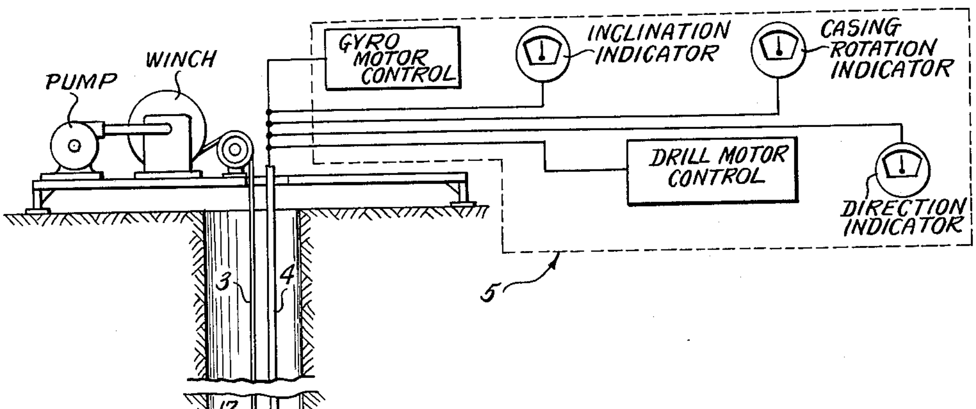
Dec. 21, 1965 F. G. WEEDEN, JR 3,224,513

APPARATUS FOR DOWNHOLE DRILLING

Filed Nov. 7, 1962 4 Sheets-Sheet 1



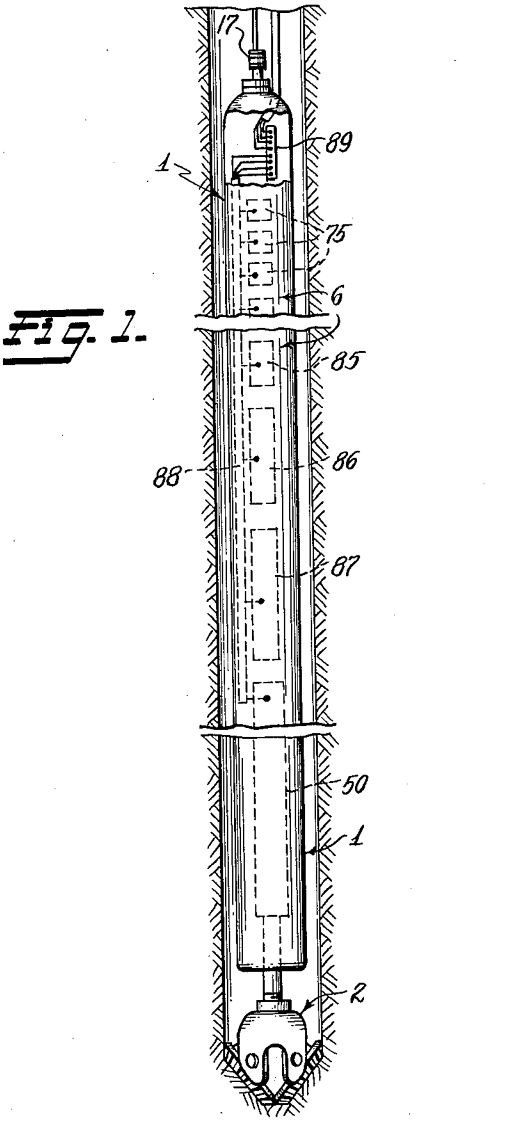


Fig. 1.

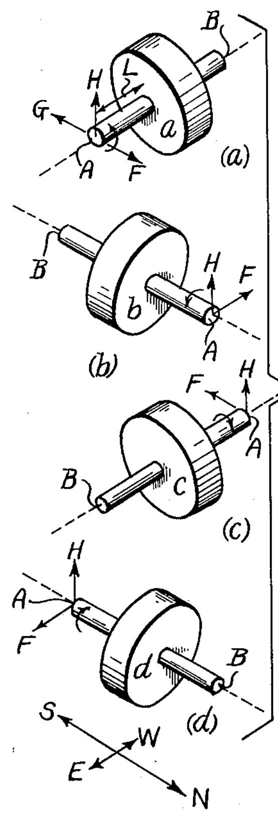


Fig. 8.

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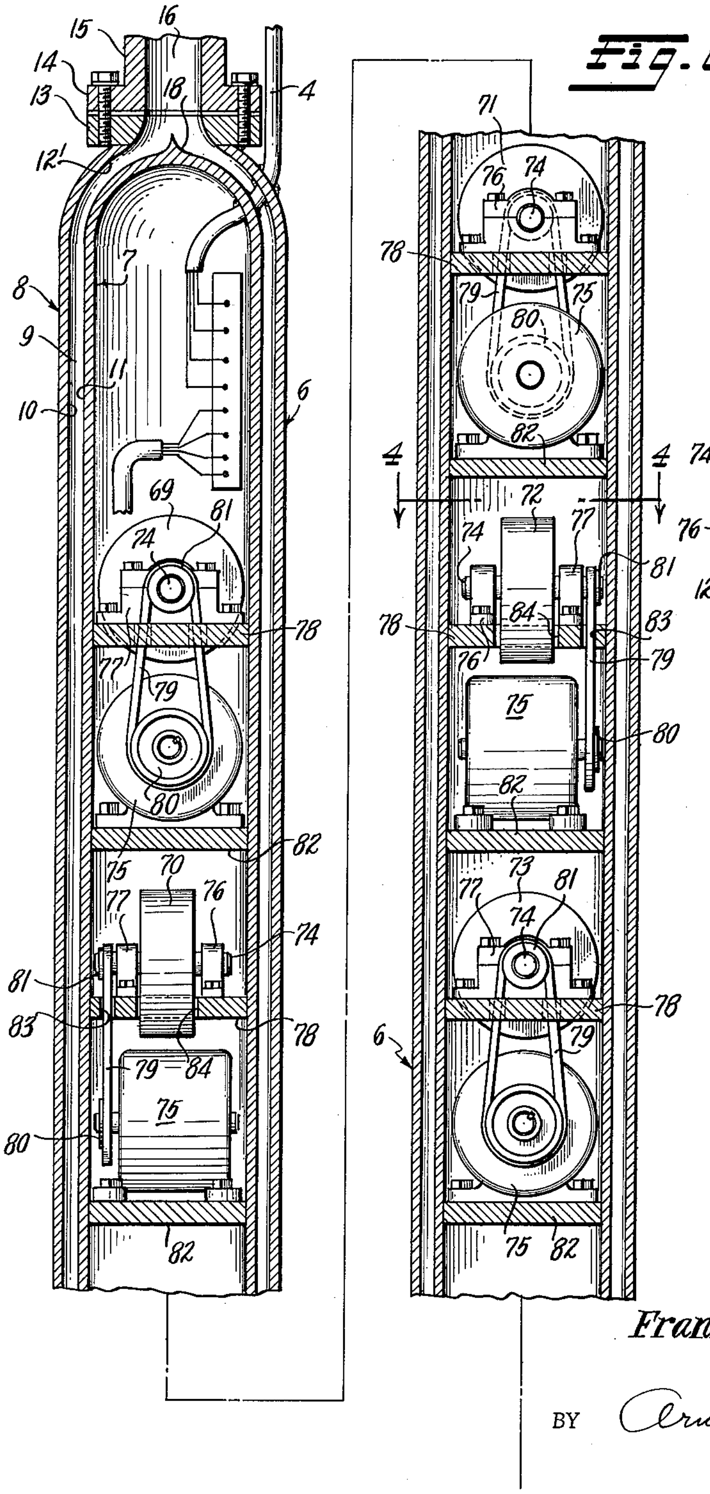
Fig. 2.



