REACTION COUNTERBALANCED EARTH BORING

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ABSTRACT

Earth boring using a machine having a plurality of cutters which are disposed at mechanically balanced positions on a casing co-axial with and rotatable about the center axis of the machine, the output of a motor being divided into two, one output being used to rotate the cutters about their own axes in one direction, the other being used to rotate the casing in the opposite direction, the total torque for rotating the cutters being substantially equal to the torque for rotating the casing whereby the reaction moment required for supporting the machine is negligible.

5 Claims, 11 Drawing Figures
The present invention relates to an earth boring method and machine, and more particularly to such a method and machine in which reaction torque can be substantially counterbalanced.

In a conventional earth boring apparatus in which a drill bit is rotated through drilling pipe while being fed downwardly, it has been necessary to provide sufficient rigidity to the drilling pipe, that is, the main power transmitting member, and also to provide complicated large mechanisms on the ground for supporting and driving the drilling pipe. Further, it has also been necessary to add another pipe in every few meters of boring operation.

In order to overcome the above disadvantages of a conventional boring operation, the inventor proposed a novel method and machine for boring earth in a co-pending application Serial No. 192,217, filed Oct. 26, 1971 and entitled "Reaction Minimized Earth Boring."

The earth boring method of the above application is characterized by the fact that the output torque of a high speed motor is transmitted with a high reduction ratio to a plurality of cutters disposed at mechanically balanced positions so that each of the cutters is rotated about its own axis while revolving about the center axis of the machine so as to reduce the reaction torque on the motor supporting mechanism. According to this method, it is not necessary to have drilling pipe of a high torsional rigidity, but it is simply required to support and suspend the boring machine with a thin-walled pipe, a strong hose or a chain. Further, it is possible to substantially simplify ground equipment.

The present invention has an object the further improvement of the machine as disclosed in the co-pending application Another object is to provide a novel and excellent boring method which can reduce the reaction torque on a main body of an earth boring machine on which a motor is mounted.

The above and other objects of the present invention can be achieved by means for dividing an output of a motor means mounted on a body into two opposed torques through transmission means, and transmitting one of the torques to a plurality of cutters which are disposed at mechanically balanced positions, the other being transmitted to a casing which is rotatable with respect to the body and supports said cutters, the total torque for rotating said cutters being substantially equal to the torque for rotating said casing whereby the reaction moment required for supporting said body is negligible.

The aforementioned method of the present invention can be put into practice by an earth boring machine comprising motor means mounted on a body of the machine, transmission means such as a speed change gear means connected with said motor means to divide the output torque thereof, a casing mounted on said body and rotatable with respect thereto, a plurality of cutters disposed on said casing at mechanically balanced positions, said cutters being driven to rotate about their own axes through the transmission means and a motion transmitting member which is rotatable co-axially with respect to the casing, said transmission means being further connected with said casing so that the latter is rotated by reaction in the direction opposite to the rotation of each cutter, the torque transmitted through the motion transmitting member being substantially equal to the brake torque of said casing.

According to further aspect of the present invention, the revolvable casing may be provided with a core breaker at the center of the end surface thereof so as to break a central core that remains at the bottom of a hole being bored.

Further, in the above machine, the motors mounted on the body may be submersible motors, and a double pipe may be disposed at the center of the machine so as to feed boring water into and out of the hole being bored for applying the machine in a water boring method. This arrangement is effective to perform a forced circulation of boring water.

The above earth boring machine may be provided with water discharge nozzle means on the casing so as to jet discharge water toward the cutters, preferably the leading sides thereof. With this arrangement, it is possible to keep each cutting edge always clean and prevent mud from adhering thereto. Thus, the cutting edges can be maintained sharp and the removal of slime can be facilitated.

Further, in the earth boring machine of the present invention, each of the cutters may be supported with its drive shaft forwardly inclined in the sense of the rotation of the casing. With this arrangement, cutting edges on each cutter are kept apart from the bore bottom when they are at the trailing side as seen in the rotation of the casing. Thus, cutting performance can further be improved.

