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Omura et al.

[11] **3,771,611**

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[54] **EARTH BORING APPARATUS**

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[30] **Foreign Application Priority Data**

May 13, 1971 Japan 46/32014

[52] **U.S. Cl.** **175/348,** 175/101, 175/227, 175/401

[51] **Int. Cl.** **E21b 3/08,** E21b 9/28

[58] **Field of Search** 175/92, 95, 96, 97, 175/101, 103, 104, 106, 86, 207, 213, 215, 228, 230, 401, 371, 372, 333, 53, 57, 60, 227, 350, 348

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Primary Examiner—David H. Brown
Attorney—Richard K. Stevens et al.

[57] **ABSTRACT**

An earth boring apparatus in which cutters are secured to planetary gears meshing with a sun gear secured to a power driven center shaft, the planetary gears being rotatably carried by a planetary carrier rotatable about the axis of the center shaft, whereby each cutter is rotatable about its own axis and also can revolve about the axis of the center shaft.

7 Claims, 8 Drawing Figures

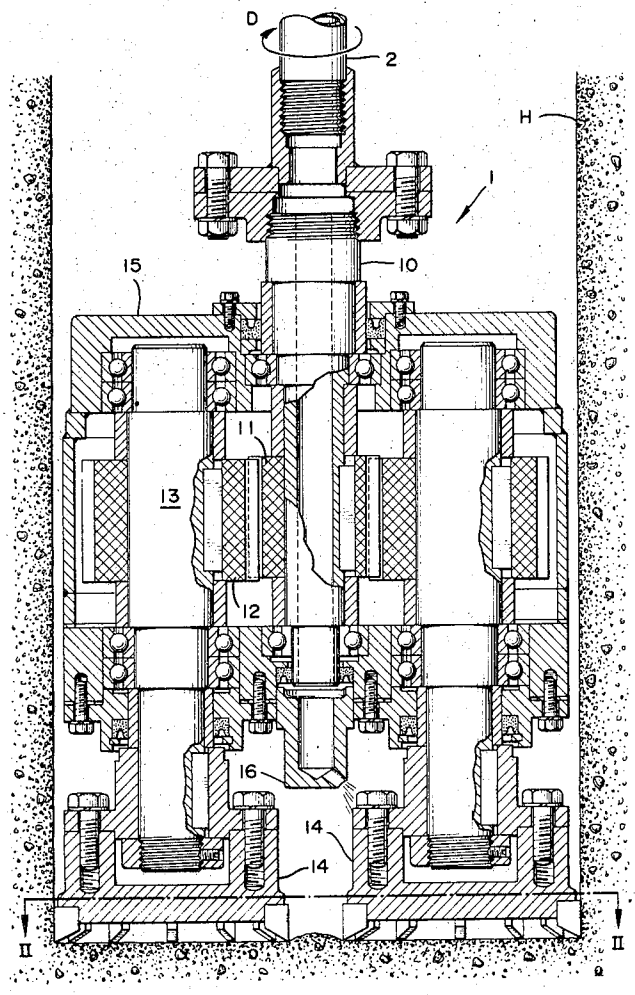


Fig. 1

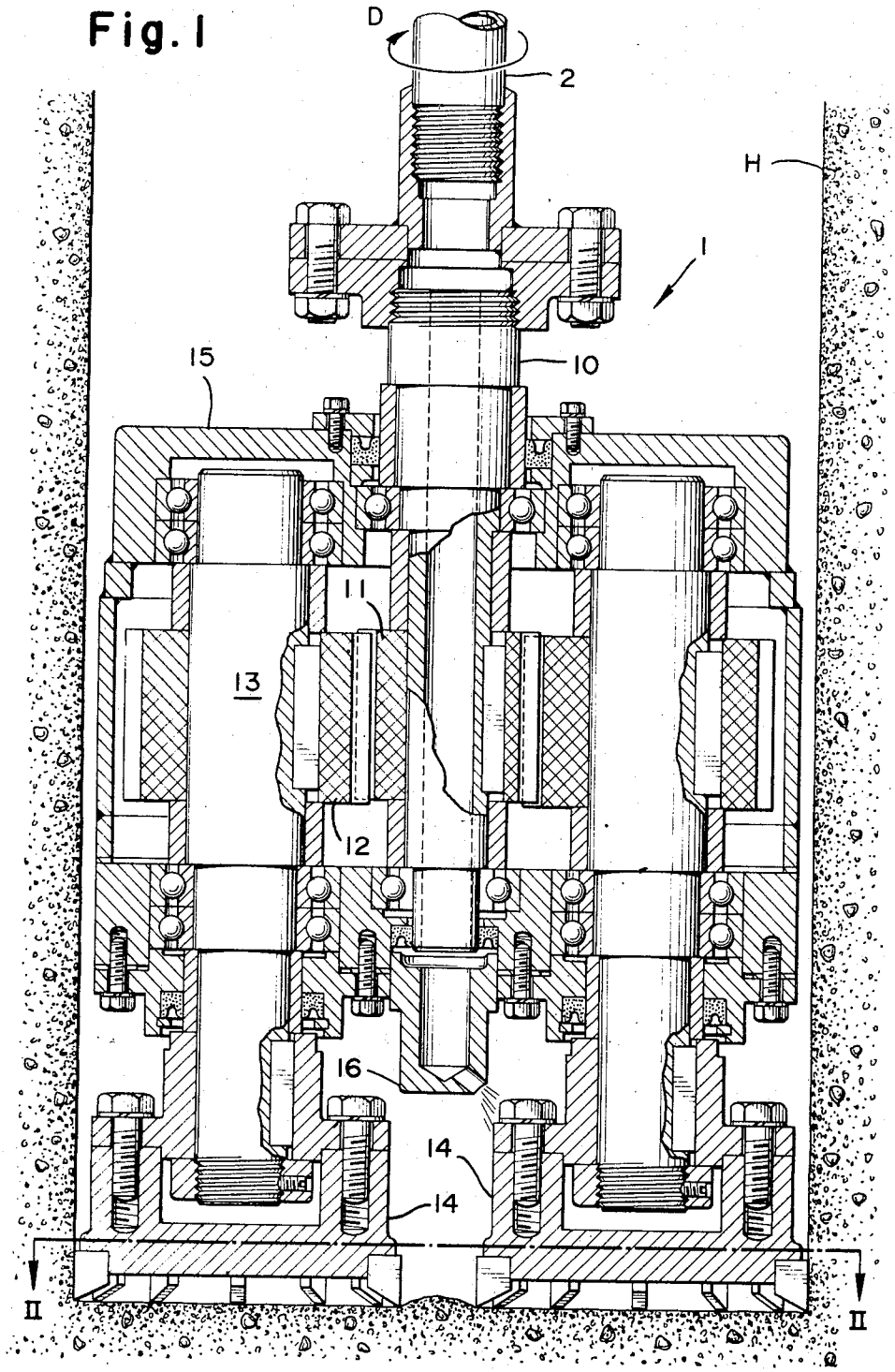


Fig. 2

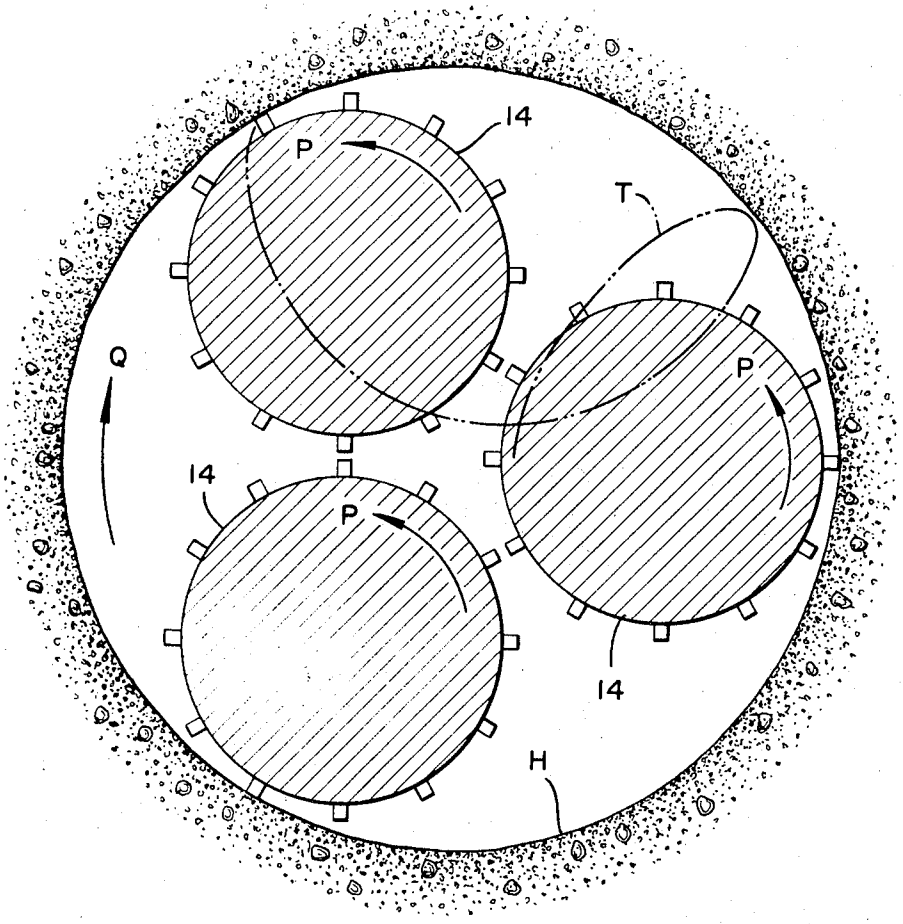


Fig. 3

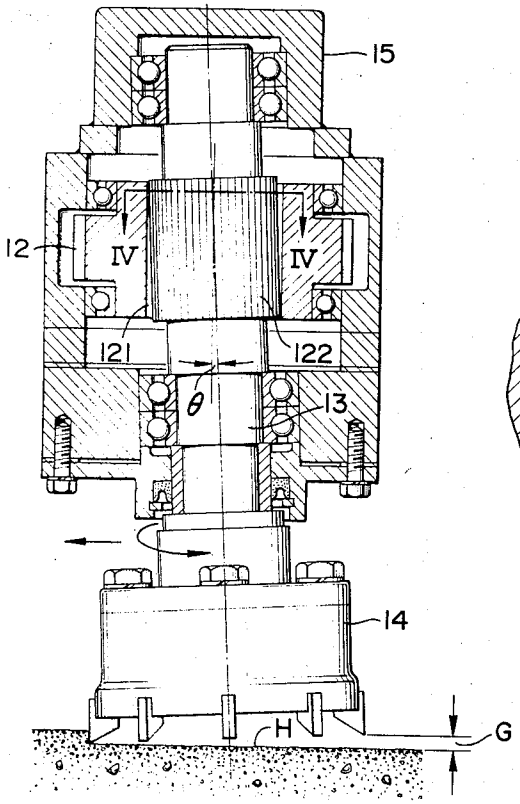


Fig. 4

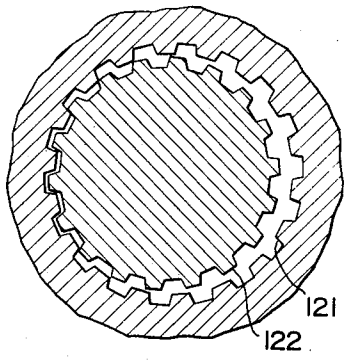


Fig. 5