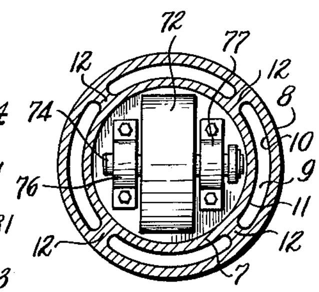


Fig. 4.

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Fig. 3.

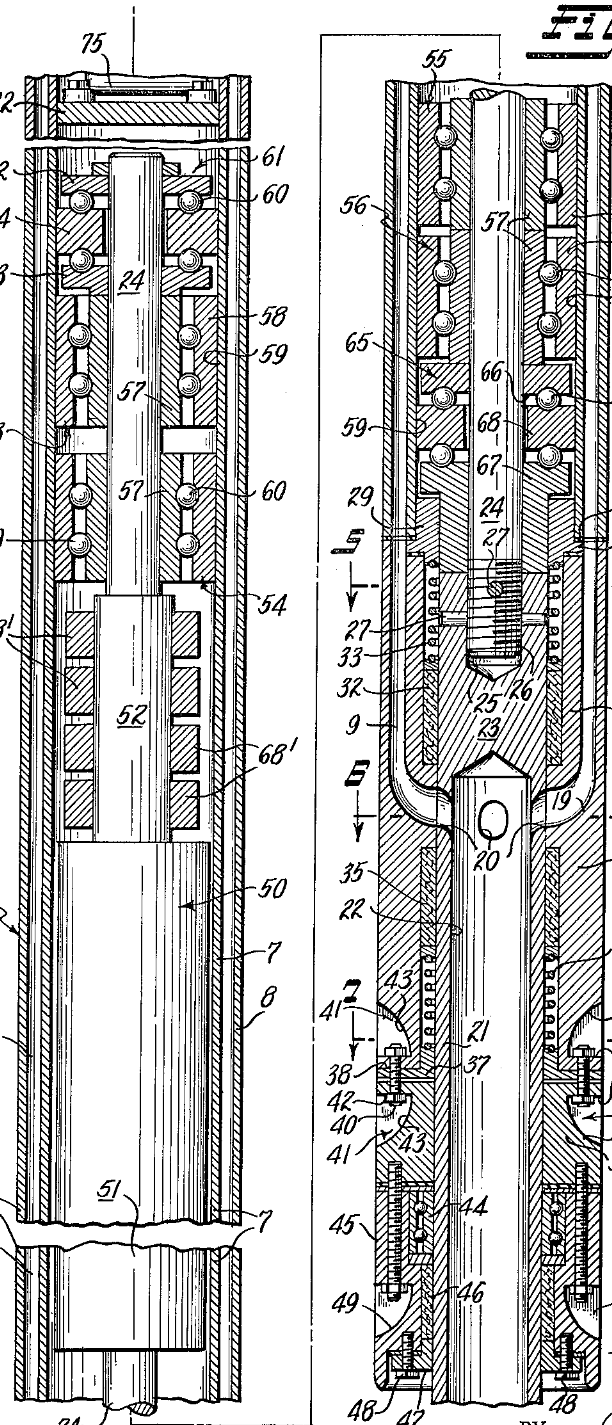


Fig. 5.

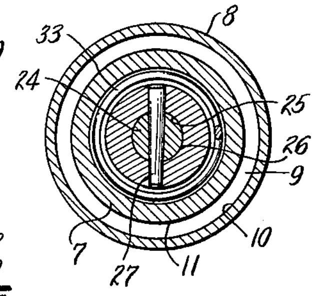


Fig. 8.

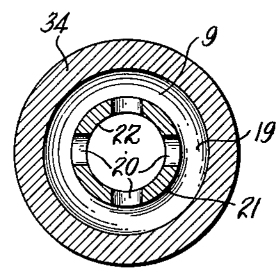
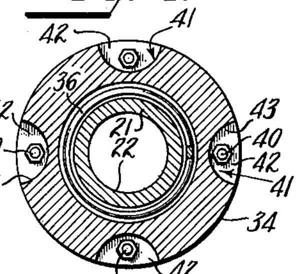


Fig. 7.



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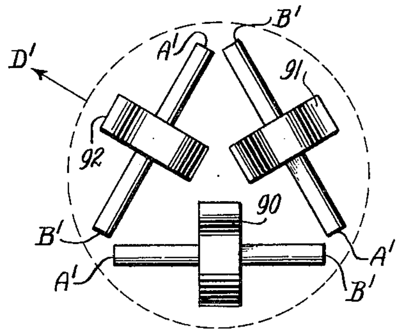

Fig. 10.

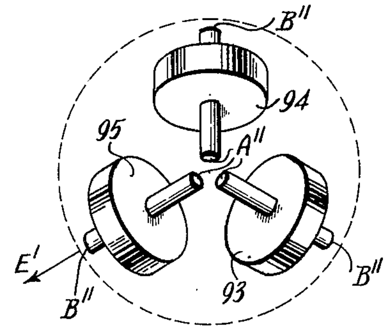

Fig. 12.

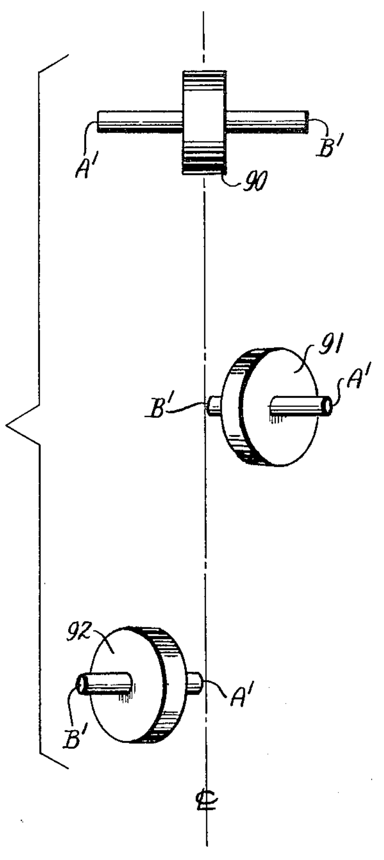

Fig. 9.