When the machine of the present invention is intended to be used in a boring water method, the revolvable casing may be a sealed casing filled with lubricating oil. In such an arrangement, the machine may be provided with a liquid pressure balancing means so as to balance the pressure of the lubricating oil with the pressure of water in the bored hole to positively maintain a seal even in a deep hole.

When the machine is used in a boring water method, it may be provided at the upper portion thereof with a thrust adjusting float which is so constructed that the amount of air therein can be readily adjusted. This arrangement is advantageous in that it is possible to maintain the optimum thrust value by varying the floating force.

According to the present invention, it is also possible to attain the advantages of the machine as disclosed in a co-pending application entitled Ser. No. 192,282, filed Oct. 26, 1971 and "An Earth Boring Apparatus" since each cutting edge on each cutter is also moved along a trochoidal path.

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

FIG. 1 is a diagrammatic elevational view, partly in vertical section, showing the general arrangement of a boring plant employing an earth boring machine according to the present invention;

FIG. 2 is an elevational view, in vertical section, showing in detail the earth boring machine shown in FIG. 1;

FIG. 3 is a sectional plan view taken along the line A—A in FIG. 2, showing the arrangement of cutters;

FIGS. 4 through 6 show sectional views similar to FIG. 3 but showing other arrangements of cutters;
FIG. 7 is a diagrammatical side elevation of another embodiment of the present invention in which each cutter is mounted on a forwardly inclined shaft, a part of the machine being shown in section to show the interior thereof;

FIG. 8 is a sectional view taken along the line VIII—VIII of FIG. 7;

FIG. 9 is a fragmentary sectional view showing a diaphragm type liquid pressure balancing means;

FIG. 10 is a fragmentary sectional view showing a piston type liquid pressure balancing means; and,

FIG. 11 is a diagrammatical view with parts broken away of a thrust adjusting float in accordance with the present invention.

Referring to the drawings, particularly to FIG. 1, there is diagrammatically shown the general arrangement of an earth boring plant by which the present invention is applied in a water reverse circulation method.

In FIG. 1, the reference numeral (1) generally shows an earth boring machine embodying the present invention. The machine includes motors, however, as will be explained later in more detail by a torque analysis, the body of the machine is substantially free from a twisting torque load so that it is not required to use a drilling pipe of a high rigidity as has been required in a conventional earth boring apparatus. Thus, it is possible to suspend the machine (1) by means of a thin-walled pipe or a chain (2) shown in FIG. 1.

When an earth hole (H) is formed by a water boring method, submersible electric or hydraulic motors may be used as driving power sources. In the illustrated embodiment, electric motors are employed and supplied with electric power through cables (3). The cables (3) are continuously fed from a cable reel (9) as the depth of the hole (H) increases.

When hydraulic motors are used, oil hoses and hydraulic pump means are used in the place of the cables (3).

Water is supplied under pressure through a hose (4) and discharged at the bottom end of the boring machine to clean cutting edges on cutters and prevent slime from adhering thereto. The slime and gravel are exhausted through an exhaust hose (5). For this purpose, it may be possible to use a centrifugal pump, however, it is a usual practice to feed air bubbles from an air supply hose (6) into the exhaust conduit so as to effect an air lifting. The reference numeral (13) designates an air compressor used for this purpose.

The slime-containing-water is circulated through a mud screen (11) and a cyclone (12) into a water supply pump (10).

The ground equipment may include a derrick (7) which may be of a simple and light duty construction as compared with that in a conventional apparatus. According to the present invention, as will be explained later in detail, it is not necessary to provide on the ground a prime mover and a transmission for applying rotation to a drilling pipe. Therefore, it is possible to suspend the machine (1) by a suitable lifting means such as the chain (2) shown in the drawing. In such an arrangement, the derrick (7) is only required to support an electrically operated chain block (8) or a head pulley for a hoist. Further, according to the present invention, water can be circulated through hoses (4) and (5) so that it is not necessary to provide swivel joint means for water passages.

If desired, a guide (14) may be provided around the machine (1) for securing straight boring.