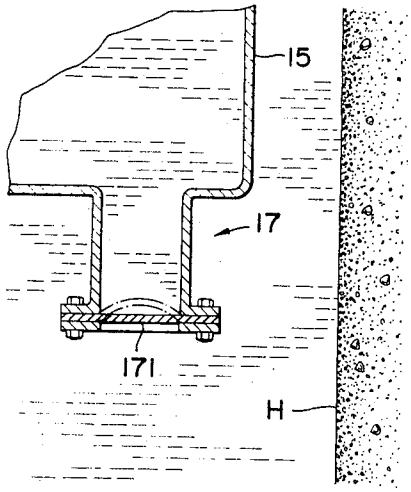


Fig. 6

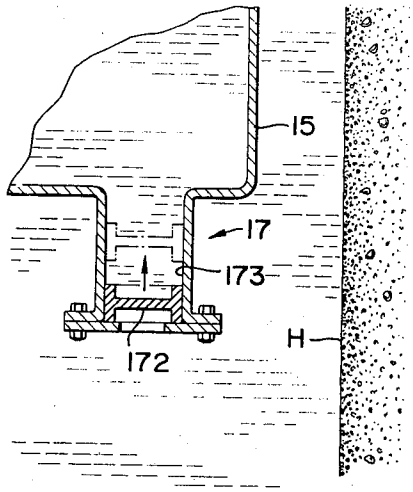


Fig. 7

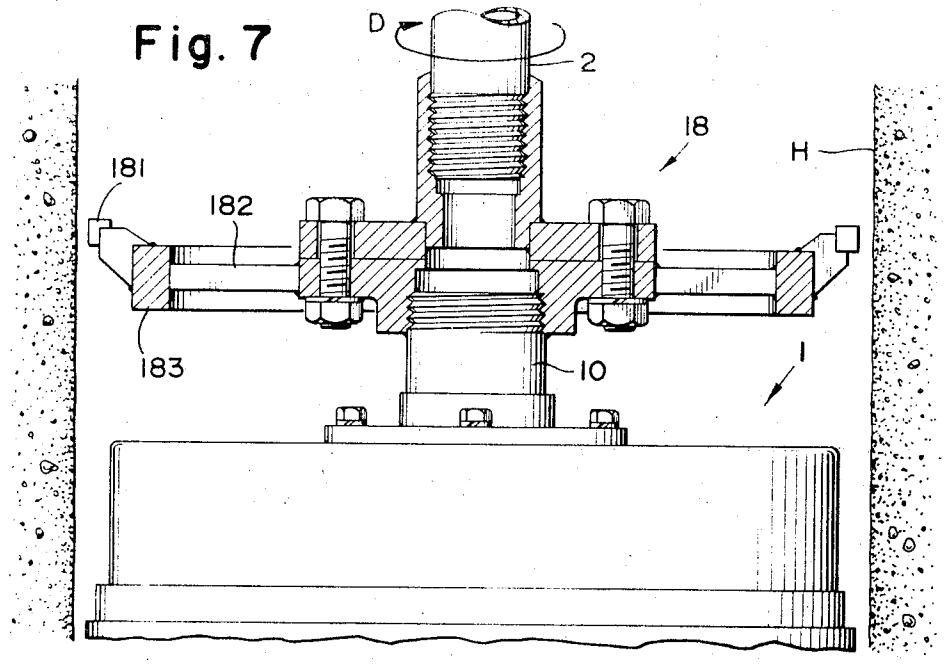
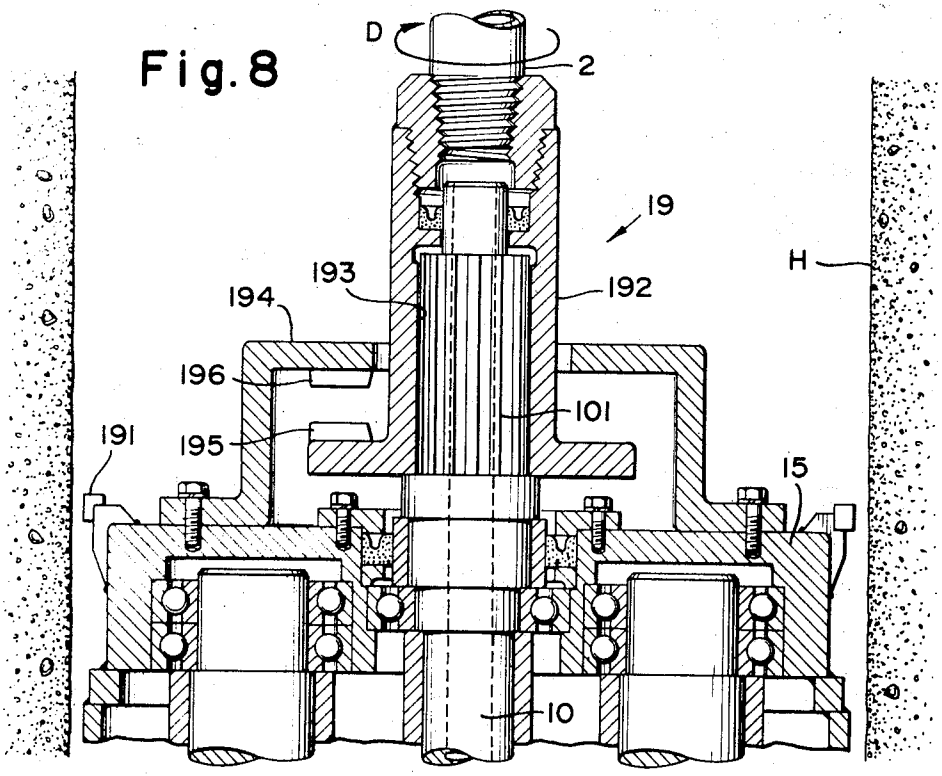


Fig. 8



EARTH BORING APPARATUS

The present invention relates to an earth boring apparatus being driven by a drilling pipe, and more particularly to such an apparatus which can effectively penetrate, among others, earth formations containing gravel and boulders.

