditions.

It is obvious that if one wished to drill an oversize hole, that is, one larger in diameter than the column member 27, he could do so simply by using a bit of larger diameter. In which case the shank of the bit can be used as a hole annulus barrier to restrict fluid flow up the annulus. There may be cases wherein it is desirable to permit fluid flow up the hole annulus, in such cases the shank of the bit can be fluted to permit free passage of fluid.

The invention may be modified in various respects as will occur to those skilled in the art and the exclusive use of all modifications as come within the scope of the appended claims is contemplated.

I claim as my invention:

1. In an earth-boring drill comprising in combination: a dual-conduit drill pipe having an outer drill pipe and a concentric inner pipe secured therein, said outer drill pipe and said inner pipe forming a pipe annulus therebetween, said dual-conduit drill pipe made in composite lengths which are adapted to be joined end to end to form a long string of dual-conduit drill pipe;

a drilling bit having a hollow shank and fluid flow channels threadedly attached to the lower end of the dual-conduit drill pipe assembly, said bit adapted to bore into the earth when rotated under mechanical pressure to produce a borehole;

the wall of said borehole and said outer drill pipe forming a borehole annulus therebetween, when the said dual-conduit drill pipe is in the hole;

a drilling fluid under pressure introduced at the earth's surface into the said drill pipe annulus, thence flowing downwardly through said drill pipe annulus, thence through said flow channels in said bit, thence upwardly in said bit's hollow shank, thence upwardly in the said inner pipe to the earth's surface, carrying therewith any cuttings, or cores, formed by the said bit;

the improvements for rotating said bit and for applying weight on said bit, said improvements comprising:

an axial flow turbine motor inserted in the dual-conduit drill pipe string above said bit, said turbine motor motivated by the said fluid flow in the said drill pipe annulus, said turbine motor comprising an outer turbine stator barrel rigidly inserted in the said dual-conduit drill pipe string and forming a part thereof; and an inner, rotatable, hollow rotor spindle, serving as a continuation of the said concentric inner pipe; said rotor spindle positioned opposite the said stator barrel by flow-passing radial bearings, said turbine barrel and said turbine spindle forming a turbine annulus therebetween, which turbine annulus is a continuation of said drill pipe annulus, said flow-passing radial bearings being positioned in said turbine annulus and said drill pipe annulus; the upper end of said rotor spindle rotatably sealed to the next above said concentric inner pipe be rotation permitting seal means, the lower end of the said turbine rotor having a downward, tubular spindle extension that is threadedly connected to the inside top of said bit's hollow shank to transmit rotation to said bit by said turbine rotor, the said turbine rotor and said downward tubular spindle extension being free of any compression, and free to move longitudinally within narrow limits to maintain a compression free condition;

the required weight on the said drill bit impressed thereon by the weight of the dual-conduit drill pipe string, or portion thereof, the said required weight being transmitted downwardly through the said turbine barrel, thence downwardly through a downward tubular extension of said turbine barrel, thence through a low-friction thrust bearing, which bearing is mounted on the top of said bit sub and external of the said tubular extension, thence through the said bit sub to the said bit.

2. The earth-boring drill defined by claim 1, in which the said bit is a coring bit, including:

a core breaker positioned in the said tubular spindle extension just above the said core bit to engage the emerging core and to break it.

3. The earth-boring drill defined by claim 1, including:

the said drill bit having a shank whose diameter is substantially borehole diameter to effectively block fluid flow from the said bit upwardly in the said borehole annulus.

4. The earth-boring drill defined by claim 1, including:

a section of pipe in the said outer drill pipe string having a diameter substantially borehole diameter to block thereby fluid flow past it in the borehole annulus.