The detail of the machine (1) shown in FIG. 1 will now be described with reference to FIG. 2.

In FIG. 2, there is shown an earth boring machine (1) embodying the present invention and intended to be used under water. Thus, the machine (1) has a self-contained driving means in the form of a submersible electric motor.

The machine (1) has a body (100) including a central member (110), a transmission gear box (130) secured to the central member (110) and submersible electric motors (120) mounted on the gear box (130).

In the illustrated arrangement, the central member (110) is a double pipe construction including an inner pipe (111) and an outer pipe (112) which are respectively connected with the aforementioned water exhaust hose (5) and the water supply hose (4). The water supplied under pressure through the water supply hose (4) is passed between the inner pipe (111) and the outer pipe (112) and discharged from nozzles (141). The inner pipe (111) is connected at an intermediate portion thereof to the aforementioned air supply hose (6) to be supplied with compressed air for exhausting slime through the water exhaust hose (5).

With the above arrangement in which the central member (110) is in the form of a double pipe having the aforementioned inner and outer pipes (111) and (112), the pressurized water from the ground is directly discharged to the bottom of the hole which is being bored by cutters. The water then carries the slime produced during the boring operation through the inner pipe (111) for discharging it from the hole. Thus, the machine of the present invention is effective to maintain a water reverse circulation.

The submersible motors (120) are secured to the double pipe or central member (110). In the illustrated embodiment, two motors (120) are used, however, it should be understood that the present invention is not intended to limit the number of such motors. As mentioned above and illustrated in the drawings, a double tubular shaft means (150, 151) is disposed about and coaxially with the central member (110). In one embodiment shown by the drawings, one tubular shaft (151) is arranged to rotate the revolution casing (140), while another tubular shaft (150) is used as a transmission member of power for the drill bit (160).

Each of the motors (120) has an output shaft secured to a sun gear (I-1) of a first stage planetary gear means. A plurality of planetary gears (I-2) are in meshing engagement with the sun gear (I-1). The first stage planetary gear means is constituted by the sun gear (I-1) and the planetary gears (I-2).

Each of the planetary gears (I-2) is connected with a planetary gear (II-1). A sun gear (II-2) is disposed coaxially with the sun gear (I-1) and meshes with the planetary gears (II-1). The planetary gears (II-1) and the sun gear (II-2) constitute a second stage planetary gear means.

A planetary carrier (131) for supporting the planetary gears (I-2) and (I-2) is rotatable with respect to the gear box (130). The planetary carrier (131) has a co-axial gear (III-1) secured thereto. The gear (III-1) engages with a gear (III-2) secured to a revolvable casing (140) which is rotatable with respect to the body. The gears (III-1) and (III-2) constitute a third stage speed reduction gear means.
A plurality of cutters (160) are rotatably mounted on the casing (140) at mechanically balanced positions. A gear (IV-1) is secured to the sun gear (II-2) of the second stage planetary gear means. The gear (IV-1) serves to drive a gear (IV-2) which is secured to a transmission member (150). The gears (IV-1) and (IV-2) constitute a fourth speed reduction gear means. The transmission member (150) is rotatable with respect to the casing (140).

A gear (V-1) is provided beneath the transmission member (150) for driving a gear (V-2) secured to the support shaft of each cutter (160). The gears (V-1) and (V-2) constitute a fifth stage gear means. In the illustrated embodiment, the double pipe (110) is of a relatively large diameter with respect to the diameter of the hole (H) to be bored. Thus, the gear (V-1) has a substantial diameter and the fifth stage gear means is designed as a speed increasing stage.

A core breaker (142) may be provided at the center of the end of the casing (140) for cutting the soil portion which is left unbroken by the peripherally disposed cutters (160). Water discharge nozzles (141) are mounted on the casing (140) in proximity to its end. Suitable seal means may be provided between the body (100) and the casing (140).

The operation of the earth boring machine constructed as explained above will now be described.