In a conventional earth boring method in which a drill bit is rotationally driven while being simultaneously fed downwardly, each of cutting edges mounted on the drill bit is moved in a plan view along a circular path which is co-axial with circular paths of the other cutting edges. Therefore, in this known method, it has been difficult to take out slime as a bore is enlarged. Particularly, when an earth formation containing gravel and boulders is penetrated, free gravel and boulders are moved with the drill bit on the bottom surface of the bored hole. Under this condition, even a strong reverse circulation is not effective to take out the gravel or boulders.

Therefore, it is an object of the present invention to provide an earth boring apparatus which can effectively bore even a large size hole by means of a quite novel technique as compared with a conventional apparatus in which cutting edges on a drill bit are moved along co-axial circular paths.

According to the present invention, the above and other objects can be achieved by an earth boring apparatus comprising a center shaft adapted to be connected with a power driven drilling pipe, a sun gear secured to the center shaft, at least one planetary gear directly meshing with said sun gear and carrying a cutter, and a planetary carrier rotatable with respect to said center shaft and rotatably supporting said planetary gear.

When it is intended to use the apparatus with boring water such as bentonite mud water, the planetary carrier may be provided with water discharge nozzle means for discharging water under pressure against each cutter, preferably the leading side thereof as viewed in the direction of rotation of the planetary carrier. With this arrangement, it becomes possible to clean the heavily loaded leading side of the cutting edge so as to prevent slime from adhering thereto. Thus, the cutting edge can always be maintained sharp and slime removal can be facilitated.

Further, in the earth boring apparatus, the cutters may be mounted in such a manner that their axes are inclined in the direction of rotation of the planetary carrier. With this arrangement, the cutting edges on each cutter are placed away from the bottom of the bore at the trailing side as viewed in the direction of the planetary carrier rotation. Thus, the sharpness of the cutting edges can be maintained for a prolonged period.

When the apparatus of the present invention is designed to be used with boring water, a lubricant filled sealed casing constituting the planetary carrier may be provided with a liquid pressure balancing device for balancing the pressure of the lubricant in the casing and the water pressure in the bored hole so as to ensure a positive seal even in a deep hole.

The apparatus of the present invention may be added at the upper portion thereof with a reaming device for facilitating lifting of the apparatus in a hole drilled in crumbly formations.

The above and other objects and features of the present invention will become apparent from the following description of preferred embodiments taking reference to the accompanying drawings, in which;

FIG. 1 is a longitudinal sectional view showing one embodiment of the earth boring apparatus in accordance with the present invention;

FIG. 2 is a plan view taken along the line II—II in FIG. 1, showing the arrangement of cutters;

FIG. 3 is a diagrammatical side elevational view, with a part shown in section, of another embodiment of the present invention in which cutters are mounted on inclined axes;

FIG. 4 is a sectional view taken along the line IV—IV of FIG. 3;

FIG. 5 is a diagrammatical sectional view of a diaphragm type liquid pressure balancing device;

FIG. 6 is a diagrammatical sectional view of a piston type liquid pressure balancing device;

FIG. 7 is a sectional view of a reaming device; and,

FIG. 8 is a sectional view similar to FIG. 7 showing another embodiment.

Referring now to the drawings, FIG. 1 shows one embodiment of the earth boring apparatus in accordance with the present invention, the apparatus being shown in operation in longitudinal section. In the drawing, the earth boring apparatus is generally shown by the reference numeral 1 and comprises a center shaft 10 connected to a power driven drilling pipe 2. The apparatus 1 is supplied with a driving torque and a thrust force through the drilling pipe 2.

The center shaft 10 has a sun gear 11 secured thereto and directly meshing with planetary gears 12. In the illustrated arrangement, three planetary gears 12 are mounted at circumferentially spaced equi-distant positions (refer also to FIG. 2). A cutter 14 is fixed at the end of the shaft 13 for each planetary gear 12. The shaft 13 for the planetary gear 12 is journalled on a planetary carrier or rotatable casing 15 which is rotatable about and with respect to the center shaft 10.