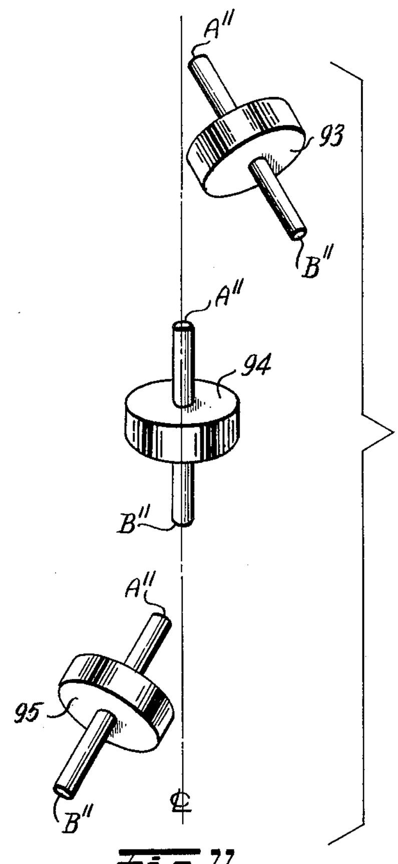

Fig. 11.

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3,224,513
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3,224,513
APPARATUS FOR DOWNHOLE DRILLING

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Filed Nov. 7, 1962, Ser. No. 236,016
12 Claims. (Cl. 175—26)

The present invention relates to an apparatus for downhole drilling and more particularly to such an apparatus in which the torques developed during the drilling operation are not transmitted to the string or line which supports the drilling tool, but are absorbed in accordance with the gyroscopic effect of inertial rotors associated with the drilling tool.

The common method for drilling a bore hole for producing an oil well is to attach a rotary cutting tool to the bottom of a drill string and rotate the string from the surface of the earth while reciprocating the string. This conventional system of drilling, of course, requires that, when the cutting tool wears out or is no longer serviceable, the drill string must be pulled to replace the cutting tool. Pulling the drill string is an expensive and time-consuming task, since the string is usually comprised of a plurality of pipe sections connected end-to-end, and in pulling the string it is necessary to disconnect and rack each section until the cutter is lifted to the surface where it can be replaced.

Another well known way to drill a bore hole is to use a drilling tool having a motor for rotating the cutting tool. The drilling tool is attached to the bottom of a rigid string which prevents the drilling tool from rotating when the cutting tool is driven by the motor. The torque resulting from drilling is prevented from rotating the drilling tool by the rigid string to which the tool is attached. The basic disadvantage of this system is the same as in the conventional rotating string system, since it is necessary to pull the entire string to replace the cutting tool.

In the present invention, the basic disadvantages of these former drilling systems are overcome by providing a drilling tool which can be suspended in a bore hole on a flexible line. The drilling tool support is substantially smooth and cylindrical to provide an unobstructed passage for the drilled particles to flow to the region above the drilling tool by the washing action of the drilling mud. The absence of projections on the sides of the drilling tool further assures that the particles due to drilling will be flushed upwardly through an unobstructed annular passage to a point in the bore hole above the drilling tool under the action of the drilling mud.

Other basic advantages of this invention are that the cutting tool can be completely withdrawn from the bore hole merely by hoisting the tool via the flexible cable or line by which it is suspended. Since the cable is flexible, the tool can be withdrawn by a winch or other surface equipment without the need for stopping periodically to disconnect the sections of drill string.

Hence it will be apparent that merely continuously winding the line onto a rotatable drum at the surface permits rapid withdrawal of the drilling tool, when it becomes necessary to replace the cutting tool. To resume drilling, it is then only necessary to reinsert the tool in the hole and rapidly lower the tool until the cutter reaches the bottom of the bore hole.

The present invention is especially suitable for increasing the depth of an existing well bore. Such further drilling is frequently done when the oil-producing formations adjacent the existing well bore have been exhausted. To drill further, it is merely necessary to lower the tool to the bottom of the well bore and commence drilling. Should the cutting tool become dull or otherwise unserviceable, the drilling tool can be quickly hoisted to the surface for repair or replacement of the cutting tool.

Where the cutting is done with the assistance of drilling mud, the flexible string which supports the drilling tool can be tubular, for example in the form of a flexible hose, to convey the drilling mud to the cutter bit under the necessary pressures.

A flexible line can be used with the drilling tool of the present invention since the gyroscopic effects resulting from the rotation of a plurality of inertial rotors are utilized to counteract the torques resulting from rotation of the cutting tool and the reaction of the cutting tool against the earth formations which are drilled. The gyroscopic effects established by the inertial rotors are sufficient to prevent or at least substantially minimize rotation of the drilling tool when the cutting tool is rotated.

In the preferred embodiment of this invention a plurality of inertial rotors are disposed in spaced relation along the axis of the drilling tool. Each rotor is driven by a different electric motor associated with the drilling tool, the motors being individually controllable from a control station at the top of the bore hole.

Ordinarily the present invention will be used to drill in a vertical direction, however, if desired, the tool can be controlled to drill in directions at an angle to the vertical. This controlled angle drilling is achieved by utilizing the gyroscopic phenomenon of "precession" which is the tendency of the end of the axle of a gyroscope to move at right angles to any force impressed on it. Since the drilling tool is restrained from moving laterally by the sides of the bore hole, the only forces acting on the drilling tool will be those forces which tend to rotate the tool itself. By properly positioning the inertial rotors and controlling the speeds of these rotors, the forces which tend to rotate the drilling tool are utilized to create "precessional" gyroscopic forces that cause the drilling tool to "keyhole," thereby changing the direction of drilling.

Accordingly an object of the present invention is to provide a drilling tool in which the torques resulting from drilling are entirely counteracted by forces established within the drilling tool.

Another object of the present invention is to provide a drilling tool in which rotary inertial members in the tool produce forces which counteract the torques resulting from rotating the cutter bit and from the reaction of the cutter bit against the earth formation.

Another object of the present invention is to provide a drilling tool of extremely narrow diameter which can be lowered into a bore hole and which has self-contained means for rotating the cutter bit as well as self-contained means for providing the necessary counteracting inertial forces to prevent rotation of the drill tool during the drilling operation.

Another object of the present invention is to provide a new and improved well drilling apparatus in which removal of the drilling tool from the bore hole is a simple operation.

Another object of the present invention is to provide a well drilling apparatus in which the drilling tool is suspended by a flexible line.

A further object of the present invention is to provide a well drilling apparatus in which the flexible suspending line for this improved drilling tool conducts drilling mud to the cutting tool.

A further object of the present invention is to provide a drill tool in which the angle of inclination of the tool relative to the vertical can be controlled from a station remote from the drilling tool and, a still further object is to provide a drilling tool which is relatively in-expensive to manufacture and which vastly reduced the cost of deep downhole drilling.