When each of the motors (120) is rotated clockwise in plan view as shown by the arrow (C), the rotation is transmitted through the gears (I-1), (I-2), (II-1) and (II-2) to the gear (IV-1) to cause it to rotate in the same direction. Thus, the gear (IV-2) which engages with the gear (IV-1) is then rotated to cause the transmission member (150) to rotate in the counterclockwise direction. Thus, the rotation is transmitted through the first, second and fourth stage speed reduction gear means.

Then, the gear (V-1) secured to the lower portion of the transmission member (150) is rotated and drives the gear (V-2) secured to the support shaft of the cutters (160). This fifth stage gear means serves to rotate the cutters (160) in the clockwise direction as shown by the arrow (P) in FIG. 3 at a slightly increased speed.

Since the planetary carrier (131) supporting the planetary gears at the first and second stage gear means is connected through the third stage gear means to the revolvable casing (140), the casing is rotated counterclockwise as shown by (Q) due to the reaction produced by the rotation of the cutters (160) (refer to FIG. 3). As the casing (140) is rotated counterclockwise (Q), the planetary carrier (131) is caused to rotate clockwise through the third stage gear means. Thus, the torque for supporting the body (100) can be counterbalanced as will be explained later in detail.

In this manner, as the output shaft of each motor (120) is rotated clockwise as shown by the arrow (C), each of the cutters (160) is rotated about its own axis as shown by the arrow (P) in FIG. 3, while revolving about the axis of the machine or the hole in the counterclockwise direction as shown by the arrow (Q).

The following is an analysis of torques acting in the earth boring machine (1) in accordance with the present invention.

When the output torque of the motor is designated by \( T_M \), and the speed reduction ratios at the first and second stage planetary gear means by \( R_I \) and \( R_{II} \) respectively, the torque \( T \), transmitted to the gear (II-2) can be represented by the following equation.

\[
T_H = R_I \cdot R_{II} \cdot T_M
\]  

On the other hand, the torque \( T_C \) appearing at the planetary carrier (131) is represented by the following equation.

\[
T_C = (1 - R_I \cdot R_{II}) \cdot T_M
\]

Since the gear (III-1) secured to the planetary carrier (131) is engaging with the gear (III-2) secured to the revolvable casing (140), the reaction torque \( T_{III} \) acting on the gear (III-2) can be represented by the following equation,

\[
T_{III} = -R_{III} \cdot T_C = -(1 - R_I \cdot R_{II}) \cdot R_{III} \cdot T_M
\]

where:

\( R_{III} \) designates the speed reduction ratio at the third stage gear means.

The torque \( T_{IV} \), transmitted from the gear (II-2) through the gear (IV-1) to the gear (IV-2) can be represented by the following equation,

\[
T_{IV} = -R_{IV} \cdot T_H = -R_I \cdot R_{II} \cdot R_{IV} \cdot T_M
\]

where:

\( R_{IV} \) is the speed reduction ratio of the fourth stage gear means.

The torque \( T_{IV} \) is transmitted through the transmission member (150) to the gear (V-1) secured thereto. Further, the torque \( T_V \) transmitted to each cutter (160) which is driven by the gear (V-2) meshing with the gear (V-1) can be represented by the following equation,

\[
T_V = -T_{IV} \cdot r_1 \cdot r_2 \cdot l \cdot b \cdot F = + R_I \cdot R_{II} \cdot R_{IV} \cdot T_M \cdot (r_2 \cdot r_1)
\]

where:

\( r_1 \) is the radius of the pitch circle of the gear (V-1) and \( r_2 \) is the radius of the pitch circle of the gear (V-2). Thus, the force \( F \) acting on the gear (V-2) can be represented by the following equation.

\[
F = T_V / r_2 = R_I \cdot R_{II} \cdot R_{IV} \cdot T_M \cdot (1/r_1)
\]

Therefore, the revolving torque \( T_V' \) about the center axis of the machine produced by the force \( F \) acting on the cutter (160) can be represented by the following equation.

\[
T_V' = -F \cdot (r_1 + r_2) = -R_I \cdot R_{II} \cdot R_{IV} \cdot T_M \cdot (1 + (r_2/r_1))
\]