The operation of the earth boring apparatus described above will now be explained with respect to a boring of a earth hole H.

It is supposed that the drilling pipe 2 is driven to be rotated in a clockwise direction as viewed from the top as shown by an arrow D in FIG. 1. The rotation is then transmitted through the center shaft 10 to the sun gear 11. Thus, each planetary gear 12 meshing with the sun gear 11 is caused to revolve in the counterclockwise direction. As a result, all of the cutters 14 are caused to rotate about their own axes in the counterclockwise direction as shown by the arrows P in FIG. 2. At the same time, the planetary carrier or casing 15 is caused to rotate in the clockwise direction as shown by the arrow Q. Thus, each of the cutters 14 is caused to revolve in the direction of the arrow Q, while simultaneously being rotated about its own axis in the direction of the arrow P. It should be understood that the torque for causing the revolution is the sum of the torque load on the cutter 14 and that on the drilling pipe 2, so that an excessive torque will cause the cutters 14 to revolve about the axis of the apparatus. In other words, since the revolution is produced in accordance with the load in the illustrated arrangement, an excessive shock load can be avoided and a smooth boring can be performed.

It should be noted that, according to the arrangement of the invention, each cutting edge on each cutter 14

is moved along a hypotrochidal path as shown by a chain line T in FIG. 2. It should of course be pointed out that the cutting edge does not always move along a geometrically exact hypotrochoidal path as shown by the line T, because, as previously referred to, the ratio of speed of rotation to that of revolution changes in response to the resistance given by the earth being bored. When each of the cutters **14** is rolled on the bottom surface of the bore H without any slippage, the trace of each cutting edge is considered to conform to an exact hypotrochoidal curve. Particularly, a cutting edge mounted on the outer-most periphery of the cutter moves along a hypocycloidal curve.

The present inventor has found that the performance of the boring apparatus can be substantially improved by providing an arrangement in which each cutting edge on a cutter **14** is moved along a substantially trochoidal curve.

According to a conventional apparatus, each of the cutting edges on a drill bit is always moved along a circular path while simultaneously being fed downwardly. In contrast to this, according to the arrangement of the present invention, each of the cutting edges on the cutter **14** is never moved repeatedly along the same path. Further, according to the present invention, each cutting edge is moved with a radial speed component, so that an area on the bottom of the bored hole which is in one moment cut by an edge moving with a radially outward speed component may in another moment be cut by another cutting edge moving with a radially inward speed component.

The arrangement of the present invention is understood to provide significant advantages partly due to the fact that a rough surface is produced on the bottom of the bored hole resulting in a slime of greater size.

Previously, it has usually been considered that it is very difficult to produce a bore penetrating the earth formations containing gravel or boulders. However, it has been found by the present inventor that the apparatus of the invention is effective to penetrate even the formations containing gravel or boulders. In fact, the pieces of gravel or boulders excavated by the cutters **14** are displaced radially outwardly toward the wall surface of the hole being bored due to the radial speed component of the cutting edge movement. In fact, as viewed in the direction of revolution, the cutting edge at the leading side has a radially outwardly directed speed component, so that the pieces of gravel or boulders located in front of the rotating cutter are displaced toward the hole wall H so as to be forced into the soft earth. This is considered to be a unique effect obtained by the present invention. In an arrangement in which a revolving casing or planetary carrier is positively driven at a predetermined speed which is independent from the load thereon, it would not be possible to force the pieces of stone instantaneously into the bore wall, so that an excessive driving torque would possibly be encountered and the boring operation would often be blocked. In contrast to this, according to the present invention, although the planetary carrier continues to be revolved, it is not positively driven so that there can be provided a sufficient time to force the gravel or boulders into the bore wall H.

Similarly, slimes other than gravel or boulders can also be forced toward the bore wall, so that the wall can be reinforced sufficiently to prevent breaking thereof. Further, since the slime content in circulation water is possibly reduced, the slimes can be readily taken out and the efficiency of operation of the apparatus can be improved.

In fact, according to experiments made by the inventors, it has been found that a lot of gravel and boulders are embedded in the bore wall H.