In order that the manner in which these and other objects are attained, in accordance with the invention, can be understood in detail, reference is had to the accompanying drawings which form a part of this specification, and wherein:

FIG. 1 is a schematic view of the drilling apparatus including the drilling tool and the above-ground controls and equipment;

FIG. 2 is a cross-section view in side elevation of the upper portion of the down hole drilling tool;

FIG. 3 is a cross-section view in side elevation showing the lower portion of the downhole drilling tool;

FIG. 4 is a sectional view of the drilling tool looking along line 4—4 of FIG. 2;

FIG. 5 is a sectional view of the drilling tool looking along line 5—5 of FIG. 3;

FIG. 6 is a sectional view of the drilling tool looking along line 6—6 of FIG. 3;

FIG. 7 is a sectional view of the drilling tool looking along line 7—7 of FIG. 3;

FIG. 8 is a drawing in perspective of the inertial rotor arrangement of FIG. 2, showing the various forces acting on the rotors;

FIG. 9 is a view in perspective of another arrangement of inertial rotors along the longitudinal axis of the drilling tool;

FIG. 10 is a top plan view of the rotor arrangement of FIG. 9;

FIG. 11 is a view in perspective of a third arrangement of inertial rotors along the longitudinal axis of the drilling tool; and

FIG. 12 is a top plan view of the rotor arrangement of FIG. 11.

Referring to the drawings in detail, my improved drilling apparatus as shown in FIG. 1 comprises a downhole drilling tool **1**, having a rotary cutter **2** at the bottom end of the drilling tool. At its upper end, drilling tool **1** is attached to a flexible line **3** that is connected to a winch or other well known surface equipment for pulling a flexible line from the top of the bore hole. Flexible line **3** is preferably a tubular conduit, for example a hose to permit flowing drilling and mud to the rotary cutter **2** by means of the mud pump located above the top of the bore hole. Rotary cutter **2** is dimensioned to cut a borehole which is larger than the outside diameter of the drill tool **1**. Hence, there is an annular clearance space between drilling tool **1** and the wall of the bore hole, through which drilling mud and drilled particles can pass upwardly away from rotary cutter **2**.

A multiple conductor water proof cable **4** contains the electrical conductors for controlling the operation of drilling tool **1** from the control station indicatied generally at **5**. The cable **4** which is attached to the top end of the drilling tool **1**, is fed and retracted by a motor driven drum (not shown) which preferably operates in synchronism with the winch. If desired cable **4** could be releasably attached to flexible line **3**, cable **4** and line **3** being separated at the surface. Cable **4** also contains electrical conductors which transmit to the top of the bore hole the information relating to the conditions at the drilling tool **1** which are sensed by appropriate instruments in the drilling tool. The sensed information is transmitted to the control station **5** where the operator can adjust the various controls in accordance with the conditions desired. Both the operation and details of the control equipment will be discussed subsequently.

Referring now to FIGS. 2 and 3, drilling tool **1** includes an elongated supporting structure **6** which comprises an inner hollow cylindrical member **7** and an outer hollow cylindrical member **8** concentric with inner cylindrical member **7**. An annular drilling mud passage **9** which extends the length of the inner cylindrical member **7**, is defined by a uniform diameter inner cylindrical surface **10** of outer cylindrical member **8** and a uniform diameter outer cylindrical surface **11** of inner cylindrical member **7**. Outer cylindrical member **8** is rigidly secured to inner cylindrical member **7** by circumferentially spaced web members **12** (FIG. 4) which extend generally radially from outer surface **11** to inner surface **10**. Although, in the preferred embodiment, web members **12** are not continuous along the length of annular passage **9**, these web members **12** can, if desired, be continuous along the length of annular passage **9**.

At the necked-in end **12'** of outer cylindrical member **8** is a flange **13** attached to a flange **14** at the lower end of connector **15** (not shown in detail) is provided with a central opening which forms passage means **16** for directing drilling mud to annular passage **9**. The other end of connector **15** (not shown in detail) is provided with a suitable coupling **17** (FIG. 1) to connect with the lower end of flexible line **3**.

Inner cylindrical member **7** has a dome shaped end **18** which provides a smooth surface for directing the drilling mud radially outwardly to annuar passage **9**. Dome shaped end **18** is preferable integral with inner cylindrical member **7**.

Adjacent the other end of cylindrical member **7** (FIG. 3), inner surface **10** of cylindrical member **8** curves radially inwardly as at **19** to direct drilling mud from annular passage **9** through circumferentially spaced generally circular openings **20** in rotary cutter shaft **21**. As seen in FIG. 6, there are four openings **20** in cutter shaft **21**. Shaft **21** has a central bore **22** through which the drilling mud passes to rotary cutter **2** attached to the lower end of shaft **21** by a suitable threaded coupling (not shown). At its upper end, cutter shaft **21** is coupled to the lower end of drill motor shaft **24**. At the coupling solid head portion **23** of cutter shaft **21** has an internally threaded bore **25** screwed on the externally threaded bottom end **26** of motor shaft **24**. Tapered locking pins **27** extend through the coupling to prevent relative rotation between motor shaft **24** and cutter shaft **21**.

At its bottom end **28**, cylindrical member **7** has a ring member **29** with a peripheral flange **30** and cylindrical sleeve **31** attached to the lower face of flange **30**. Packing **32** energized by longitudinally acting compression spring **33** is provided in the annular recess in the inside of sleeve **31**. The upper end of spring **33** seats on the lower face of ring member **29**. Packing **32** prevents drilling mud from leaking through the rotational clearance space between cutter shaft **21** and the inner surface of sleeve **31** into cylindrical member **7**.

The lower end of cylindrical member **8** includes a cylindrical sleeve **34** extending downwardly around cutter shaft **21**. Sleeve **34** as an annular recess for packing **35** energized by longitudinally acting compression spring **36** to prevent drilling mud from leaking into the rotational clearance space between cutter shaft **21** and sleeve **34** from annular passage **9**. The lower end of spring **36** seats on ring member **37** having flange **38** interposed between the lower face of sleeve **34** and the upper face of sleeve member **39**, the various members being secured by nut and bolt combinations **40**. To provide an outside surface of uniform diameter without external projections sleeves **34** and **39** each have recesses **41** with a flat surface **42** on which the threaded nuts can seat, and an arcuately curved side **43** to provide clearance for a wrench or other suitable tool to turn the nuts.

At the lower end of drilling tool **1** is a bearing **44** in which cutter shaft **21** is journaled. Bearing **44** is supported by sleeve **45** attached to the bottom of sleeve **39**. Packing **46**, energized by ring **47** via bolts **48**, seals against a portion of the lower end of cutter shaft **21**. Recesses **49** similar to recesses **41** accommodate the nut and bolt combinations for fastening sleeve **45** to the bottom of sleeve **39**. Since cutter shaft **21** is sealed by packing **35** above bearing **44** and by packing **46** below bearing 44, drilling mud and other abrasive well fluids are prevented from leaking into the bearing 44 and the portion of cutter shaft 21 between the packing 35 and 46. Such sealing is very essential since the abrasives in the well fluid and mud could cause the cutter shaft 21 and bearing 44 to wear out very quickly when shaft 21 is rotated.