Thus, the total revolving torque \( T \) acting on the drill bit (160) is represented by the following equation.
The requirement for free supporting the cutter can be represented as follows.

\[ T = T_p \]  

(9)

In order that the requirement is met, the following relation must be present as is apparent from the equations (5) and (8).

\[ (R_p R_{II} - 1) R_{III} = R_p R_{II} R_{IV} \]  

(10)

This yields;

\[ T_{IV} = -T_{III} \]  

(11)

Therefore, if the gear train is designed so that the requirement of the equation (10) is met, then the requirement of the equation (11) can be met. In other words, when the gear train is so designed that the requirement of the equation (11) is met, the rotating torque \( T_p \) acting on each cutter (160) becomes equal to the revolving torque (T). Since the rotation of the cutter (160) is in the opposite direction to the revolution thereof, the rotating torque \( T_p \) acting on the cutter can be completely counterbalanced with the revolving torque (T).

The above is the torque analysis regarding only one of the cutters (160), however, the same may be applied to the other cutters and the condition of the equation can be achieved when the requirements of the equations (10) and (11) are met.

Thus, according to the present invention, it is possible to make the total rotating torque \( 2T_p \) acting on the cutters (160) equal and opposite to the total torque \( 2T \) for causing the revolution of the cutters (160) so that they are counterbalanced with each other. Further, it is clear from the equation (11) that a desirable result can be obtained also by connecting the gear (111-2) with the gear (V-1) for driving the drill bit (160) through the transmission member of the double tubular shaft means (150, 151) and by connecting directly the gear (IV-2) with the revolution casing (140).

In the above analysis, the efficiency of the gear train, the frictional resistance of the sealing means and other minor factors have been neglected, however, by taking these factors into account, a more exact design can be achieved.

Thus, according to the present invention, the reaction torque acting on the body (100) of the earth boring machine (1) can be completely counterbalanced or at least reduced to such an extent that it does not have any effect on the means for suspending the machine. Therefore, the body (100) of the machine can be suspended by a chain (2), wire rope and the like without any risk that the chain (2) or wire rope is twisted or entangled with the cable (3) and the hoses (4), (5) and (6).

Further, according to the present invention, the following advantages can also be obtained.

Generally, when one uses a bearing, it is essential to determine the "DN" value which is the product of the diameter (mm) and the rotational speed (r.p.m.) below an allowable limit. (In a usual needle roller bearing, the allowable DN value is about 200,000.)

In a usual arrangement in which a sleeve member rotates at a relatively high speed with respect to a central member as disclosed in the above mentioned co-pending patent application entitled "Reaction Mini-imized Earth Boring," a specially designed bearing must be used in order to increase the diameter thereof. In contrast to this, according to the arrangement of the present invention, the central transmission member is directly connected with the revolving casing (140) so that it rotates at a slower speed. Therefore, even a large diameter bearing can be made of a usual bearing material. For this reason, it is possible to provide a large diameter exhaust pipe such as the pipe (111) at the center of the machine for performing a strong reverse circulation in order to remove by suction even relatively large gravel. Further, since the machine of the present invention includes the aforementioned unique torque transmission arrangement, the amount of output torque does not have any remarkable effect on the means for supporting the machine, so that it is possible to use a low speed high torque motor. For this reason, the power transmission means can be simplified by eliminating a complicated speed reduction means. In other words, since the apparatus does not include any high speed rotating part, there can be attained remarkable structural advantages.

As is apparent from the above description, the machine of the present invention is particularly suitable for boring a large diameter hole in an earth formation containing gravel or boulders by performing a strong reverse circulation through a large diameter water discharge pipe provided at the center of the machine.

FIG. 3 shows an example of arrangement of the cutters (160) in the machine shown in FIG. 2. As shown in the drawing, each of the cutters (160) is rotated about its own axis while simultaneously revolving in the opposite direction about the axis of the machine. As a result, each cutting edge on each cutter (160) is moved along a trochoidal path. Thus, the machine of the present invention also has features as disclosed in the above-noted co-pending patent application entitled "An Earth Boring Apparatus," so that it provides excellent performance.