Referring to a trailing side, it has a speed component directed radially inwardly and moves apart from the gravel or boulders behind the cutter, so that it does not serve to collect the gravel or boulders at the center of the bore. Therefore, according to the present invention, it is possible to rapidly remove fine floating slimes by means of a reverse circulation through a suction port provided at the center of the apparatus. Thus, the efficiency of operation can further be raised.

When the apparatus of the present invention is used in boring soil formations, boring water may be injected toward the cutter, preferably the front surface of each cutter as viewed in the direction of revolution so as to prevent the mud from adhering to the cutting edges. Thus, the sharpness of the cutters can be maintained for a long period.

An example of such an application will now be described taking reference to the drawings. In this case, the center shaft **10** is used as a water supply pipe and a water discharge nozzle **16** is provided at the center of the bottom surface of the revolving casing or planetary carrier **15.** Thus, the nozzle **16** is located on a line which is an extension of the hollow central shaft **10.** The angle of water discharge is so adjusted that the water injected from the nozzle **16** is directed toward the cutting edges at the leading side of the cutter. Since the discharge nozzle **16** is secured to the revolving casing **15,** the relative position between the nozzle **16** and the cutter **14** does not change and the water discharged from the nozzle **16** is always directed toward the front surface of each cutter. Thus, the water discharged from the nozzle **16** is effective to clean the cutting edges at the leading side of each cutter, which performs most of effective work accomplished by the cutter.

Further, in the apparatus of the present invention, each cutter may be mounted on a forwardly inclined axis so as to improve the cutting performance. An example of such an arrangement will now be described taking reference to FIGS. **3** and **4.**

Referring to FIG. **3,** a cutter **14** having cutting edges on the outer periphery is supported on a shaft **13** which is inclined by an angle θ from a vertical line forwardly as viewed in the direction of revolution. With this arrangement, the cutting edges at the leading side of the cutter **14** are always in engagement with the bottom surface of the hole H to perform work while those at the trailing side are placed apart from the bottom. Thus, the cutting edges on the cutter **14** intermittently come into engagement with the hole bottom.

It should be understood from the drawing that the cutting edges at the leading side of the cutter performs most of the work. Therefore, in an arrangement in which the cutter is mounted with no inclination, the cutting edges at the trailing side of the cutter merely slide on the bottom surface without performing any substantial work. In this view, the arrangement is not preferred from the standpoint of wear. According to the arrangement in which the cutter is mounted on a forwardly inclined shaft, the above problems can be solved.

The arrangement in which the cutter is mounted on an inclined shaft is considered to be preferable in view of the mode of cutting the earth, however, in putting the arrangement into practice, there may be several technical problems. For example, there may be problems in transmitting a high driving torque between a pair of non-parallel shafts.

It has been known to use screw gear means for transmitting a rotation between a pair of skewed shafts. However, it should be pointed out that the screw gear means operate in theory with a point engagement between two gears, so that it is not suitable to transmit power although it may be useful as a motion transmitting mechanism. In view of the fact that the apparatus of the present invention is subjected to a heavy load, the screw gear means is not preferable to this apparatus.

The drawings show an embodiment which can eliminate the above problems. Referring to FIGS. 3 and 4, a gear 12 meshing with a gear 11 has therein internal gear teeth 121 which mesh with a spline 122. According to the present invention, the gear teeth 121 mesh with the spline 122 with a gap as shown in FIG. 4. The gap allows arrangement of the longitudinal axis of the support shaft 13 with a slight inclination as indicated by the angle θ with respect to a vertical line or the longitudinal axis of the gear 12. According to the inventor's experiment, the spline engagement has proven to be practically advantageous. The angle of inclination θ may be less than 5°, and usually 2° to 3°.

According to the present invention, it may be possible, in order to provide a sufficient lubrication of gear arrangements and bearing means, to fill the interior of the sealed planetary carrier or revolvable casing 15 with lubrication oil. When the apparatus is used in an earth boring method in which the operation proceeds while filling the hole with boring water such as bentonite mud water, it may be liable to come into the casing 15 as the head of the water increases. In order to prevent this problem, a liquid pressure balancing means may be provided at a suitable position in the casing 15. FIGS. 5 and 6 show examples of the liquid pressure balancing means 17 mounted in the casing 15 which is filled with a lubricant oil. The balancing means 17 shown in FIG. 5 comprises a diaphragm 171 which can deflect in response to the difference between the oil pressure in the casing 15 and the water pressure in the hole so as to reduce the difference to a minimum. FIG. 6 shows a balancing means 17 comprising a piston 172 and a cylinder 173 receiving the piston 172. By providing either type of pressure balancing means 17 at a suitable position in the casing 15, it is possible to maintain the pressure difference between the interior and the exterior of the casing 15 so that a positive seal can be ensured even during a deep boring operation.

As previously mentioned, the apparatus of the present invention is advantageous in that each of the cutting edges on cutters is moved along a trochoidal path so that the wall surface of the bored hole H can be reinforced. However, when the apparatus is used in extremely loose soil, it may be difficult to withdraw the apparatus from the bored hole H, even though the drilling pipe is forcedly driven, because the revolvable casing 15 does not revolve under the no-load condition. In order to overcome this problem, the apparatus may preferably be provided with a reaming device to assist lifting of the apparatus.

The reaming device 18 shown in FIG. 7 includes reaming bits 181 secured to the center shaft 10. Alternatively, the reaming bits 181 may be secured directly to the drilling pipe 2. The bits 181 are mounted on the periphery of a rim 183 supported on rib portions 182 extending radially outwardly from a flange on the center shaft 10. With this arrangement, when the apparatus 1 is lifted in the bored hole H while driving the pipe 2, the reaming bits 181 serve to remove obstructions even when the bore wall is broken. Thus it is possible to lift the apparatus 1 without any trouble.

FIG. 8 shows a reaming device 19 which can move with the planetary carrier or revolvable casing 15 during the boring operation but can be positively driven in lifting the apparatus. In this arrangement, reaming bits 191 are mounted on upper peripheral edges of the casing 15. Further, a coupling member 192 is secured to the lower end of the drilling pipe 2. The center shaft 10 is provided at the upper portion with male spline teeth 101 which mesh with female spline teeth 193 of the coupling member 192. Thus, the pipe 2 and the center shaft 10 are connected through a coupling member 192 and a spline means. The coupling member and spline means can rotate together but are axially slidable with each other. A second coupling member 194 is secured to the upper surface of the casing 15. The coupling members 192 and 194 have co-operating clutch elements 195 and 196 respectively.

In FIG. 8, the apparatus is shown in a boring operation. In this position the clutch elements 195 and 196 are disengaged, so that the driving force from the drilling pipe 2 is not transmitted to the casing 15. When the drilling pipe is lifted, the clutch elements 195 and 196 on the coupling members 192 and 194 respectively are put into engagement. Therefore, it is possible to drive the reaming bits 191 on the casing 15 by rotating the pipe 2, so as to remove any obstructions by the reaming bits 191 in order to allow the withdrawal of the apparatus from the bored hole.

From the above description, it will be apparent that the apparatus of the present invention, in which each cutting edge of each cutter is moved along a trochoidal path, can be very effectively used in boring earth, particularly such earth formations containing gravel or boulders.

What is claimed is:

1. An earth boring apparatus comprising:
   a. a power driven drilling pipe;
   b. a center shaft connected to said pipe and rotatable therewith;
   c. a sun gear connected to said center shaft;
   d. at least one planetary gear meshing with said sun gear;
   e. a cutter carried by said planetary gear and rotatable in a direction opposite to the rotation of said center shaft; and
   f. a revolving casing rotatably supporting said planetary gear and rotatable in the same direction as said center shaft, said cutter being driven by the torque on the drilling pipe and said revolving casing being driven by the reaction torque generated in the casing.

2. An earth boring apparatus in accordance with claim 1, in which said cutter is supported on said revolving casing with the axis inclined forwardly with respect to the direction of revolution of said revolving casing.

3. An earth boring apparatus in accordance with claim 1, in which said revolving casing is a sealed casing filled with lubricant oil and provided with liquid pressure balancing means.

4. An earth boring apparatus in accordance with claim 1, which further comprises reaming means for removing obstructions when the apparatus is being lifted.

5. An earth boring apparatus in accordance with claim 1 wherein at least one cutting edge is mounted on the outermost periphery of said cutter.

6. An earth boring apparatus in accordance with claim 1, which further comprises water discharging nozzle means mounted on said revolving casing for discharging water under pressure toward each cutter.

7. An earth boring apparatus in accordance with claim 6 in which said water discharging nozzle means discharges water under pressure towards the leading side of each cutter.

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