Motor shaft 24 extends the length of electric motor 50 which drives rotary cutter 2 by rotating cutter shaft 21. Motor 50 is illustrated as a D.C. motor having an armature 51 and commutator 52 that are carried by motor shaft 24. Alternatively, other types of motors can be used, including an A.C. reversible motor to rotatably drive rotary cutter 2. The upper portion of shaft 24 is journaled in ball bearings 53 and 54, the lower portion being journaled in ball bearings 55 and 56 to support the shaft 24 against lateral movement. Adjacent each end of motor shaft 24 are ball-type thrust bearings 61 and 65 to support shaft 24 against axial movement.

Radial ball bearings 53, 54, 55 and 56 each comprise an inner race 57 which is attached to and rotates with shaft 24, an outer race 58 which is attached to wall 59 of cylindrical member 7, and a plurality of ball members 60 which ride in suitable grooves between inner and outer races 57 and 58.

Thrust bearing 61 at the top end of shaft 24 comprises a flat annular top race 62 axially spaced from a flat annular bottom race 63 both races being attached to shaft 24 to rotate therewith. The stationary ring-shaped race 64 of the thrust bearing 61 is attached to wall 59 and is disposed between races 62 and 63. Ball members 60 are disposed between the lower face of top race 62 and the upper face of stationary race 64, and between the lower face of stationary race 64 and the upper face of bottom race 63.

Thrust bearing 65, at the lower end of shaft 24 is similar to thrust bearing 61, and includes a top race 66, bottom race 67, stationary race 68, and ball members 60 between the faces of the respective races. Races 66 and 67 rotate with shaft 24 whereas stationary race 68 is attached to wall 59 of cylindrical member 7.

Motor brushes 68′ suitably supported in contact with the surface of commutator 52 supply current to the armature 51 to drive motor 50 to rotate rotary cutter 2.

As best seen in FIGS. 3 and 5, the axis of rotation of drill motor shaft 24 and cutter shaft 21 is coincident with the longitudinal axis of the cylindrical member 7 and hence the supporting structure 6.

Carried by the upper portion of cylindrical member 7 (FIG. 2) are a plurality of inertial rotors 69, 70, 71, 72, and 73 each having an axle 74 and reversible electric driving motor 75. Several types of motors can be employed, including A.C. or D.C. types having provision for speed and direction of rotation control. Each axle 74 is journaled in suitable bearings in bearing blocks 76 and 77, one on each side of the inertial rotor, for example inertial rotor 70. Inertial rotor 70 is a solid wheel of high density material, such as steel or cast iron, which is fastened to its axle 74. Alternatively, inertial rotor 70 can be a wheel with an outer rim, spokes, and hubs, the greatest part of the weight being in the rim. Bearing blocks 76 and 77 are secured by threaded fasteners to a flat transverse support 78 attached to wall 59 of cylindrical member 7. Inertial rotor 70 is positioned so that its center of mass is coincident with the longitudinal axis of supporting structure 6, and its axis of rotation is at right angles to and intersects the longitudinal axis of the supporting structure. Reversible electric motor 75 drives inertial rotor 70 via drive belt 79 and pulleys 80 and 81. Other types of drive mechanisms can be used to connect motor 75 to rotate inertial rotor 70. Pulley 80 is keyed to the shaft of motor 75 and is preferably of larger pitch diameter than pulley 81 which is keyed to one end of axle 74 of inertial rotor 70. Motor 75 is spaced longitudinally from rotor 70 and has an axis of rotation which is parallel with the axis of rotation of inertial rotor 70, and intersects the longitudinal axis of the supporting structure. Motor 75 is fastened by bolts to flat transverse motor support 82 which is secured to wall 59 of cylindrical member 7. Transverse support 78 has an opening 83 through which drive belt 79 passes, and an opening 84 to accommodate the lower portion of inertial rotor 70.

The inertial rotors 69, 71, 72 and 73 are identical to inertial rotor 70 and have identical bearings and transverse supports. Motors 75 are also identical and each motor 75 has an axis of rotation parallel with the inertial rotor which it drives.

Each successive inertial rotor is disposed with its axis of rotation at right angles to the axis of rotation of an immediately preceding inertial rotor. As best seen in the embodiment of FIG. 2, the axis of rotation of inertial rotor 70 is turned 90° counterclockwise to the axis of rotation of inertial rotor 69. The axis of rotation of inertial rotor 71 is turned 90° counterclockwise to the axis of rotation of inertial rotor 70. Similarly, the axis of rotation of inertial rotor 72 is turned 90° to that of inertial rotor 71, and the axis of rotation of inertial rotor 73 is turned 90° to that of inertial rotor 72. Since each inertial rotor has its axis of rotation turned 90° counterclockwise to the axis of an immediately preceding inertial rotor, the pulley of rotor 70 is 90° counterclockwise from the pulley of rotor 69; the pulley of rotor 71 is 180° counterclockwise from the pulley of rotor 69; the pulley of rotor 72 is 270° counterclockwise from the pulley of rotor 69; and the pulleys of rotors 73 and 69 have the same relative angular position. As a result of this arrangement of inertial rotors along the longitudinal axis of the supporting structure, it follows that the axes of rotation of every second inertial rotor are parallel, i.e., the axes of rotation of inertial rotors 69 and 71 are parallel; the axes of rotation of inertial rotors 70 and 72 are parallel; and the axes of rotation of inertial rotors 71 and 73 are parallel, etc. The described arrangement of rotors is very important to operation and control of the drilling tool as will be subsequently explained.

Control system

As best seen schematically in FIG. 1, the electrical equipment supported by drilling tool 1 includes reversible electric motors 75, a direction sensing instrument 85, an inclinometer 86, a rotation sensing device 87, and drill motor 50. A conduit 88 carries the necessary wires connected to a terminal block 89 for the various electrical equipment in the drilling tool. The wires carried by cable 4 are also connected to terminal block 89 to electrically connect the control equipment at station 5 with the electrical equipment in drilling tool 1.

The electric motors 75 are conventional direct current motors controllable by the "Gyro Motor Control" at control station 5. The "Gyro Motor Control" is provided with rheostats in series with the field winding of each motor to allow the speed of each motor to be regulated independently of the other motors. The "Gryro Motor Control" also has suitable switching devices to allow reversing the polarity of the current to any desired motor 75. The "Gyro Motor Control" thus enables the speed as well as the direction of rotation of any motor 75 to be controlled from control station 5, remote from the drilling tool 1.