FIGS. 4 through 6 show alternative arrangements of a plurality of cutters by plan views similar to FIG. 3. In FIG. 4, three cutters (160) of the same diameter are arranged at equi-distant positions on a circle coaxial with the machine. In FIG. 5, two large diameter cutters (160) and two small diameter cutters (161) are alternately arranged. By this arrangement, the large diameter cutters (160) can be positioned relatively close together, so that it is possible to prevent substantially core formation at the center of the hole bottom. In FIG. 6, four cutters (160) are positioned at mechanically balanced but not circumferentially equi-distant positions.

In using the machine of the present invention in boring earth through a boring water method, pressurized water is discharged through the nozzles (141) toward each cutter (160), preferably the leading side thereof. Since the relative position between each water discharge nozzle (141) and each cutter (160) remains un-
changed, it is possible to continuously clean the leading side cutting edges on each cutter (160) which are expected to perform a substantial part of the effective work. Thus, it is possible to maintain sharpness of the cutting edges.

According to the present invention, it is also possible to support a cutter (160) having cutting edges on its outer periphery with the axis inclined forwardly. By this arrangement, cutting performance of the cutter can be further improved. An example of such an arrangement will now be described with reference to FIGS. 7 and 8.

Referring to FIG. 7, the cutter (160) having cutting edges at the outer periphery is supported on a drive shaft having a longitudinal axis (S) inclined forwardly or in the direction of revolution by an angle (Θ). With this arrangement, the cutting edges at the leading side always contact the bottom of the hole (H), while those at the trailing side are spaced therefrom as shown by the gap (G). In other words, the cutting edges on the cutter (160) intermittently come into engagement with the hole bottom.

As is apparent from the drawing it is at the leading side that the cutting edges perform most of their work. Therefore, in a usual arrangement in which the cutter is mounted on a vertical shaft so that the cutting edges are located in a horizontal plane, the cutting edges merely slide along the hole bottom at the trailing side of the cutter. Thus, the power is wasted and the conventional arrangement is not desirable from the viewpoint of wear of cutting edges. According to the arrangement of the present invention, the aforementioned disadvantage can be eliminated.

Actually, in a milling machine, it has been recognized that, by providing a slight inclination to the tool axis, the cutting performance can be significantly improved. However, in a milling machine, such an inclination produces a concave surface, so that the inclination is allowed only in a rough cutting stage. By contrast, in an earth boring operation, a concave bottom surface is acceptable and it is not necessary to take this into account as an disadvantageous feature.

As is apparent from the above description, an advantageous result can be obtained by supporting each cutter on a forwardly inclined shaft, however, another technical problem is encountered in putting this feature into practice. In fact, there is a problem of transmitting a large torque between non-parallel shafts.

In order to transmit power between offset shafts, a screw gear has commonly been used. However, since the screw gear performs its function through a point contact, although it may be useful when it is desired to transmit a motion, it cannot bear a heavy load. Particularly, in an application of the machine in accordance with the present invention where the machine is subjected to a heavy load, it cannot be used since it is heavily worn.

This technical problem can be solved by the arrangement shown in the drawing. Referring to FIGS. 7 and 8, the gear (V-2) engaging with the gear (V-1) is formed with internal spline teeth (V-3) for engagement with an external spline (V-4). According to the present invention, apart from a usual spline connection, a gap is provided between the splines (V-3) and (V-4) as shown in FIG. 8. The provision of the gap enables arrangement of the drive shaft with its axis (x) slightly inclined by an angle (Θ) with respect to the vertical line. The inventor found through experiments that the novel spline connection is practically useful. The angle (Θ) of inclination may be less than 5°, and usually 2 to 3°.