The rotation sensing device 87 preferably comprises a sensitive centrifugally actuated rheostat, or other well known device for sensing rotation of the drilling tool 1 about its longitudinal axis. The rotation sensing device operates a "Casing Rotation Indicator" at station 5 to indicate any rotation of drilling tool 1 to the operator of the equipment.

The inclinometer 86 senses the angle of the longitudinal axis of the drilling tool relative to the vertical. Inclinometer 86 can be of any well known type, for example that disclosed in Patent 2,309,905. Inclinometer **86** operates an "Inclination Indicator" to indicate to the operator at control station **5** what the orientation of the drilling tool is relative to the vertical.

The direction sensing device **85** is an instrument for sensing the compass orientation of a particular point on the drilling tool. Such a sensing device **85** is preferably a gimballed gyroscope (not shown) mounted in a casing freely rotatable about the longitudinal axis of drilling tool **1**. The casing of the gyroscope would include an electrical contact which engages a circular resistance element, the position of the contact on the resistance element being determinative of the compass orientation of a point on the drilling tool **1**. The compass orientation determined by direction sensing device **85** is indicated by a "Direction Indicator" at control station **5**. Since the compass direction of a particular point on the drill tool **1** is indicated to the operator, the compass direction of any axle **74** of any inertial rotors **69** to **73** will also be known.

Drill motor **50** is also reversible and its speed of rotation can be controlled by a "Drill Motor Control" at control station **5**.

Operation of inertial rotors

Referring to FIG. 8, there is shown a schematic, in perspective, of the inertial rotors shown in FIG. 2. Inertial rotors *a, b, c* and *d* correspond respectively to inertial rotors **69** to **72** and each has a shaft with one end designated A and the other end designated B. When a straight line hole is drilled, inertial rotors *a, b, c* and *d* are rotated in the same direction as viewed from the end A of each shaft. The characteristic of a gyroscope, i.e., the inertial rotor, is that when a rotor is rotating about a given axis it resists any attempt to cause it to rotate about a different axis. Since the ends of the shafts of the inertial rotors in the drilling tool are journaled in bearings secured to the drilling tool, any tendency for the tool to rotate about its axis will be resisted by the gyroscopic effect of the rotors. Assuming that the cutter, when viewed from the top of the drilling tool, rotates in a clockwise direction, the torques tending to rotate the drilling tool will act in a counterclockwise direction. To prevent such rotation of the drill tool the resisting torques developed by the rapidly spinning inertial rotors must oppose the counterclockwise torque due to rotation of the cutting tool. As shown in FIG. 8(*a*), the torque resulting from rotation of the cutter produces a force F which tends to turn the end A of the rotor shaft AB to the right. This force F is counteracted by a force G, established by the inertial rotor, which acts to the left. By suitable proofs, it can be shown that the resisting force G can be made relatively large for each rotor.

Hence, when a large number of inertial rotors are provided, for example twenty-five (25) or thirty (30), a very large resisting torque will be realized, that will be sufficient to prevent rotation of the drill tool due the torque established when drill motor **50** is rotated.

As a result of the resisting force established by the rotors there is another force H which acts at a right angle to force F, but only when force F is of sufficient magnitude to move the end A of the shaft of the rotor. Such movement of the end of the shaft is termed "precession," and operates to change the direction of the axis of rotation of the rotor by turning the rotor about its center of mass. This condition could arise when the rotary cutter jams, thereby causing the drilling tool **1** to rotate slightly. The effect of "precession" is force H which establishes a couple HL that tends to turn the drilling tool in a direction perpendicular to its longitudinal axis. The direction of the force H depends on the direction of rotation of the inertial rotor. If the force F is thought of as due to the pressure of a flat board against the side of the rotating shaft, then the force H will act in the direction that the

shaft would naturally roll if the board were rough. Hence, if rotor *a* (FIG. 8) is rotated in a counterclockwise direction as viewed from the shaft end A and precesses in the direction of force F, the direction of force H is up as shown. However, if rotated in a clockwise direction, the force H would act downwardly. In the apparatus previously described each successive inertial rotor has its axis of rotation displaced 90° to the axis of rotation of an immediately preceding rotor. Such is the arrangement shown in perspective in FIG. 8 wherein rotors *a, b, c* and *d* each rotate in a counterclockwise direction as viewed from the ends of the shafts designated A. With this arrangement the couple resulting from force H at rotor *a* is equal but opposite to the couple resulting from force H at rotor *c*, and thus the couples are balanced. Similarly, the couple resulting from force H at rotor *b* is equal to and opposes the couple resulting from the force H at rotor *d*. Hence, when the rotors are each rotated at the same speed in the same direction, as indicated, the drilling tool will remain in line with the axis of the bore hole even when the drilling tool is rotated slightly.

In some instances it may be desirable to drill a bore hole, a portion of which is vertical, and a portion of which is at an angle to the vertical. Such drilling can be done with this drilling apparatus. Assuming that the portion of the bore hole extending to the surface is to be vertical, the operator at control station **5** adjusts the "Gyro Motor Control" to rotate the inertial rotors in the same direction as viewed from the ends A of the shafts, as shown in FIG. 8. Drilling is commenced by energizing drill motor **50** to rotate rotary cutter **2**. The previously described forces established by the inertial rotors will counteract the torques due to drilling and, hence, the drilling tool will not rotate about its longitudinal axis.

When it is desired to drill at an angle to the vertical, the drill motor **50** and the inertial rotor motors are all turned off. The direction indicator is then inspected to determine the compass direction of at least one shaft of an inertial rotor. Assuming that it is desired to drill toward the north and that none of the rotors has its axis in a north-south direction, the drill motor only will be energized for an instant to rotate the drilling tool until the shaft of one rotor is in a north-south direction. For purposes of explanation the shafts of rotors *b* and *d* of FIG. 8 are assumed to be in a north-south direction with north being toward the end A of rotor *b*.

The rotor *b* is then rotated by its motor in a counterclockwise direction as viewed from end A of its shaft. Rotor *d* is rotated in a counterclockwise direction as viewed from end B of its shaft. Both shafts are now seen to rotate in the same direction as viewed by an observer looking toward the drilling tool from the north. Rotors *a* and *c* are not rotated. Drill motor **50** is energized and its speed is slowly increased. When the torque resulting from the rotation of the drill motor **50** and rotary cutter **2** begins to rotate the drilling tool **1**, the rotors will precess and the couples produced by rotors *b* and *d* will be additive to cause the drilling tool to keyhole so that the rotary cutter end of the drilling tool is forced toward the north. At the same time, the top end of the drilling tool will be forced south against the side of the bore hole. When the tool has keyholed to the extent possible by the clearance between the tool and bore hole, rotors *a* and *c* are also rotated and normal straight line drilling is commenced for a few feet. Then the shafts of rotors *b* and *d* are again aligned in a north-south direction, and are again rotated as previously described to force the rotary cutter toward the north when the rotors precess, thereby increasing the angle of the tool with the vertical. This procedure is repeated until the desired angle is obtained whereupon the procedure for straight line drilling is resumed. Due to the weight of the tool it may be necessary to occasionally correct the angle of inclination as previously described.