In the earth boring machine in accordance with the present invention, each of the sealed casings (130) and (140) may be filled with lubricant oil in order to provide lubrication of the transmission means and the bearings. When the lubricant filled machine is used in a boring water method in which the boring operation proceeds while filling the hole with the water or bentonite solution, water head increases as the depth of the hole increases and the water tends to leak into the casings (130) and (140) through the seal means. In order to solve this problem, the casing (130) may be provided with liquid pressure balancing means at an appropriate position. In FIGS. 9 and 10, there is shown examples of such liquid pressure balancing means (190) adapted to be provided on the casing (130). FIG. 9 shows a liquid pressure balancing means (190) including a diaphragm (191) for balancing the oil pressure in the casing and the water pressure in the bored hole. In FIG. 10, the liquid pressure balancing means (190) comprises a piston (192) and a cylinder (193).

By providing a liquid pressure balancing means (190) at an appropriate position in the casing (130), the difference between the liquid pressure in and out of the casing can be reduced irrespective of the depth of the hole. Therefore, the machine can be used for drilling a deep hole maintaining a positive seal.

The earth boring machine (1) of the present invention may be suspended by a chain (2) or the like as shown in FIG. 1. In such a case, downward thrust is produced by the weight of the machine itself. When the weight of the machine is estimated to be insufficient in view of the nature of the earth formations to be penetrated, a weight or a drill collar may suitably be added.

When the hole being bored is filled with water, a thrust adjusting float may conveniently be used. An example of such an application is shown in FIG. 11. In this example, a thrust adjusting float (200) is disposed above the boring machine (1) and suspended by a chain (2). When it is desired to decrease the thrust due to the change of the nature of the earth formations, compressed air is supplied through an air hose (202) into an air chamber (201) so as to discharge the water through a water port (203). By decreasing the water level in the chamber (201), the buoyancy of the chamber (201) is increased with the result that the downward thrust acting on the cutters (160) is correspondingly decreased. When the machine encounters relatively hard formations, a part of the air in the chamber (201) is removed through the air hose (202) so as to increase the water level therein. Thus, the buoyancy of the chamber (201) is decreased and the downward thrust acting on the cutters (160) is correspondingly increased. As described above, in a boring water method in which the boring operation is performed while filling the bore with water, it is possible to perform the work with the most suitable thrust force simply by adding the thrust adjusting float (200).

From the above descriptions, it will be apparent that the method of the present invention can positively provide the advantageous features of the co-pending patent application entitled "Reaction Minimized Earth Boring" that it does not require any large diameter stiff drilling pipe as in a conventional apparatus, and that the ground equipment can be simplified so that the efficiency of the boring operation can be improved.
Further, the machine of the present invention is particularly effective to perform the above novel method, and is particularly suitable for boring a large diameter hole with a water boring method.

According to a further feature of the present invention, each cutting edge on each cutter is moved along a trochoidal path, so that the cutting performance can remarkably be improved as compared with a conventional apparatus.

Particularly, according to the present invention, the earth boring machine may be provided at the center part thereof with a large diameter water exhaust pipe. Thus, it is possible to perform the boring operation with a strong reverse circulation for removing gravel, boulders and the like. This advantageous feature has been recognized by experiments performed by the inventor.

What is claimed is:

1. An earth boring machine comprising a power source secured to a central member, a speed change gear means having a first casing rotatable coaxially with the output shaft of said gear means, two tubular shafts disposed rotatably about and coaxially with said central member, a second revolution casing rotatable about said central member and connected to one of said tubular shafts, a drill bit rotatably supported on said revolution casing about its own axis and connected with the other one of said tubular shafts, wherein the directions of the rotation torques of said tubular shafts are opposite to each other and the intensities of the rotation torques thereof are substantially the same.

2. An earth boring machine according to claim 1 in which a core brake is disposed on said revolution casing at lower end thereof.

3. An earth boring machine according to claim 1 in which said central member is a double pipe structure comprising inner and outer pipes to form a cylindrical gap between them extending to the lower end portion thereof, through which gap water is fed to nozzle means disposed at the lower end portion of said revolution casing to supply water into the bottom of a bored hole and through which inner pipe slime is exhausted.

4. An earth boring machine according to claim 1 in which said revolution casing is a sealed casing filled with lubricant oil and provided with liquid pressure balancing means.

5. An earth boring machine according to claim 1 further comprising a thrust adjusting float.