With reference to FIGS. 9 and 10, there is shown another preferred arrangement of inertial rotors for the drilling tool 1 of the present invention.

Inertial rotors 90, 91 and 92 are arranged with their centers of mass spaced from the longitudinal axis of the drilling tool. The axes of rotation are therefore skew with regard to the longitudinal axis of the drilling tool. However, an imaginary line drawn from the center of mass perpendicular to the longitudinal axis will define, with the axis of rotation, a plane perpendicular to the longitudinal axis of the drilling tool. As shown in FIG. 9, inertial rotors 90, 91 and 92 are spaced along the longitudinal axis of the drilling tool. When viewed from above, FIG. 10, the axes of rotation form an equilateral triangle.

During vertical or other straight line drilling rotors 90, 91 and 92 are each rotated in the same direction as viewed from the end designated A'. Then, if the drilling tool rotates, the forces due to "precession" will be equal and opposite and will cancel each other without tending to keyhole the drilling tool.

To drill at an angle, rotor 90 is rotated clockwise as viewed from shaft end B', and rotor 91 is rotated clockwise as viewed from shaft end A'. Then counterclockwise rotation of the drilling tool will force the bottom of the tool in the direction D' (FIG. 10). This arrangement of rotors has the advantage that the forces for drilling at an angle to the vertical are larger and can be more closely controlled than with the previous embodiment. It is to be understood that appropriately supported reversible electric motors similar to the motors 75 will be provided and that the rotors will be suitably journaled in appropriate bearings supported inside inner cylindrical member 7.

With reference to FIGS. 11 and 12, there is shown another preferred arrangement of inertial rotors for the drilling tool 1, of the present invention. In this embodiment, inertial rotors 93, 94 and 95 are spaced along the longitudinal axis of the supporting structure of drill tool 1. The axes of rotation of the rotors intersect the longitudinal axis of the drill tool at an angle, and successive rotors have their centers of mass spaced circumferentially at an angle of 120° one to the other. The axes of the rotors, as viewed from the top of the drilling tool (FIG. 12), lie along the edge of a regular tetrahedron having its base triangle at right angles to the longitudinal axis of the drill tool, and the altitude of the tetrahedron coincident with the longitudinal axis of the tool. With this arrangement, the axes of rotation of the rotors form an angle of approximately 34° with the longitudinal axis of the drill tool. However, the axes of the rotors could be at any desired angle, for example 20°, 40°, 60°, etc. to the longitudinal axis of drill tool 1.

As previously described, the forces resulting from precession must cancel when drilling in a straight line to prevent unwanted keyholing of the drill tool. Rotating rotors 93, 94 and 95 in the same direction, as viewed from the ends A'' of the axles, will cause the forces due to precession to cancel thereby permitting straight line drilling.

To drill at an angle, any two of the rotors, for example 93 and 94, can be rotated in the same direction, as viewed from axle end A''. Then when precession occurs, the bottom of the drilling tool will be forced in a direction E (FIG. 12) when the direction of rotation of rotors 93 and 94 is clockwise, as viewed from axle end A''. If the direction of rotation of rotors 93 and 94 is counterclockwise, the bottom of the tool will be forced in a direction opposite to E. If desired, only one rotor can be rotated to initiate drilling at an angle to a previously drilled straight bore. Although, only the intertial rotors are shown in FIGS. 11 and 12, it is to be understood that the rotors will be driven by electric motors like motors 75, and that the axles of the rotors will be journaled in appropriate bearing blocks supported in inner cylindrical member 7. The various other electrical equipment in drill tool 1 and at control station 5 will also be provided, as previously described. It is also to be understood that when operating the drill tool provided with the arrangements of rotors of FIG. 9 or 11, the shaft of any selected rotor can be oriented in the desired compass direction when drilling at an angle, as previously described, to cause the tool to incline in the proper direction.

Although the rotor arrangements of FIGS. 8, 9 and 11 show five or less inertial rotors, as many rotors as necessary can be provided, for example twenty-five (25) or thirty (30). Also, the arrangement of rotors need not be the same along the length of the rotor, i.e., there may be four rotors disposed in accordance with the arrangement of FIG. 8; the next three or six rotors being in accordance with the arrangement of FIG. 9, and the next three or multiple thereof being in accordance with the arrangement of FIG. 11. When the arrangements of rotors are so intermixed, it is to be noted that the FIG. 8 arrangement should be provided in groups of four rotors, and that the FIGS. 9 and 11 arrangements should be provided in groups of three rotors to enable balancing the forces due to precession.

Even though in the preferred embodiments of this invention, the inertial rotors are mounted to rotate about axles which are spaced from the driving motors, the inertial rotors could be mounted on the motor shafts, or alternatively, the motors themselves may be provided with large inertial armatures which would provide the same result as the described inertia rotors.

While, for illustrative purposes, the invention has been shown with a rotary cutter driven by a motor attached to the lower end of the drilling tool, it is to be understood that any rotary type cutter can be used and that the cutter can be driven by any known means. Also, the supporting structures for the inertial rotors and the rotary cutter could be separate members suitably fastened together to provide the desired below ground supports, and that any suitable means could be provided to conduct the drilling mud from the upper end to the lower end of the drill tool. It is hence to be understood that the novel features of this invention find more general application as set forth in the appended claims.

I claim:

1. A downhole drilling tool for penetrating the earth in a generally vertical direction comprising

an elongated supporting structure including a top and bottom end and having a longitudinal axis;

a rotary cutting tool having an axis of rotation coincident with said longitudinal axis carried at the bottom end of said supporting structure;

motor means intermediate the ends of said supporting structure for operating said cutting tool;

means adjacent the top end of said supporting structure for attaching a conduit thereto;

passage means communicating with said top and bottom ends of said supporting structure to direct drilling mud to said cutting tool from the top end of said supporting structure;

a plurality of inertial rotors carried by said supporting structure in spaced relation along the longitudinal axis of said supporting structure, said inertial rotors being disposed in a number and in an arrangement sufficient to permit upon rotation of the rotors cancellation of the forces of precession developed during drilling, and said inertial rotors being arranged to establish upon rotation of the rotors a gyroscopic effect in opposition to torque resulting from rotation of said rotary cutting tool;

said inertial rotors having axes of rotation at right angles to said longitudinal axis of said supporting structure with the centers of mass of said inertial rotors disposed along said longitudinal axis;

each succeeding inertial rotor having its axis of rotation disposed at right angles to the axis of rotation of an immediately preceding inertial rotor so that the axes of rotation of alternate rotors are parallel, the directions of rotation of said alternate rotors being of opposite hand, and

motor means for rotating said inertial rotors, thereby permitting establishment of a gyroscopic effect opposing torque resulting from the rotation of said cutting tool and cancellation of the forces of precession developed during drilling.

2. A downhole drilling tool in accordance with claim 1 in which said motor means for rotating said cutting tool is an electric motor controllable from a control station remote from the drilling tool, and said motor means for rotating said inertial rotors comprise a plurality of electric motors, one for each inertial rotor, which are individually controllable from a control station remote from the drilling tool.

3. A downhole drilling tool in accordance with claim 1 in which said motor means for rotating the inertial rotors comprise a plurality of motors, one for driving each inertial rotor, and each of said motors has an axis of rotation parallel to the inertial rotor which it drives.

4. An apparatus for drilling a generally vertical borehole extending to the surface of the earth comprising

a downhole drilling tool including an elongated supporting structure having a longitudinal axis which is ordinarily vertical,

a rotary cutting tool carried by the lower end of said supporting structure, and means for driving said rotary cutting tool,

a plurality of inertial rotors spaced along the longitudinal axis of said supporting structure, each of said inertial rotors being fixedly mounted to have its axis of rotation disposed at an angle with regard to said longitudinal axis, said inertial rotors being disposed in a number and in an arrangement sufficient to permit upon rotation cancellation of the forces of precession developed during drilling, and said inertial rotors being arranged to establish upon rotation a gyroscopic effect in opposition to torque resulting from rotation of said rotary cutting tool,

a flexible suspending member attached to the upper end of said supporting structure to suspend said drilling tool below the top of a borehole,

means above the top of the borehole to raise and lower said drilling tool via said flexible suspending member,

rotation sensing means carried by said supporting structure for sensing rotation of said supporting structure,

indicating means above the top of the borehole for indicating the rotation sensed by said rotation sensing means,

means above the top of the borehole for controlling the speed of rotation of said means for driving said rotary cutting tool,

means carried by said supporting structure for rotating said inertial rotors to establish a gyroscopic effect opposing torque resulting from rotation of said cutting tool, and

means above the top of the borehole for controlling the speed of rotation of said means for rotating said inertial rotors, thereby permitting control of the forces of precession developed during drilling.

5. A drilling tool suitable for suspension on a flexible suspending member and penetration into earth, which tool comprises a supporting structure having a longiutdinal axis; a rotary cutting tool rotatably mounted near the lower end of said supporting structure with its axis of rotation substantially coincident with said longitudinal axis; means associated with said structure for rotating said cutting tool; a plurality of inertial rotors mounted in said structure, each of said inertial rotors disposed with its axis of rotation at an angle with regard to said longitudinal axis, said inertial rotors being disposed in a number and in an arrangement sufficient to permit upon rotation of the rotors cancellation of the forces of precession developed during drilling, and said inertial rotors being arranged to establish upon rotation of the rotors a gyroscopic effect in opposition to torque resulting from rotation of said rotary cutting tool; and means for rotating said inertial rotors about their axes of rotation.

6. The drilling tool defined in claim 5 wherein at least one set of four inertial rotors is mounted in said supporting structure, each of said four inertial rotors having its axis of rotation perpendicular to said longitudinal axis and its center of mass on said longitudinal axis, and each set of said four inertial rotors being arranged to provide a gyroscopic effect in opposition to torque resulting from rotation of said rotary cutting tool and to permit cancellatin of the forces of precession developed during drilling.

7. The drilling tool defined in claim 5 wherein at least one set of three inertial rotors is mounted in said supporting structure, each of said three inertial rotors having its center of mass spaced from said longitudinal axis and its axis of rotation spaced from said longitudinal axis, the axes of rotation of said three inertial rotors forming an equilateral triangle about said longitudinal axis when viewed therealong, and each set of said three inertial rotors being arranged to provide a gyroscopic effect in opposition to torque resulting from rotation of said rotary cutting tool and to permit cancellation of the forces of precession developed during drilling.

8. The drilling tool defined in claim 5 wherein at least one set of three inertial rotors is mounted in said supporting structure, each of said three inertial rotors having its center of mass spaced from said longitudinal axis and its axis of rotation intersecting said longitudinal axis at an acute angle, each of the axes of rotation of said three inertial rotors lying uniquely along one of the edges of a regular tetrahedron having the plane of its base triangle perpendicular to said longitudinal axis and its altitude coincidental with said longitudinal axis when viewed therealong, and each set of said three inertial rotors being arranged to provide a gyroscopic effect in opposition to torque resulting from rotation of said rotary cutting tool and to permit cancellation of the forces of precession developed during drilling.

9. The drilling tool defined in claim 5 wherein said means for rotating said cutting tool is an electric motor controllable from a control station remote from the drilling tool, and said means for rotating said inertial rotors comprise a plurality of electric motors, one for each inertial rotor, which are individually controllable from a control station remote from the drilling tool.

10. The drilling tool defined in claim 5 wherein said means for rotating said inertial rotors comprise a plurality of electric motors, one for driving each inertial rotor, and each of said motors has an axis of rotation parallel to the inertial rotor which it drives.

11. A method for drilling a well bore and regulating the inclination thereof, which method comprises providing a drilling tool comprising a supporting structure having a cutting tool rotatably mounted thereon and containing a plurality of inertial rotors arranged to permit upon rotation of the rotors establishment of a gyroscopic effect in opposition to torque resulting from rotation of said cutting tool during drilling and to permit upon rotation of the rotors cancellation of forces of precession developed during drilling; actuating said driling tool to drill said well bore; actuating said inertiar rotors to establish a gyroscopic effect in opposition to torque resulting from rotation of said cutting tool during drilling; and controlling individually said inertial rotors to regulate forces of precession, thereby regulating the inclination of said well bore.

12. A method for changing the angle of inclination of a well bore during drilling thereof, which method comprises providing a drililng tool comprising a supporting structure having a cutting tool rotatably mounted thereon and containing a plurality of inertial rotors arranged to

permit upon rotation of the rotors establishment of a gyroscopic effect in oposition to torque resulting from rotation of said cutting tool during drilling and to permit upon rotation of the rotors control of, including cancellation of, forces of precession developed during drilling; actuating said drilling tool to drill said well bore; actuating said inertial rotors to establish a gyroscopic effect in opposition to torque resulting from rotation of said cutting tool during drilling; and controlling individually said inertial rotors such that the forces of precession developed during drilling are uncanceled and the resultant precessive force will be such as will cause said drilling tool to change its direction of advance.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,224,513 December 21, 1965

Frank G. Weeden, Jr.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 54, for "indicatied" read -- indicated --; column 4, line 13, for "of connector 15 (not shown in detail) is provided with a" read -- of connector 15. Flange 13 and connector 15 have a --; column 12, line 64, for "driling" read -- drilling --; line 65, for "inertiar" read -- inertial --; line 73, for "drililng" read -- drilling --; column 13, line 2, for "oposition" read -- opposition --; line 13, after "advance" insert -- in said well bore --.

Signed and sealed this 27th day of December 1966.

(SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents