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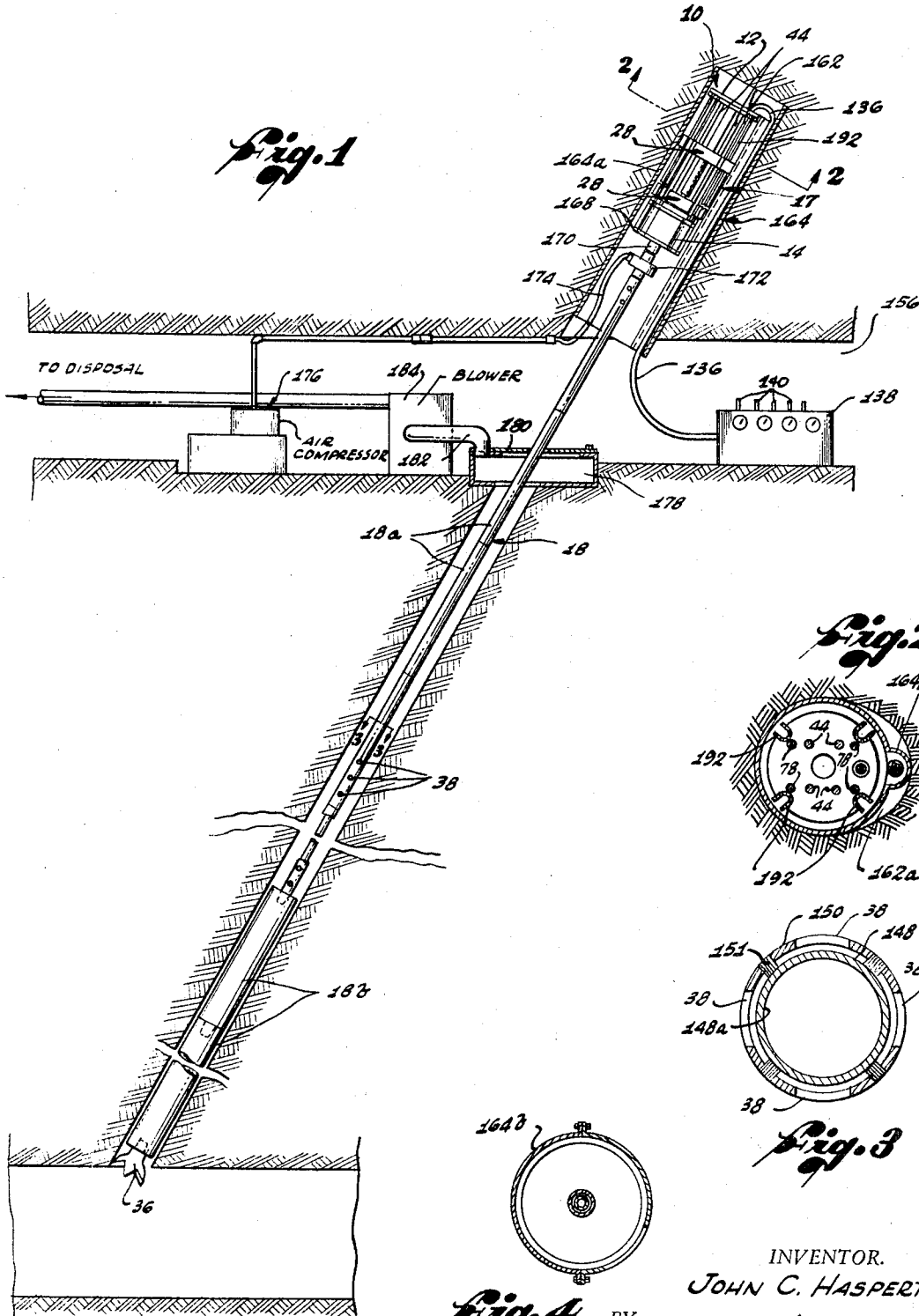
J. C. HASPERT

3,399,738

RAISE DRIVER

Filed June 6, 1966

6 Sheets-Sheet 1



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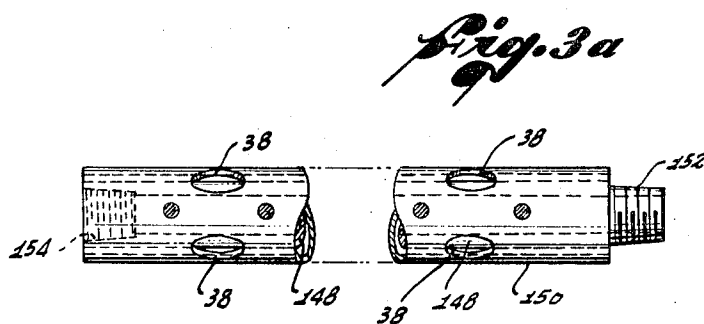
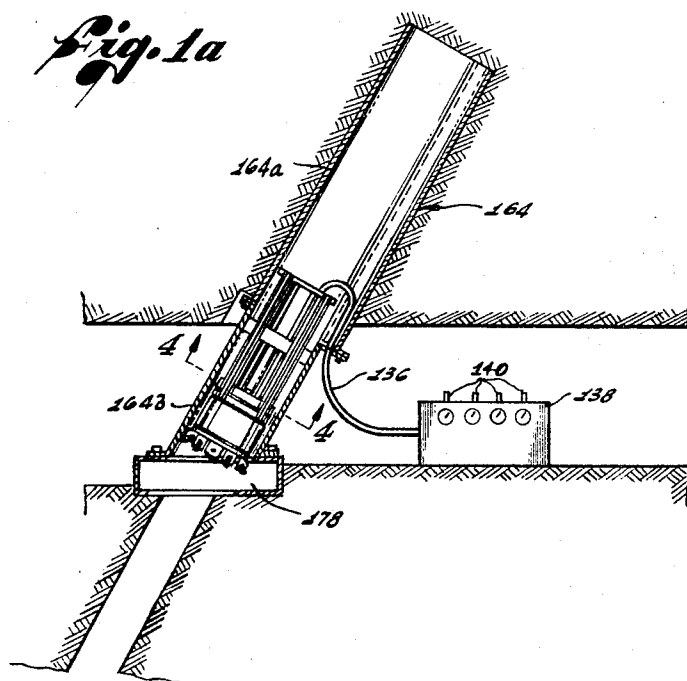
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Filed June 6, 1966

6 Sheets-Sheet 2



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Filed June 6, 1966

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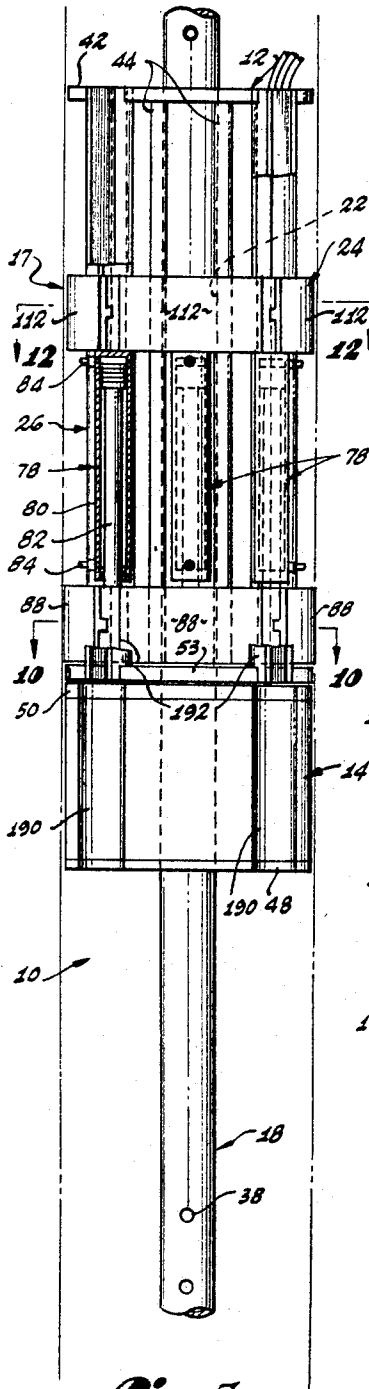


Fig. 5

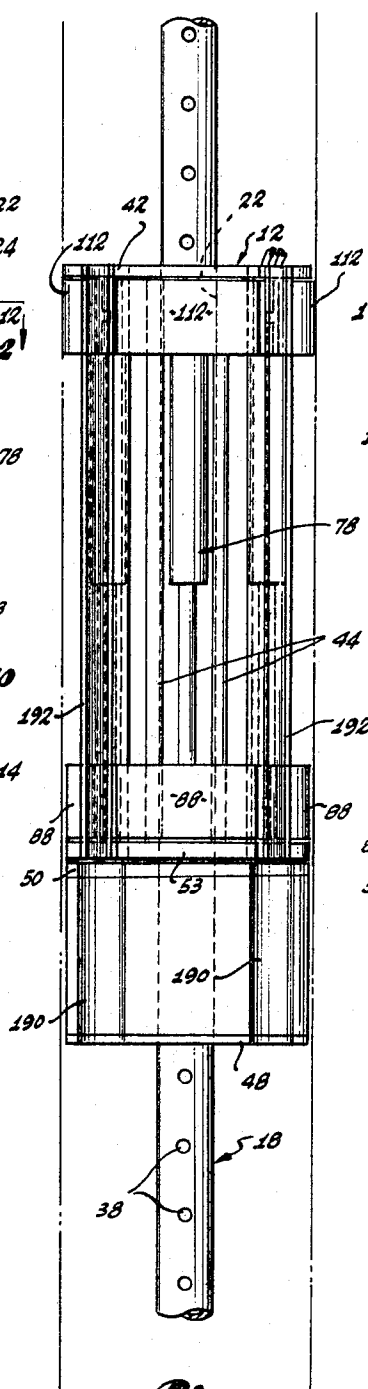


Fig. 6

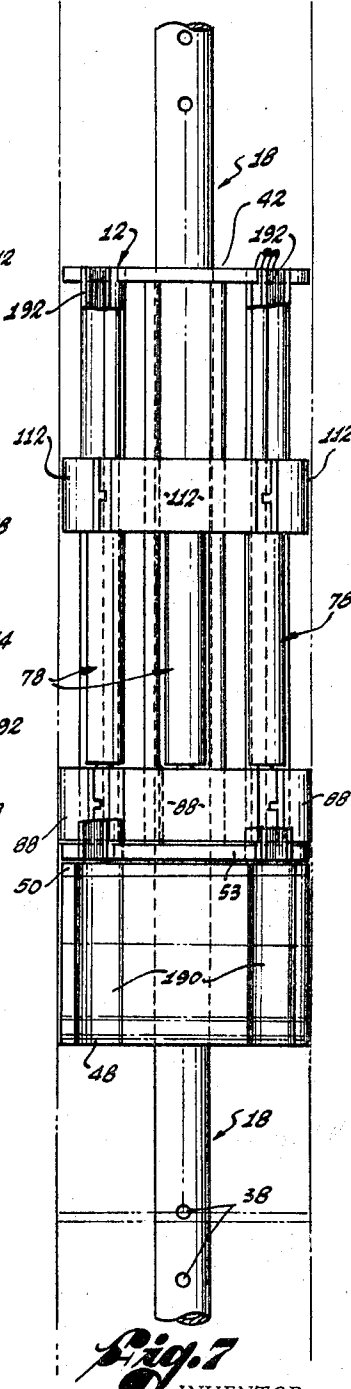


Fig. 7

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Fig. 8

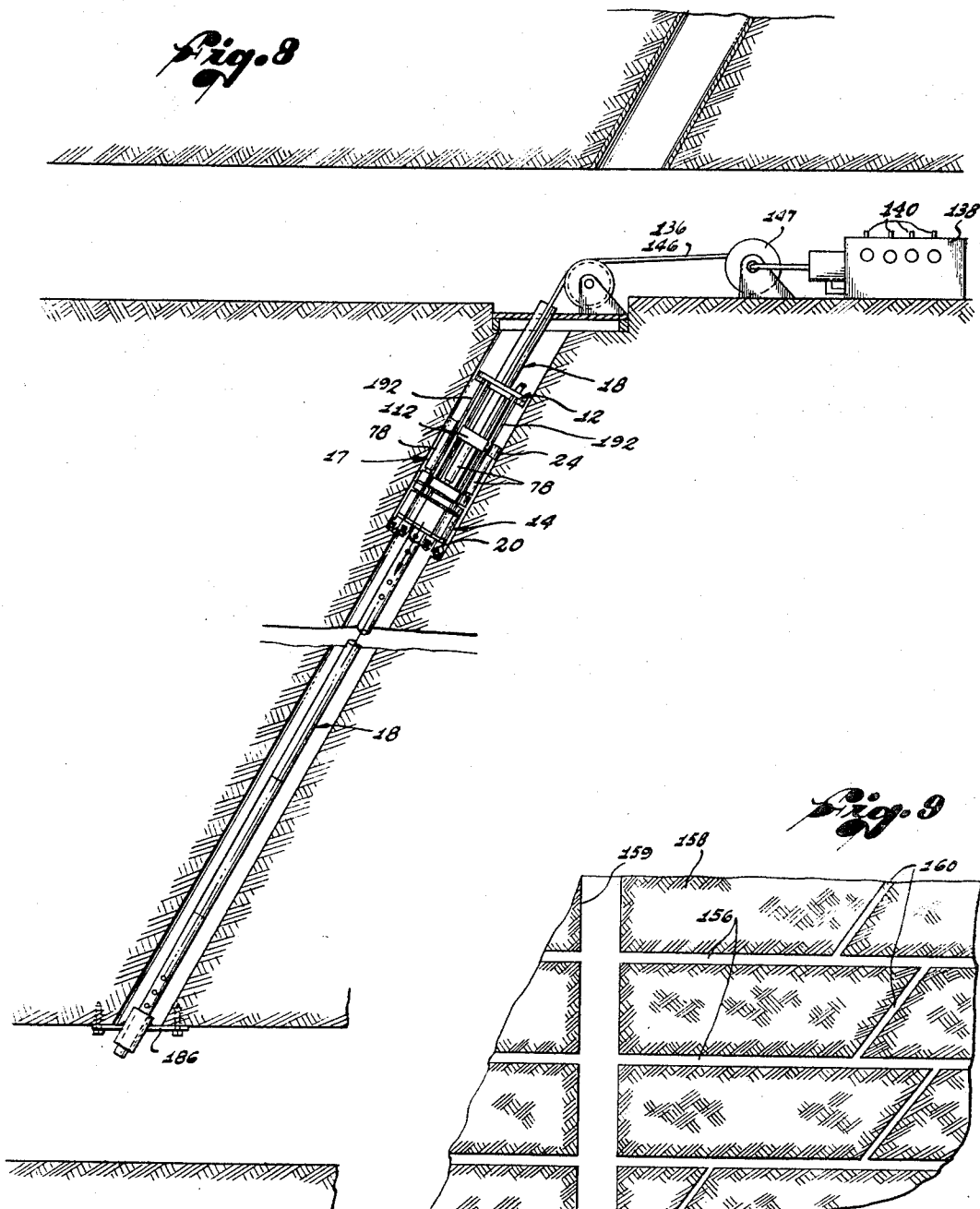
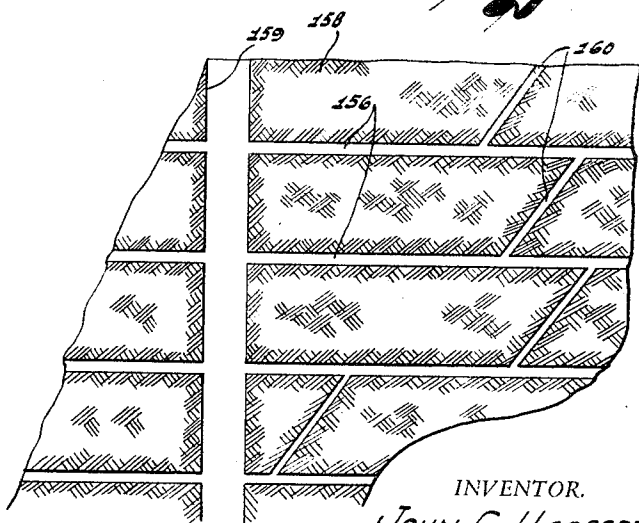


Fig. 9



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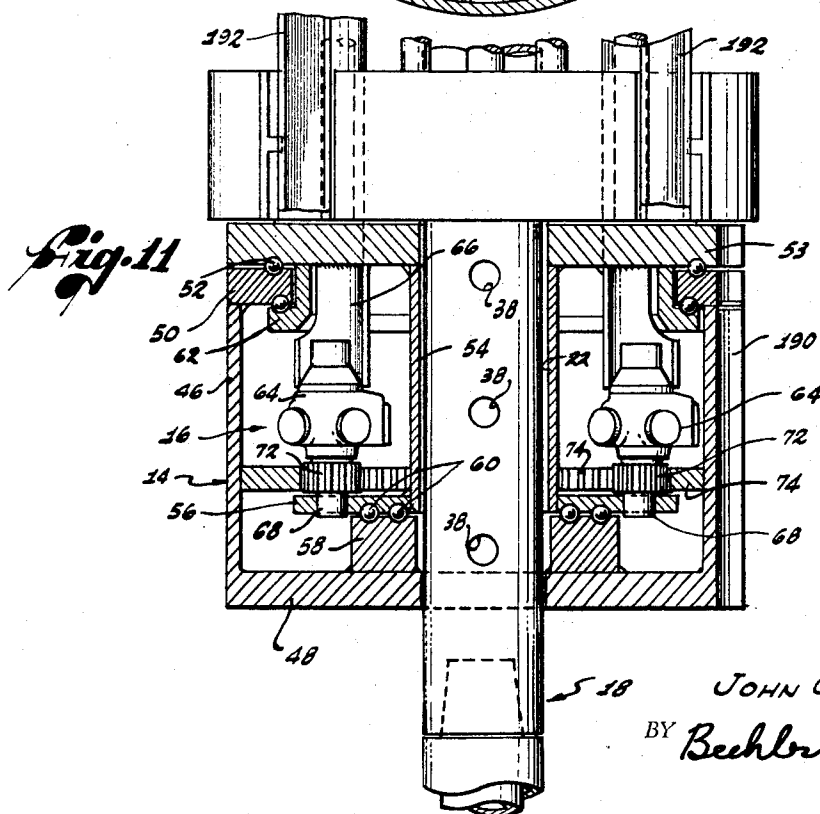
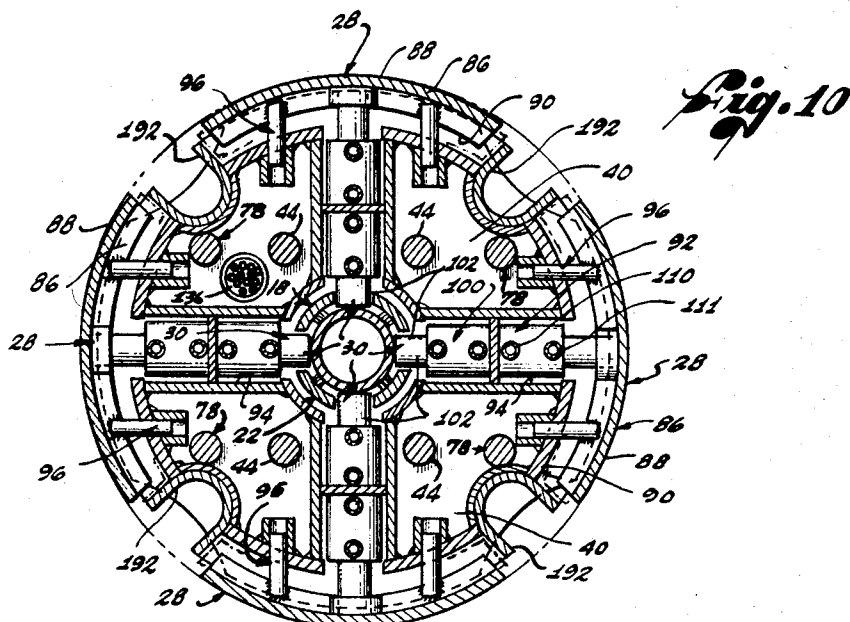
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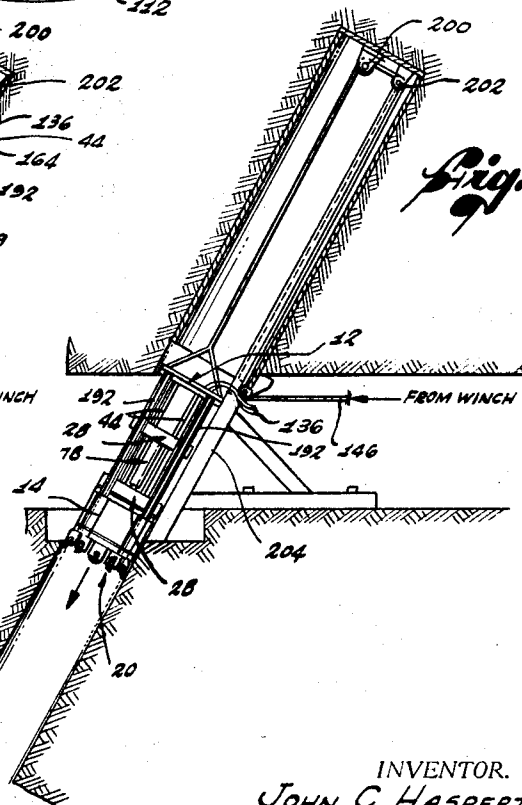
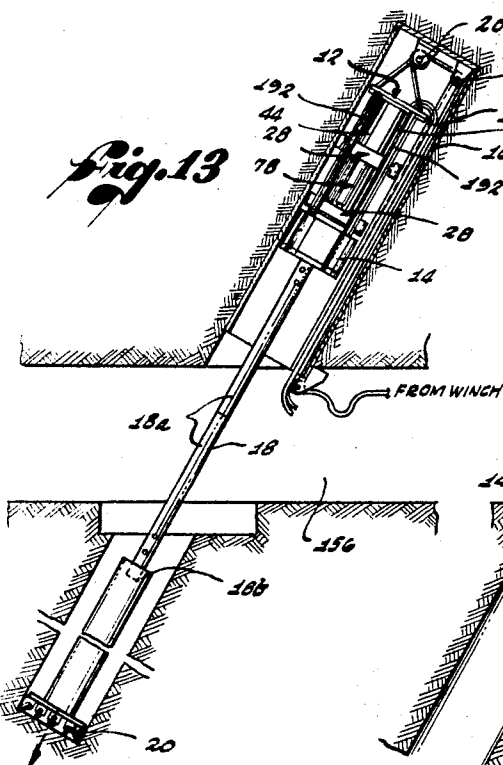
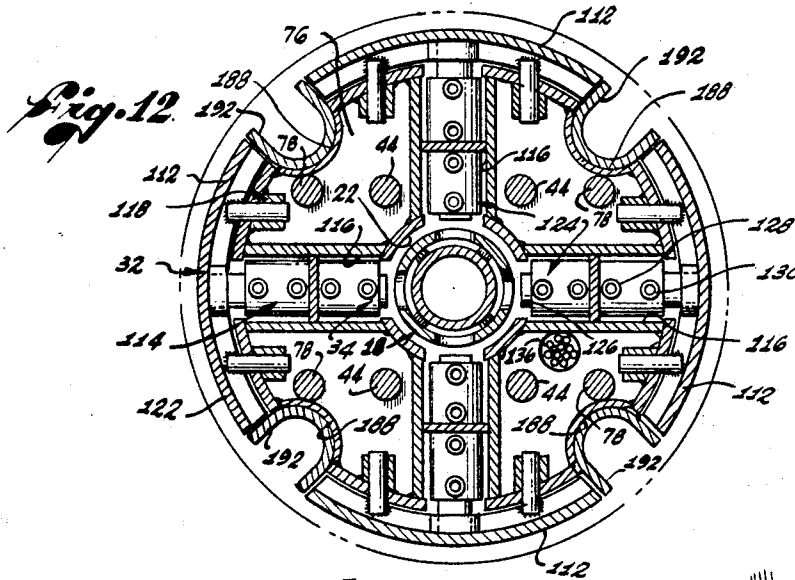
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RAISE DRIVER

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Filed June 6, 1966, Ser. No. 560,953

15 Claims. (Cl. 175—53)

ABSTRACT OF THE DISCLOSURE

A self-propelled earth boring machine as provided for drilling a pilot hole through an earth formation and then reaming the hole. The machine has a front main carriage mounting a power driven rotary cutter support, a rear feed carriage, and power means operatively connected between the carriages for driving the carriages in relative endwise reciprocation. The carriages mount power operated thrust means which may be selectively extended and retracted laterally of the carriages. When drilling a pilot hole, the feed carriage is anchored in a surrounding casing by extension of its thrust means into anchoring engagement with the casing. The main carriage is then driven in reciprocation relative to the feed carriage, and drill stem sections are successively connected end to end to the rotary cutter supports when the main carriage is retracted in such a way as to cause the drill stem to progressively penetrate the earth formation during forward extension of the main carriage. When reaming the pilot hole, the carriages are driven in relative reciprocation, and the thrust means on the carriages are alternately extended and retracted into and from anchoring engagement with a fixed rail extending through the pilot hole and/or the reamed wall of the hole to cause stepwise progression of the machine through the earth formation.

This invention relates to the earth boring art and has more particular reference to a novel self-propelled earth boring machine and to a novel method of boring a hole in an earth formation.

As will appear from the ensuing description, the present earth boring machine may be designed to bore holes for any purpose through an earth formation. For example, the machine may be designed to bore vertical shafts, tunnels, mine drifts, and the like. However, the machine is particularly designed for use as a so-called "raise driver" in the mining industry and, accordingly, will be disclosed herein primarily in connection with this particular application thereof.

A typical subterranean mine comprises a number of generally horizontal tunnels, or drifts as they are commonly referred to, located at different sublevels and interconnected by one or more vertical shafts which accommodate elevators or lifts for transporting miners and equipment between the surface and the various sublevels. The drifts are also interconnected with one another and with the surface by a number of bore holes, known as raises, through which fresh air is circulated to ventilate the drifts. These raises also accommodate electrical and fluid conduits for conveying electrical power, fresh water, high pressure air, and the like to the sublevels of the mine. The machines which are employed to drill or bore such raises are known as raise borers or raise drivers.

According to common practice a raise is most often formed by first drilling a pilot hole through the earth formation between the two points to be connected by the raise. Thereafter, the pilot hole is reamed out to the desired diameter of the finished raise. The diameter of a typical raise is on the order of 40 inches or larger. In each of these drilling and reaming operations, the cutter

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may be driven downwardly or upwardly through the intervening earth formation.

A conventional raise driver comprises a mobile support, such as a self-propelled crawler, mounting a drill rig for axially and rotatably driving a drill stem. According to the preferred method of operation such a raise driver, a suitable cutting bit is mounted on the leading end of the drill stem and the latter is driven in one axial direction through the earth formation to form a pilot hole. Thereafter, the cutting bit is replaced by a reamer and the drill stem is driven in the reverse direction through the earth formation to ream out the pilot hole to the desired diameter of the completed raise. In other cases, the reaming cutter is fed or pushed through the pilot hole in the same direction as the pilot hole drill.

While the existing raise drivers are capable of drilling or boring a satisfactory raise in many types of earth formations, these drivers have certain inherent deficiencies which this invention seeks to cure. One of the major deficiencies of the existing drivers resides in the fact that additional sections must be periodically added to the drill stem as the latter progresses through the earth formation and these sections must be subsequently removed from the stem as the latter is retracted from the formation. This addition and removal of sections to and from the drill stem is a very time consuming and laborious operation even under ideal working conditions, such as at the surface, for example, where the working space is unrestricted. Addition and removal of sections to and from a drill stem within the confines of a mine drift, of course, is substantially more time consuming and laborious. Accordingly, the labor time and costs involved in drilling each raise are quite high. Moreover, a conventional raise driver and the supply of drill stem sections which are essential to the operation of the driver consume substantial space and thus seriously interfere with other mining operations as well as with movement of equipment and personnel through the mine drift in which the driver is located.

Another deficiency of the existing raise drivers resides in the fact that the couplings between adjacent drill stem sections are often times difficult to uncouple. Moreover, the power source of the existing raise driver and the cutter which engages the earth formation are separated by a long intervening length of drill stem. This intervening length of drill stem possesses substantial torsional elasticity and undergoes substantial torsional strain or twisting during a drilling operation. Quite often, a drill stem is twisted beyond its elastic limit. Also, the long elastic drill stem is subject to torsional vibration and oscillation as a result of fluctuations in the resisting force or torque exerted on the cutting bit by the earth formation. Each time a new section is added to the drill stem, the torsional stress on the stem is relieved and the stem unwinds. This alternate twisting and untwisting of the drill stem generally occurs many times during the drilling of each raise. Such torsional vibrations or oscillations and frequent twisting and untwisting of the drill stem combine to produce fatigue in the stem which substantially reduces the operating life of the stem and frequently results in failure of the stem. An efficient raise driver operator avoids failure of the stem by periodically replacing the drill stem sections before they are fatigued to the point of failure. This, however, further reduces the effective life of the drill stem sections and, thereby, increases the overall cost of the drilling operation. Also, periodic replacement of the drill stem section is time consuming and costly. In addition to rendering the drill stem prone to failure, torsional vibrations or oscillations in the stem and periodic twisting and untwisting of the stem quite often results in loosening or complete separation of one or more couplings

in the stem. This tendency for the stem couplings to loosen or separate is minimized by prestressing of the couplings to a predetermined torque related to the anticipated maximum drilling torque required during a drilling operation. Such prestressing of the drill stem couplings, however, further complicates and adds to the overall time and cost of a drilling operation.

Existing raise drivers are further deficient for the reason that it is very difficult to control the cutting direction of a cutter mounted on the end of a long drill stem, particularly when drilling through an earth formation which is not homogeneous about the entire circumference of the bore. As a consequence, it is often difficult or impossible to drill a raise which satisfies all of the specifications pertaining to the maximum permissible angular deviation of the raise and other critical raise parameters.

It is evident at this point, therefore, that there is a definite need for an improved raise driver which is not subject to the foregoing deficiencies of the existing raise drivers. This invention provides a self-propelled earth boring machine which is intended primarily for use as a raise driver and is devoid of the above noted and other deficiencies of the existing drivers. As noted earlier, however, and as will become evident from the ensuing description, the present earth boring tool is not limited in application to a raise driver and may be employed for drilling or boring holes, tunnels, shafts, drifts and the like for any purpose in an earth formation.

According to its broader aspects, the invention provides an earth boring machine which may be employed to drill a pilot hole in an earth formation, or ream a pre-drilled pilot hole, or both drill and ream a pilot hole. To this end, the machine is equipped with a main supporting carriage mounting a rotary cutter support to which may be attached either a pilot hole drill stem or a pilot hole reaming cutter, a first drive means for driving the cutter support in rotation, and a second drive means which is adapted for driving engagement with a fixed drive or thrust surface and is operatively connected to the carriage in such a way as to drive the carriage endwise relative to the fixed surface. When drilling a pilot hole, a section of drill stem, mounting a forward cutter, is coupled to the cutter support when the boring machine carriage is retracted to the rear end of its stroke with the carriage drive means anchored in a fixed position. The cutter support is then driven in rotation and the carriage is driven forwardly in a feed stroke, to cause the drill stem to penetrate the earth formation. When the carriage reaches its forward limiting position, the drill stem is uncoupled from the cutter support and the carriage is again retracted to its rear limiting position. Thereafter, an additional drill stem section is inserted between the cutter support and the first drill stem section, whereupon the cutter support is again driven in rotation and the carriage is again driven forwardly to effect further penetration of the drill stem into the earth formation. This procedure of alternately driving the drill stem into the earth formation, uncoupling the drill stem from the boring machine, inserting an additional section of drill stem, and then driving the drill stem further into the earth formation is repeated until the pilot hole has been drilled to its desired depth.

When reaming a predrilled pilot hole, a reaming cutter is mounted on the rotary cutter support of the boring machine and the carriage drive is operated to drive the carriage forwardly through or along the predrilled pilot hole in such a way as to cause the reaming cutter to ream the pilot hole to the desired final diameter. A highly important feature of the invention resides in the unique construction and arrangement of the carriage drive means, whereby the present earth boring machine, in effect, propels itself through the earth formation. According to one aspect of the invention, for example, the carriage drive means comprises a feed carriage mounted on the main supporting carriage for endwise movement relative there-

to, power means operatively connected between the carriages for driving the carriages in relative movement in either endwise direction thereof, and wall anchor means mounted on the feed carriage for lateral extension into and from driving engagement with the wall of the reamed pilot hole. In operation of this carriage drive means, the feed carriage is extended into its forward limiting position relative to the main carriage and the wall anchor means on the feed carriage are extended into driving engagement with the wall of the reamed pilot hole. Thereafter, the power means is operated to drive the main carriage forwardly in a feed stroke relative to the feed carriage, thereby to drive the rotating reaming cutter forwardly through the earth formation. When the main carriage reaches its forward limiting position relative to the feed carriage, the wall anchor means are retracted and the power means are operated to drive the feed carriage forwardly in a repositioning stroke relative to the main carriage to the forward limiting position of the feed carriage. This cyclic operation of the earth boring machine is repeated until the pilot hole has been reamed to its desired depth. In the event that it is necessary for the machine to drill upwardly through an earth formation, the main carriage of the machine is also equipped with wall anchor means which may be extended into driving engagement with the wall of the reamed pilot hole for restraining the main carriage against retrograde movement during each repositioning stroke of the feed carriage. The external geometry of the main and feed carriages is such that these carriages fit closely within the reamed pilot hole, whereby the carriages serve to guide the reaming cutter as the latter travels forwardly through the earth formation, thus to enable the cutter to follow the course of the redrilled pilot hole. A unique and important feature of the invention resides in the fact that the wall anchor means may be selectively operated to control the lateral position and/or the angle of the reaming cutter rotation axis in the reamed pilot hole, thereby to permit accurate control of the drilling direction.

According to a second aspect of the invention, the drive means for propelling the main carriage forwardly through an earth formation during reaming of a pre-drilled pilot hole are designed to co-act with a rail which is centrally positioned in the pilot hole and anchored at its ends to the earth formation at the ends of the pilot hole. In this case, the main carriage, cutter support, and reaming cutter are provided with an axial opening for receiving the rail and the carriage drive means includes rail anchor means which are operatively engageable with the rail in such a way as to propel the main carriage forwardly along the rail. This rail, then, serves the dual function of providing fixed drive or thrust surface means against which the drive means for the main machine carriage may react to propel the carriage forwardly through the earth formation and providing guidance for the main carriage during its forward travel through the earth formation. In regard to this guiding function of the rail, a unique feature of the invention resides in the fact that the rail is stressed in tension during each feed stroke of the main carriage in such a way that the rail provides an effectively laterally rigid guide track for the main carriage, thereby permitting straight holes to be bored with relatively high precision through many, if not all, types of earth formations. According to the preferred practice of the invention, the present machine, when employed to ream a predrilled pilot hole with the aid of a guide rail, is equipped with both wall and rail anchor means for anchoring the machine to both the wall of the reamed pilot hole and to the guide rail.

When the present earth boring machine is utilized to both drill and ream a pilot hole, the pilot hole drill stem is first coupled to the machine and the latter is operated, as described earlier, to effect penetration of the drill stem into the earth formation. Thereafter, the drill stem is uncoupled from the machine and replaced by the ream-

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ing cutter, after which the machine is operated to cause the same to propel itself through the earth formation, along the pilot hole, thereby to ream the pilot hole as described above. This reaming operation may be carried out with or without the aid of the axially fixed guide rail in the pilot hole. According to a further, unique and highly important aspect of the invention, however, the pilot hole drill stem serves as the guide rail for the earth boring machine during the reaming operation. This is accomplished by leaving the drill stem in the pilot hole after the latter has been drilled to its final depth, and anchoring at least the forward end of the drill stem to the earth formation. In this case, the drill stem is uniquely constructed to provide thrust surfaces against which the rail anchor means of the main carriage drive means may react to propel the carriage forwardly along the drill stem during the reaming operation.

As noted earlier, the reamed hole produced by the present machine may be a tunnel, shaft, mine drift or the like. However, the machine is particularly adapted for drilling raises in subterranean mines. In this regard, a highly important advantage of the machine resides in the fact that it eliminates the use of drill pipe during the pilot hole reaming operation, and, thereby, the difficulties and disadvantages, discussed earlier, which attend the use of such drill pipe. Moreover, during both pilot hole drilling and reaming operation of the machine, the latter is remotely controlled from a central panel which may be situated any distance from the immediate work area, thus to leave this area unrestricted. In addition, the control panel may be positioned in a niche in the wall of a mine drift or otherwise located in such a way as to not impede the movement of men or equipment through the drift. The present earth boring machine is also relatively small in size with the result that it may be lowered into a mine and subsequently removed from the mine for transportation to a new job site without being dismantled.

The present earth boring machine may utilize any suitable fluid, i.e., water, compressed air, or the like, for flushing cuttings from the bore during downward drilling of the pilot hole. To this end, the machine is uniquely constructed to accommodate the passage of cuttings through the pilot bore. No flushing media is required while reaming. In mine applications, compressed air is the preferred flushing fluid.

It is a general object of this invention, therefore, to provide an improved earth boring machine of the character described.

A more specific object of the invention is to provide an earth boring machine which is capable of drilling a pilot hole in an earth formation, reaming a predrilled pilot hole to a desired final diameter, and both drilling and reaming a pilot hole.

A related object of the invention is to provide an earth boring machine which is capable of driving a rotary drill stem into an earth formation to form a pilot hole and thereafter propelling itself forwardly through the earth formation along the pilot hole, to ream the pilot hole to the desired final diameter.

Another object of the invention is to provide an earth boring machine equipped with a rail to be axially fixed within a pilot hole in an earth formation for guiding the machine during the reaming operation.

A related object of the invention is to provide an earth boring machine wherein the drill stem which initially drills the pilot hole serves also as the rail for guiding the machine during the reaming operation.

Yet another object of the invention is to provide an earth boring machine which eliminates the use of drill pipe when reaming a pilot hole, and, thereby, avoids the difficulties and disadvantages which attend the use of such drill pipe.

Still another object of the invention is to provide an earth boring machine whose drilling direction may be accurately controlled.

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A further object of the invention is to provide an earth boring machine which is compact in size, rugged, easy to transport from one job site to another and to install at each job site, reliable in operation, relatively inexpensive to manufacture to operate, and may be designed to drill and ream holes for any purpose, i.e. tunnels, mine drifts and raises, shafts, and the like.

Yet a further object of the invention is to provide a novel method of drilling and reaming a pilot hole in an earth formation.

Other objects, advantages, and features of the invention will become readily evident as the description proceeds.

With these and other objects in view, the invention consists in the construction, arrangement, and combination of the various parts of the earth boring machine, whereby the objects contemplated are attained, as herein-after set forth, pointed out in the appended claims and illustrated in the accompanying drawings.

In these drawings:

FIGURE 1 illustrates an earth boring machine according to the invention in the act of drilling a pilot hole from one drift to an adjacent lower drift of a subterranean mine, preparatory to reaming the pilot hole to form an interconnecting raise between the drifts;

FIGURE 1a illustrates the machine in the act of initially reaming the upper end of the pilot hole;

FIGURE 2 is an enlarged section taken on line 2—2 in FIGURE 1;

FIGURE 3 is an enlarged section taken on line 3—3 in FIGURE 1;

FIGURE 3a is an enlarged side elevation, partially broken away, of one section of the pilot hole drill string;

FIGURE 4 is an enlarged section taken on line 4—4 in FIGURE 1a;

FIGURE 5 is an enlarged side elevation of the machine, partially broken away, illustrating the machine in one of its operative positions during the pilot hole reaming operation;

FIGURE 6 is a view similar to FIGURE 5 illustrating the machine in a second operative position;

FIGURE 7 is a view similar to FIGURE 5 illustrating the machine in a third operative position;

FIGURE 8 is a view similar to FIGURE 1 illustrating the machine in the act of reaming the pilot hole with the assistance of a guide rail;

FIGURE 9 is an enlarged vertical section through a typical subterranean mine illustrating, in particular, a number of raises which are formed by the present earth boring machine, or raise driver;

FIGURE 10 is an enlarged section taken on line 10—10 in FIGURE 5;

FIGURE 11 is an enlarged side elevation of the front end of the machine with the front rotary cutter support of the machine shown in axial section to expose the cutter support drive means contained therein;

FIGURE 12 is an enlarged section taken on line 12—12 in FIGURE 5;

FIGURE 13 illustrates an alternative procedure for reaming the initial portion of the pilot hole to a depth sufficient to accommodate the machine; and

FIGURE 14 illustrates the machine being lowered into the initially reamed portion of the pilot hole.

Considered generally, the earth boring machine 10 of the invention which has been selected for illustration in these drawings comprises a main supporting carriage 12 having front and rear ends. Mounted on the front end of the carriage, for turning on an axis substantially parallel to the longitudinal axis of the carriage, is a rotary cutter support 14. As will appear from the ensuing description, carriage 12 has a generally external cylindrical shape and the rotation axis of the cutter support 14 coincides, approximately with the central axis of the carriage. Mounted on the front end of the carriage 12, within the cutter support 14, are drive means 16 for driving the support in rotation. Mounted on the rear of the main carriage are

drive means 17 for propelling the carriage axially. As noted earlier, and hereinafter explained in greater detail, the present earth boring machine 10 is adapted to both drill and ream a pilot hole. When drilling a pilot hole, a drill stem 18 is coaxially secured to the front face of the cutter support 14. When reaming a pilot hole, the front face of the cutter support mounts a reaming cutter 20. As also noted earlier, and hereinafter described in greater detail, during a reaming operation, the earth boring machine 10 is adapted to be guided by a rail which is axially fixed within the pilot hole. To this end, the carriage 12 and cutter support 14 have an axial opening 22 extending therethrough for receiving the rail. According to the preferred practice of the invention, the drill stem 18 is utilized as the guide rail for the machine during the reaming operation. Accordingly, the central opening 22 through the carriage 12 and cutter support 14 is dimensioned to receive the drill stem 18. For reasons to appear presently, the diameter of the opening 22 is preferably somewhat greater than the diameter of the rail or drill stem 18.

In the illustrated embodiment of the invention, the main carriage drive means 17 comprises a feed carriage 24 which is mounted on the main carriage for endwise movement relative thereto. Operatively connected between the carriages are power means 26 for driving the carriages in relative movement in either endwise direction thereof. The main carriage drive means further comprise front external and internal anchor means 28 and 30, respectively, on the main carriage, and rear external and internal anchor means 32 and 34, respectively, on the feed carriage 24. As will appear presently, the external anchor means 28 and 32 are mounted on the respective carriages for lateral movement relative to the carriages between outer extended positions wherein these anchor means are disposed for driving engagement with the wall of a hole containing the boring machine 10, thereby to restrain the carriages against endwise movement in the hole, and inner retracted positions wherein the carriages are released for endwise movement in the hole. Similarly, the internal anchor means 30 and 34 are mounted on their respective carriages for lateral movement relative to the carriages between inner extended positions wherein the anchor means are disposed for driving engagement with the guide rail 18, when the latter is positioned in the axial machine opening 22, thereby to restrain the carriages against endwise movement along the drill stem and outer retracted positions wherein the internal anchor means are disengaged from the drill stem to release the carriages for endwise movement along the stem.

Drill stem 18 is composed of a number of separate small and large diameter sections 18a and 18b which are releasably coupled end to end, as shown. Mounted on the leading end of the drill stem is a cutter 36. It is significant to note at this point that the external diameter of the drill stem sections 18b adjacent the cutter 36 approximates the cutting diameter of this cutter. The external diameter of the remaining drill stem sections 18a, on the other hand, is substantially smaller than the cutting diameter of the cutter 36. In a typical earth boring machine according to the invention, for example, the cutting diameter of the drill stem cutter 36 is on the order of 17 inches, the external diameter of the drill stem sections 18a is on the order of 10 to 12 inches and the external diameter of the drill stem sections 18b is on the order of 16 inches. Extending into the external surface of the drill stem 18, at positions spaced therealong, are a number of thrust holes 38. As will appear presently, these thrust holes are adapted to receive the front and rear internal anchor means 30 and 34 on the main carriage 12 and feed carriage 24, respectively, to afford driving engagement between the main carriage drive means 17 and the drill stem 18, thereby to render the drive means

effective to propel or drive the main machine carriage 12 forwardly along the drill stem.

Briefly, in operation of the earth boring machine 10 to drill a pilot hole in an earth formation, the feed carriage 24 is anchored in a fixed position opposite the surface of the formation through which the pilot hole is to be drilled, in such manner that the rotation axis of the cutter support 14 intersects the surface at the desired position of entrance of the pilot hole into the surface and the front face of the cutter support faces the surface. The power means 26 are then operated to retract the main carriage 12 rearwardly to its rear limiting position relative to the feed carriage. One or more of the drill stem sections 18a, 18b are then coupled end to end to make up an initial drill stem having a length which is sufficiently less than the spacing between the front face of the cutter support 14 and the confronting surface of the earth formation to permit coaxial attachment of the rear end of this initial drill stem to the front face of the cutter support. After attachment of the drill stem to the cutter support, the cutter support drive means 16 are operated to drive the support in rotation and the carriage drive power means 26 are operated to drive the main carriage 12 forwardly in a feed stroke relative to the currently fixed feed carriage 24. During this forward feed stroke of the main carriage, the initial length of drill stem penetrates the earth formation to a depth determined by the stroke length of the main carriage. When the main carriage reaches the forward end of its stroke, the cutter support drive means 16 are stopped and the initial drill stem is uncoupled from the support. The main carriage 12 is then again retracted to the rear end of its stroke and one or more additional drill stem sections are coupled to the initial drill stem and to the cutter support 14. After installation of the new drill stem section or sections, the main carriage is again driven forwardly in a feed stroke to drive the drill stem deeper into the earth formation. This procedure is repeated until the pilot hole has been driven to the desired depth.

When reaming the pilot hole to a desired final diameter, the drill stem 18 is uncoupled from the cutter support 14 and is replaced by the reaming cutter 20. In the event that the drill stem is to be employed as a guide rail for the earth boring machine 10 during the reaming operation, the drill stem is left in the pilot hole and the end of the drill stem remote from the machine is anchored to the surrounding earth formation. The earth boring machine 10 is then placed over the adjacent, extending end of the drill stem in such a way that the latter extends through the axial opening 22 in the machine. After the machine has thus been installed on the extending end of the drill stem, the front internal anchor means 30 on the main machine carriage 12 are extended into operative engagement with the adjacent thrust holes 38 in the drill stem, to anchor the main carriage to the drill stem, and the carriage drive power means 26 are operated to advance the feed carriage 24 to the forward limit of its stroke relative to the main carriage. Thereafter, the front internal anchor means are retracted and the rear internal anchor means 34 on the feed carriage are extended into operative engagement with the adjacent drill stem thrust holes 38, the cutter support drive means 16 are activated, and the carriage drive power means 26 are operated to drive the main carriage forwardly in a feed stroke relative to the feed carriage. The rotating reaming cutter 20 is thereby driven forwardly against the confronting earth formation to ream the adjacent end of the previously formed pilot hole. When the main carriage has been driven to the forward limit of its stroke, the front internal anchor means 30 are re-extended, the rear internal anchor means 34 are retracted, and the power means 26 are operated to drive the feed carriage 24 forwardly in a repositioning stroke relative to the main carriage. Thereafter, the front internal anchor means 30 are again retracted, the rear internal anchor means 34 are again extended, and the power

means 26 are operated to again drive the main carriage 12 forwardly in a feed stroke relative to the feed carriage. This procedure is repeated until the pilot hole has been reamed to the desired depth. After the earth boring machine 10 has penetrated the earth formation to a distance wherein the rear end of the machine no longer projects beyond the surface of the formation, the adjacent end of the drill stem 18 is anchored to the formation. During the above described reaming operation of the earth boring machine 10, the front and rear external anchor means 28 and 32 on the main carriage 12 and feed carriage 24 may be extended and retracted in unison with the adjacent internal anchor means, thereby to effect anchoring of the carriages to both the drill stem, or guide rail, and the reamed wall of the pilot hole. In the event that a pilot hole is to be reamed without the aid of the guide rail or drill stem, the feed carriage 24 is restrained against endwise movement in the reamed hole during each feed stroke of the main carriage 12, and the main carriage is restrained against endwise movement in the reamed hole during each repositioning stroke of the feed carriage, solely by driving engagement of the front and rear external anchor means with the surrounding reamed wall of the pilot hole. As will appear presently, the external wall anchor means 28, 32 may be selectively operated to control the drilling direction of the machine 10.

Referring now in greater detail to the illustrated earth boring machine 10, the main carriage 12 comprises a front circular thrust plate 40, a rear circular thrust plate 42, and a number of guide or supporting rods 44 extending between and rigidly secured at their ends to the thrust plates. Thrust plates 40 and 42 are coaxially disposed on the rotation axis of the cutter support 14. Guide rods 44 are generally uniformly circumferentially spaced about and parallel this axis. The external diameter of the thrust plates is just slightly less than the cutting diameter of the reaming cutter 20. Extending axially through the front and rear thrust plates are circular openings which define portions of the drill stem receiving opening 22. These thrust plate openings are dimensioned to receive the rear, small diameter sections 18a of the drill stem 18.

Cutter support 14 comprises a cylindrical wall 46 having an external diameter just slightly less than the cutting diameter of the reaming cutter 20. The front end of the cutter support is closed by an integral face plate 48 disposed in a plane normal to the rotation axis of the support. This plate has a central opening defining a portion of the drill stem receiving opening 22. At the inner end of the cutter support 14 is an internal annular thrust shoulder 50. Thrust shoulder 50 is rotatably supported by thrust bearings 52 on a cutter thrust disc 53 which is rigidly secured to the front face of the front thrust plate 40.

Cutter support drive means 16 comprises a supporting sleeve 54 which is centered on the axis of the drill stem receiving opening 22 and is internally dimensioned to receive the drill stem 18. The rear end of the supporting sleeve 54 is welded or otherwise rigidly joined to the front face of the cutter thrust disc 53. Surrounding and rigidly joined to the front end of the supporting sleeve 54 is an annular flange 56 which is disposed in a plane normal to the rotation axis of the cutter support 14. An annular thrust ring 58 is coaxially secured to the inner surface of the cutter support face plate 48 and is rotatably supported on the flange 56 by means of thrust bearings 60. The rearward axial thrust exerted on the cutter support 14 during drilling and reaming operations, therefore, is resisted by the thrust bearings 52 and 60. The cutter support is restrained against forward axial movement relative to the main carriage 12 by means of a rear internal thrust shoulder 62 on the thrust disc 53 which engages over the cutter support thrust shoulder 50. Bearings may be placed between these shoulders, as shown. Generally uniformly circumferentially spaced about the interior of the cutter support 14, between the front thrust plate 40

on the main carriage 12 and the flange 56, are a number of cutter drive motors 64. These motors may be either electrically operated or fluid pressure operated motors. According to the preferred practice of the invention, however, motors 64 comprise rotary hydraulic motors. The axes of these motors parallel the rotation axis of the cutter support 14. At the rear of each motor 64 is a mounting bracket 66 which is rigidly attached at its rear end to the front thrust disc 53 and at its front end to the adjacent motor. Each motor has an output shaft 68, the front end of which is rotatably supported in the supporting flange 56. Fixed on each motor shaft 68, between the respective motor and the supporting flange 56, is a pinion 72 which meshes with an internal ring gear 74 fixed to the cylindrical wall of the cutter support 14. It is evident at this point, therefore, that the motors 64 are effective to drive the cutter support 14 in rotation.

The feed carriage 24 comprises a generally circular thrust plate 76 which is slidably supported on the main carriage supporting rods 44. The feed carriage thrust plate 76, therefore, is movable endwise of the main carriage 12 between the front and rear thrust plates 40 and 42 of the latter carriage. The carriage drive power means 26 comprise a number of hydraulic linear actuators 78 which are uniformly circumferentially spaced about the longitudinal axis of the carriages and are disposed in the spaces between the main carriage supporting rods 44. Each actuator 78 comprises a hydraulic cylinder 80 which is rigidly secured, at its rear end, to the feed carriage thrust plate 76 and extends forwardly from this thrust plate parallel to the longitudinal axis of the carriages. Slidable in each actuator cylinder 80 is a piston having a rod 82 which extends through the forward end of the respective cylinder. The forward end of each piston rod 82 is rigidly joined to the front thrust plate 40 of the main carriage 12. Actuators 78 are double acting and have hydraulic hose connections 84 at opposite ends thereof. It is evident at this point, therefore, that admission of hydraulic fluid under pressure to the forward ends of the actuator cylinders 80 and venting of the rear ends of the cylinders is effective to drive the feed carriage 24 forwardly along the main carriage supporting rods 44. Similarly, admission of hydraulic fluid under pressure to the rear ends of the actuator cylinders and venting of the forward ends of the cylinders is effective to drive the feed carriage rearwardly along the main carriage supporting rods.

The front external wall anchor means 28 on the main carriage 12 comprise a number of cylindrically curved anchor shoes 86 which are uniformly circumferentially spaced about and extend circumferentially of the front thrust plate 40 on the main carriage 12. Each anchor shoe 86 has an outer convex, cylindrically curved thrust face 88, and an inner concave, cylindrically curved seating face 90. Each anchor shoe is operatively connected to a hydraulic linear actuator 92, mounted within a radial opening or cavity 94 in the front thrust plate 40, for radial extension and retraction of the shoe by the actuator, as indicated by solid and phantom lines in FIGURE 10. In the inner limiting positions of the anchor shoes 86, hereinafter referred to as their retracted positions, the inner seating faces 90 on the shoes are located adjacent or seat against the outer edge of the front thrust plate 40. The axes of curvature of the inner and outer anchor shoe thrust faces 88 and 90 approximately coincide with the rotation axis of the cutter support 14 when the anchor shoes occupy their retracted positions. The anchor shoes are longitudinally or circumferentially dimensioned such that when the shoes are retracted, the ends of adjacent shoes are spaced but a small distance apart, whereby the several outer anchor shoe thrust face 88 define a coaxial cylindrical surface about the front end of the main carriage 12 of approximately the same diameter as the cylindrical edge surface of the rear thrust plate 42 on the main carriage. As will appear presently,

this effective coaxial cylindrical surface furnished by the outer thrust faces of the retracted anchor shoes 86 and the cylindrical edge surface of the rear thrust plate provide front and rear lateral supporting and guiding surfaces, respectively, on the main carriage for laterally supporting and guiding the carriage during a reaming operation. The outer limiting positions of the anchor shoes 86 are hereinafter referred to as their extended positions. The anchor shoes 86 are retained in coplanar relation with the front thrust plate 40 by guide means 96 on the shoes and plate.

The front internal rail anchor means 30 on the main carriage 12 comprise linear hydraulic actuators 100 which are mounted within the inner ends of the radial thrust plate cavities 94. These actuators contain pistons (not shown) having rods which extend from the inner ends of the actuator cylinders to form anchor dogs or pins 102. These anchor pins which are dimensioned to fit closely within the thrust holes 38 in the drill stem 18. The anchor pins 102 are movable to inner limiting positions wherein the pins project into the central opening through the front thrust plate 40 sufficient to engage in the thrust holes 38 in the drill stem 18 when the latter is positioned in the central opening 22 in the earth boring machine 10. These inner limiting positions of the anchor pins 102 are hereinafter referred to as their extended positions. In the outer limiting positions of the anchor pins 102, hereinafter referred to as their retracted positions, the pins are retracted out of the central opening through the front thrust plate 40.

The anchor shoe actuators 92 and the anchor pin actuators 100 are double acting hydraulic actuators having hydraulic hose connections 110 and 111. At this point, therefore, it is evident that the anchor shoes 86 and anchor pins 102 may be extended and retracted independently or in unison by appropriate pressurizing and venting of the ends of the actuator cylinders through the hose connections 110, 111.

The rear external wall anchor means 32 and internal rail anchor means 34 are identical to the front external wall anchor means 28 and internal rail anchor means 30, described above. Accordingly, the rear anchor means will not be described in detail. It suffices to say that the rear external wall anchor means 32 comprise a number of cylindrically curved anchor shoes 112 which are uniformly circumferentially spaced about and extend circumferentially around the edge of the feed carriage thrust plate 76. Each anchor shoe is extended and retracted by a hydraulic linear actuator 114 mounted in a radial cavity 116. The anchor shoes 112 are retained in co-planar relationship with the thrust plate 76 by guide means 118 on the shoes and thrust plate. Each anchor shoe 112 has an outer convex, cylindrically curved thrust face 122. When the anchor shoes 112 are retracted, the axes of curvature of the outer thrust faces 122 approximately coincide with the rotation axis of the cutter support 14, and the several thrust faces define a cylindrical surface about the feed carriage coaxial with and of approximately the same diameter as the cylindrical edge surface of the rear thrust plate 42 and the effective cylindrical surface defined by the thrust faces 88 of the retracted front anchor shoes 86 on the main carriage 12. The internal rail anchor means 34 on the feed carriage comprise hydraulic linear actuators 124 which are mounted in the inner ends of the feed carriage thrust plate cavities 116. The piston rods of these actuators extend inwardly to form anchor dogs or pins 126 which are dimensioned to fit closely in the thrust holes 38 in the drill stem 18.

Each feed carriage actuator 114, 124 has hydraulic hose connections 128 and 130 through which the ends of the actuator cylinders may be vented and pressurized. Thus, the feed carriage anchor shoes 112 and anchor pins 126 may be extended and retracted independently or in unison.

Hydraulic fluid flow to and from the cutter support drive motors 64, hydraulic carriage actuators 78, and the

several anchor shoe and anchor pin actuators 92, 100, 114, 124 occurs through a bundle of hydraulic hoses 136. These hydraulic hoses extend to a master control panel 138 which is located in the vicinity of the drilling operation. Control panel 138 is equipped with a hydraulic fluid reservoir, a hydraulic fluid pump, and valves 140 for selectively communicating the reservoir and the outlet of the pump to the motors 64 and the actuators 78, 92, 100, 114, and 124 in such a way as to control the speed and direction of rotation of the motors, drive the main and feed carriages axially relative to one another, and extend and retract the front and rear anchor shoes and pins. The control panel valves permit these operations to be performed independently or in unison in any sequence.

During operation of the earth boring machine 10, it is necessary to periodically remove the machine from the hole being drilled for servicing as well as replacement of drill stem sections and the reaming cutters. To this end, a hoist cable 146 is attached to the rear thrust plate 42 of the main machine carriage 12. During a drilling operation, when it is necessary to retract the machine 10 from the hole being drilled, the cable 146 is attached to a winch 147 for hoisting the machine from the hole and subsequently lowering the machine into the hole.

Referring now to FIGURES 3 and 3a it will be observed that each of the drill stem sections 18a comprises an inner drill pipe 148 and an outer drill pipe 150 concentrically disposed about the inner pipe. The outer pipe 150 is shown to be slightly spaced from the inner pipe although, as well appear shortly, the spacing is not essential. The outer pipe 150 is secured to the inner pipe 148 by means of plugs 151 which are welded or otherwise rigidly secured to the pipes. At the ends of the inner pipe 148 are male and female couplings 152 and 154, respectively. The male coupling 152 extends a distance beyond the adjacent end of the outer pipe 150, as shown. The other end of the outer pipe is substantially flush with the end of the female coupling. The drill stem sections 18b are substantially identical to the drill stem sections 18a, just described. The drill stem sections 18b differ from the sections 18a only in that the outer pipes 150 of the sections 18b are larger in diameter than the outer pipes of the sections 18a. In this regard, reference is made to the earlier description, wherein the outer diameters of the drill stem sections 18a, 18b were set forth. The inner pipes 148 of all of the drill stem sections 18a, 18b have the same diameter. Accordingly, the annular clearance space between the inner and outer pipes of the drill stem sections 18b is substantially greater than the annular clearance space between the inner and outer pipes of the drill stem sections 18a. As noted earlier, the annular clearance between the inner and outer pipes of the drill stem sections 18a is not essential. The annular space between the inner and outer pipes of the drill stem sections 18b, however, is required for pilot hole drilling operations to permit flushing of cuttings from the pilot hole, as hereinafter described.

The inner pipes 148 of the several drill stem sections 18a, 18b are imperforate and provide a continuous fluid passage in the drill stem 18 through which a fluid may be recirculated for flushing cuttings from the pilot hole. The drill stem thrust holes 38, referred to earlier, extend through the wall of the outer pipes 150 of the drill stem sections 18a.

As noted earlier, and as is now evident, the present earth boring machine 10 may be employed for boring a hole for any purpose in an earth formation. However, the machine is designed primarily for boring raises between adjacent drifts and the surface in subterranean mines. For this reason, the operation of the earth boring machine 10 will be described first in connection with this particular application thereof.

Referring now to FIGURE 9 there is illustrated a typical subterranean mine including a number of tunnels or

drifts 156 which extend generally horizontally through the earth formation 158. These drifts are connected by one or more vertical shafts 159 which extend to the surface and accommodate elevators or lifts for transporting miners and equipment between the surface and the various drifts or sublevels of the mine. In most, if not all, mines, the drifts 156 are also interconnected with one another and with the surface by a number of bore holes 160, commonly known as raises, through which fresh air is circulated to ventilate the drifts. These raises also accommodate electrical and fluid conduits conveying electrical power, fresh water, high pressure air, and the like to the various sublevels of the mine. In addition, the raises provide escape routes through which miners may escape to the surface in the event of a cave-in which blocks the normal escape route to the surface via the elevator shafts 159. As noted earlier, a typical raise is on the order of 40 inches or larger in diameter. The several raises in a mine are commonly staggered, as shown, to induce air flow through the drifts.

The manner in which the present earth boring machine 10 is operated to drill a raise 160 between two adjacent mine drifts 156 will now be described. According to the present invention, a socket bore 162 is first drilled into the wall of a drift 156 opposite the surface to which the raise is to be drilled. In FIGURE 1, for example, it is assumed that a raise is to be drilled through the floor of an upper drift 156 to the next lower drift. In this case, the socket bore 162 is drilled into the ceiling of the upper drift in such a way that the axis of the bore intersects the floor of the upper drift at the desired point of penetration of the pilot hole into the floor. The socket bore axis may be inclined, as shown, or vertical, depending upon the desired route to be followed by the pilot hole. Thereafter, a steel liner 164 is preferably fixed in the socket bore. The internal diameter of the liner 164 may be just slightly greater than the common external diameter of the retracted wall anchor shoes 86, 112, and rear thrust plate 42 of the machine. In this case, the machine has a relatively close fit within the liner. If the internal diameter of the liner is made somewhat larger than this common diameter, however, to facilitate placement of the boring machine in the liner, as described below, a bearing plate (not shown) having a slip fit in the liner, may be coaxially secured to the rear thrust plate 42 of the main machine carriage 12.

Boring machine 10 is inserted, rear end first, into the socket bore liner 164 and is anchored in position by extending the rear wall anchor shoes 112 on the feed carriage 24 outwardly against the inner surface of the liner. The machine is accurately centered in the liner by selective positioning of these shoes, if necessary. Also, the front wall anchor shoes 86 may be partially extended if desirable to provide the front end of the main carriage 12 with a close sliding fit in the liner. An initial length of drill stem 18 short enough to be positionable between the front end of the machine and the floor of the drift, is then coaxially secured to the rotary cutter support 46. To this end, the boring machine is equipped with an adapter plate 168 which may be bolted or otherwise releasably secured to the cutter support and includes a coaxial coupling 170 for connection to one end of a circulation swivel 172. The other end of this swivel is coupled to the rear end of the drill stem.

During drilling of a pilot hole, the circulation swivel 172 is supplied with fluid for flushing cuttings from the pilot hole. To this end, the swivel is equipped with a hose 174 which connects to a source 176 of the flushing fluid to be circulated through the pilot hole. In the present disclosure, this fluid is assumed to be compressed air, since air is the preferred fluid for use in subterranean mines. However, other fluids, such as water or mud, may be circulated, if desired. Accordingly, in this disclosure, the fluid source 176 is considered to be an air compressor. The air delivered by this compressor to the cir-

culation swivel 172 flows downwardly through the central passage 148a in the drill stem 18 and exhausts through the leading or forward end of the stem which mounts the pilot hole cutter 36. For reasons to appear presently, the floor of the mine drift in the region of penetration of the pilot hole into the floor, is excavated to form a well or receiver 178 over which is placed a cover 180 that is pervious to air. Leading from this well is a large conduit 182 which connects to the intake of a blower 184. The blower discharges to a suitable receiver, such as a dump car (not shown).

The control panel 138 for the earth boring machine 10 is placed in a convenient position within the mine drift 156 and is operatively connected to the machine through the hydraulic hoses 136. After installation of the machine in the socket bore liner 164, the appropriate valves on the control panel are operated to supply hydraulic fluid under pressure to the inner ends of the feed carriage or rear anchor shoe actuators 114, thus to extend the rear wall anchor shoes 112 into anchoring contact with the liner.

At this point, it should be noted that the bundle 136 of hydraulic hoses which connect the boring machine 10 to the remote control panel 138 approach the machine from the rear and extend forwardly through an opening in the rear thrust plate 42. Certain of the hydraulic hoses in this bundle extend into the feed carriage thrust plate 76 for connection to the rear anchor shoe and anchor pin actuators 114, 124. The remaining hoses in the bundle extend through the feed carriage thrust plate 76. Certain of these remaining hoses connect to the carriage actuators 78. Certain other of the remaining hoses extend forwardly into the front thrust plate 40 for connection to the main carriage or front anchor shoe and anchor pin actuators 92, 160. The few remaining hoses extend through the front thrust plate 40 and cutter thrust disc 53 to the cutter support drive motors 64. It is obvious that since the rear anchor shoes 86 on the boring machine are extended into anchoring contact with the socket bore liner 164, suitable access means must be provided for passing the hydraulic hoses around the anchor shoes. This may be accomplished in various ways. In the drawings, for example, the socket bore 162 has a generally egg-shape in transverse cross section which provides a longitudinal recess 162a along one side of the socket bore line 164 to receive a lateral enlargement 164a on the line through which the hydraulic hoses extend to the rear end of the machine.

After the boring machine 10 has been properly anchored, in the manner described above, within the socket bore liner 164, the machine is conditioned for a pilot hole drilling operation by coupling one or both of the leading, large diameter drill stem sections 18b, depending upon the available clearance between the front end of the boring machine and the floor of the mine drift, to the drill stem adaptor coupling 170 on the machine. At this point, it should be noted that while the drill stem 18 has been illustrated as embodying two of the drill stem sections 18b, the number of these sections which are used in actual practice may vary. After these drill stem sections have been properly coupled to the boring machine, to provide an initial length of drill stem, the pilot hole drilling operation is initiated by supplying hydraulic fluid under pressure to the cutter support drive motors 64 and to the rear ends of the carriage actuating cylinders 80. The cutter support 46 and initial length of drill stem 18 secured thereto are thereby driven in rotation, and the main machine carriage 12 is simultaneously driven forwardly in a feed stroke relative to the currently anchored feed carriage 24, thus to effect axial penetration of the pilot hole cutter into the earth formation bounding the floor of the mine drift. Forward movement of the main carriage is continued until this carriage reaches the forward limit of its feed stroke. At this point, either of two procedures may be followed,

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depending upon the effective stroke length of the machine and the available clearance space between the floor of the mine drift and the front end of the machine. Thus, if the available clearance space and the stroke length are about equal to or somewhat greater than the length of the individual drill stem sections 18a, 18b, the initial length of drill stem is uncoupled from the machine, upon arrival of the main carriage 12 at the forward limit of its feed stroke, after which the main carriage is again retracted to the rear limit of its feed stroke. Thereafter, an additional drill stem section 18a or 18b, as the case may be, is coupled between the initial length of drill stem and the machine, whereupon the main carriage is again driven forwardly to the forward limit of its feed stroke to cause further penetration of the pilot hole cutter 36 into the earth formation. The drill stem is then again uncoupled from the machine, the main carriage is retracted, and a new drill stem section is coupled in the drill string. This procedure is repeated until the pilot hole has been driven the desired depth. It is apparent, of course, that this same procedure may be employed in the event that the available clearance space between the floor of the mine drift and the boring machine is sufficient to accommodate the coupling of two drill stem sections in the drill string after the completion of each forward feed stroke of the machine.

Assume now that the available clearance space between the floor of the mine drift and the front end of the boring machine is just sufficient to accommodate one drill stem section 18a or 18b and that the effective stroke length of the boring machine is substantially less than the length of each section. In this case, when the main carriage 12 is initially driven to the forward limit of its feed stroke, the front anchor shoes 86 on the main carriage are extended into anchoring contact with the socket bore liner 164, the rear anchor shoes 112 on the feed carriage are retracted, and hydraulic fluid under pressure is supplied to the forward ends of the carriage actuators 78 to drive the feed carriage forwardly in a repositioning stroke relative to the main carriage. The rear anchor shoes are then re-extended into anchoring engagement with the liner 164 and the front anchor shoes are retracted. Thereafter, hydraulic fluid is again supplied to the rear ends of the carriage actuators to again drive the main carriage 12 forwardly in its feed stroke relative to the feed carriage. This procedure, which results in forward stepwise movement of the boring machine through the liner 164, is repeated until the drill stem has been driven forwardly a distance at least equal to the length of one drill stem section. The drill string is then uncoupled from the machine and the latter is stepped rearwardly to its original position in the socket bore liner. Thereafter, an additional drill stem section is coupled in the drill string and the above described operating cycle of the boring machine is repeated to drive the drill string forwardly through the earth formation.

When the pilot hole has been driven the desired depth, which, in the illustrative application of the invention, occurs when the pilot hole penetrates the ceiling of the adjacent lower mine drift, the drilling operation is discontinued. The next operating phase of the boring machine 10 involves reaming out the pilot hole to the desired diameter of the finished raise 160. Either of two procedures may be followed in this reaming operation, depending upon whether the operation is to be performed with or without the assistance of the guide rail referred to earlier. Assume first that the reaming operation is to be carried out without the assistance of the guide rail. In this case, at the conclusion of the pilot hole drilling operation, the pilot hole drill string is removed from the pilot hole prior to commencement of the reaming operation. The machine is conditioned for the reaming operation by removing the drill stem adaptor 168 from the rotary cutter support 14 of the machine and mounting on this support the reaming cutter 20.

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During the actual reaming operation, the feed carriage 24 is periodically anchored to the earth formation and the main carriage 12 is driven forwardly through the pilot hole in its feed stroke relative to the main carriage while the cutter support 14, and hence the reaming cutter 20, are driven in rotation, thus to cause the reaming cutter to ream out the length of the pilot hole equal to the stroke length of the boring machine. The main carriage is then retained stationary while the feed carriage is driven forwardly in its repositioning stroke relative to the main carriage. Thereafter, the feed carriage is again anchored to the earth formation and the main carriage is again driven forwardly in its feed stroke relative to the feed carriage to remount another incremental length of the pilot hole. This procedure is continued until the entire length of the pilot hole has been reamed. Thus, the boring machine 10, in effect, crawls, in stepwise fashion, through the pilot hole.

It is evident, at this point, that the reaming operation of the boring machine 10 involves two distinct phases, to wit, an initial phase during which the adjacent or leading end of the pilot hole is reamed to a depth at which the rear anchor shoes 112 on the feed carriage 24 are disposed for initial anchoring engagement with the reamed wall of the hole and a final phase during which the remaining length of the pilot hole is reamed. Considering first the final phase of the reaming operation, the feed carriage 24 is periodically anchored to the earth formation, as mentioned, by extending the rear anchor shoes 112 into anchoring engagement with the surrounding, reamed wall of the pilot hole. As discussed above, the main carriage 12 is then driven forwardly in a feed stroke relative to the main carriage. When the main carriage reaches the forward limit of its feed stroke, the latter carriage is retained stationary, the rear anchor shoes are retracted, and the feed carriage is driven forwardly in its repositioning stroke relative to the main carriage. The rear anchor shoes are then re-extended into anchoring engagement with the reamed wall of the pilot hole and the main carriage is again driven forwardly in its feed stroke relative to the main carriage, in the manner explained earlier. In the event that the boring machine travels in a downward direction through the pilot hole during the reaming operation, the weight of the main machine carriage will retain the latter stationary during each repositioning stroke of the feed carriage. In this case, then, it is unnecessary to provide the machine with, or at least utilize, the forward anchor shoes 86. On the other hand, if, during the reaming operation, the machine travels in an upward direction through the pilot hole, it is necessary to anchor the main carriage 12 to the reamed wall of the pilot hole during each repositioning stroke of the feed carriage 24. In this case, the front and rear anchor shoes 86 and 112 are extended and retracted in alternate sequence. That is to say, during each repositioning stroke of the feed carriage, the front anchor shoes 86 are extended into anchoring engagement with the reamed wall of the pilot hole to anchor the main carriage against retrograde movement and the rear anchor shoes 86 are retracted to permit the repositioning stroke of the feed carriage. During each feed stroke of the main carriage, the front anchor shoes are retracted to permit the latter stroke and the rear anchor shoes are extended into anchoring engagement with the reamed wall of the pilot hole to anchor the feed carriage against retrograde movement.

Consider now the initial phase, referred to earlier, of the reaming operation. During the first portion of this operating phase, neither the front anchor shoes 86 on the main carriage 12 nor the rear anchor shoes 112 on the feed carriage 24 can be extended into anchoring engagement with the reamed wall of the pilot hole. During the final portion of the initial operating phase, the front anchor shoes are disposed for anchoring engagement with the reamed wall of the pilot hole but the rear anchor shoes are not. Accordingly, during the initial operating

phase of the earth boring machine 10, it is necessary to provide an auxiliary thrust surface into which the anchor shoes may be extended into anchoring engagement. One way in which this auxiliary thrust surface may be provided, for example, is by extending the socket bore liner 164 to the position adjacent the wall of the drift which is initially penetrated by the machine during the reaming operation, i.e. the floor of the drift in the illustrated application, as shown in FIGURE 1a and hereinafter described, to permit the machine to crawl, in effect, from the liner into the earth formation. Further alternative procedures for anchoring the machine during the initial operating phase will be explained presently.

At this point, it is significant to recall that the front and rear anchor shoes 86, 112, when retracted, and the rear thrust plate 42 have substantially a common external diameter which may be just slightly less than the cutting diameter of the reaming cutter 20. In this case, the front anchor shoes and the rear thrust plate coact with the reamed wall of the pilot hole to guide the main carriage 12 during each forward feed stroke thereof, thus to permit the machine to drill an accurate raise. It is further significant to recall that the anchor shoes may be selectively extended and retracted independently or in unison. This permits the drilling direction of the machine to be accurately controlled by selective radial positioning of the shoes. To this end, it may be desirable to provide the front and rear anchor shoes 86, 112, when retracted, with a common diameter which is somewhat less than the cutting diameter of the reaming cutter 20 and to provide the rear thrust plate 42 with a diameter which is equal to or less than this common diameter. In this case, guidance of the main carriage during each feed stroke thereof accomplished by extending the front anchor shoes 112 into guiding or sliding relation to the reamed wall of the pilot hole, thus to provide lateral guiding support for the front end of the main carriage, and relying on the sliding engagement of the main carriage with the feed carriage 24, which is then anchored to the reamed wall, to provide lateral guiding support for the rear end of the main carriage. This latter boring machine arrangement permits greater latitude in controlling the drilling direction of the machine. Thus, when the retracted anchor shoes and the rear thrust plate are provided with an external diameter which is substantially less than the cutting diameter of the reaming cutter, substantial angular displacement of the longitudinal axis of the machine may be achieved by selective extension and retraction of the anchor shoes; that is to say by eccentrically displacing the front anchor shoes in one direction and eccentrically displacing the rear anchor shoes in the opposite direction. Such drilling direction control may be desirable to change the drilling direction or to correct for a deviation in the drilling direction caused, for example, by a non-homogeneous formation about the pilot or reamed hole.

Consider now the reaming operation of the boring machine 10 with the assistance of the guide rail. As noted earlier, the drill stem or string 18 is uniquely constructed to serve as the guide rail. Also, as will appear from the ensuing description, a guide rail which is intended solely for this purpose may be used during the reaming operation. In the following discussion, it will be assumed that the guide rail is furnished by the drill string 18.

In this case, the pilot hole drill string 18 is left in the pilot hole at the conclusion of the pilot hole drilling operation, discussed earlier. The ends of this drill string are anchored, in some appropriate manner, to the earth formation. The boring machine 10 is then advanced forwardly along the rail by alternately extending the front and rear internal anchor dogs or pins 102 and 126 into positions of anchoring engagement with the rail wherein these pins engage in the bores or sockets

38 in the drill string or rail and alternately driving the main carriage 12 and feed carriage 24 in their feed and repositioning strokes, respectively. Thus, during the reaming operation with the assistance of the guide rail 18, the rear anchor pins 126 are extended inwardly into anchoring engagement with the rail and the carriage actuators 78 are pressurized to drive the main carriage 12 forwardly in its feed stroke relative to the feed carriage 24. The main carriage is then retained stationary, the rear anchor pins are retracted out of anchoring engagement with the rail, and the carriage actuators are pressurized to drive the feed carriage forwardly in its repositioning stroke relative to the main carriage. Thereafter, the rear anchor pins are again extended into anchoring engagement with the rail and the main carriage is again driven forwardly in its feed stroke relative to the feed carriage. In the event that the machine travels in a downward direction during the reaming operation, the weight of the main carriage will retain the latter stationary during each repositioning stroke of the feed carriage. In this case, then, the front anchor pins 102 on the main carriage are necessary or at least need not be employed during the reaming operation. On the other hand, if the boring machine 10 travels in an upward direction during the reaming operation, it is necessary to anchor the main carriage against retrograde movement during each repositioning stroke of the feed carriage. In this case, then, the front and rear anchor pins 102 and 126 must be extended and retracted, in alternate sequence, into and from anchoring engagement with the guide rail 18 during the reaming operation. In other words, during each forward feed stroke of the main carriage, the front anchor pins 102 are retracted to permit the stroke and the rear anchor pins 126 are extended into anchoring engagement with the rail 18 to anchor the feed carriage 24 against retrograde movement. During each repositioning stroke of the machine, the front anchor pins 102 are extended into anchoring engagement with the rail 18, to anchor the main carriage against retrograde movement, and the rear anchor pins 126 are retracted to permit the repositioning stroke of the feed carriage.

It is apparent at this point, therefore, that the reaming operation of the boring machine 10 with the assistance of the guide rail 18 is essentially the same as the reaming operation of the machine, described earlier, without the assistance of the rail. As will be explained presently, however, the drilling direction of the machine 10, when reaming with the assistance of the rail, may be more accurately controlled when the reaming operation is performed without the assistance of the rail. Accordingly, the preferred practice of the invention involves the use of the guide rail.

At this point, it is significant to note that the anchor pin sockets 38 in the guide rail 18 are arranged in groups or sets of four sockets, which socket sets are uniformly spaced lengthwise of the rail 18. The four sockets in each socket set are disposed in a common plane normal to the longitudinal axis of the rail and are spaced 90° apart so as to register with the four front anchor pins 102 and the four rear anchor pins 126 on the boring machine 10. In addition, the corresponding anchor pin sockets in the several socket sets are aligned lengthwise of the rail. As noted earlier, the sockets are dimensioned to slideably receive the anchor pins.

It is now evident that the front and rear anchor pins 102 and 126 on the boring machine 10 are disposed for successive anchoring engagement with the anchor pin sockets 38 and a guide rail 18 during the course of the reaming operation, just explained. Thus, at the outset of this reaming operation, the machine is manually angularly oriented about the axis of the rail in such a way as to align the rear anchor pins 126 on the feed carriage 24 with the sockets in an adjacent socket set.

The rear anchor pins are then extended into these sockets to firmly anchor the feed carriage 24 to the rail 18. The front anchor pins 102 are retained in their retracted positions during this feed stroke. Assuming that the direction of travel of the machine is downward during the reaming operation, the front anchor pins may be retained in their retracted positions throughout the entire operation as noted earlier. However, if it is desirable or necessary to utilize the front anchor pins, as when the reaming operations carried out in the upward direction, these pins are extended into contact with the rail 18 just prior to arrival of the main carriage at its forward limiting position. The front anchor pins then slide along the rail until they become aligned with the following set of anchor pin sockets 38 in the rail, whereupon the pins will drop into the sockets. It is evident, of course, that the front anchor pins will thus automatically drop into or engage in the following set of anchor pin sockets owing to the fact that the pins are retained in longitudinal alignment with the sockets, as they approach the latter, by virtue of the current engagement of the rear anchor pins 126 in a set of anchor pin sockets in the rail. After the main carriage 12 has thus been anchored to the rail the rear anchor pins 126 are retracted and the feed carriage 24 is driven forwardly in its repositioning stroke relative to the main carriage. As the feed carriage approaches its forward limiting position, the rear anchor pins are re-extended into contact with the rail and slide along the latter until they become aligned with the following set of anchor pin sockets. The pins then drop into the sockets to reanchor the feed carriage to the rail. The front anchor pins 102 are then retracted and the main carriage 12 is again driven forwardly in its feed stroke relative to the feed carriage. As noted earlier, this procedure is repeated until the pilot hole has been completely reamed. It is evident, therefore, that the boring machine 10 propels itself in stepwise fashion along the bearing rail, as explained earlier.

Up to this point, no mention has been made of the front and rear anchor shoes 86, 112 in connection with the reaming operation of the boring machine 10 with the assistance of the guide rail 18. If desired, these anchor shoes may be retained in their retracted positions throughout the reaming operation. Preferably, however, the anchor shoes are extended and retracted simultaneously with extension and retraction of their respective adjacent anchor pins in such a way as to anchor the feed carriage 24 both to the reamed wall of the pilot hole and to the rail 18 during each forward feed stroke of the main carriage 12 and to anchor the main carriage both to the reamed wall and the rail during each repositioning stroke of the feed carriage. This provides the machine with maximum lateral and axial support as is required to obtain maximum drilling pressure and minimum deviation in the finished raise.

As noted earlier and hereinafter explained in detail, the guide rail 18 is anchored to the earth formation at the ends of the pilot hole to enable the boring machine 10 to react against the rail during each stroke of the machine, and particularly during its feed strokes, and thereby produce the required axial thrust for reaming as well as repositioning of the feed carriage when reaming in an upward direction. As also indicated, the rail serves to guide the machine during its reaming operation in such a way as to enable the machine to ream a raise whose maximum deviation is well within the limits permitted by normal raise specifications. To this latter end, the rail is anchored so that it extends generally axially to the pilot hole. However, due to its inherent mass and flexibility, the rail tends to bow or bend, particularly when the pilot hole is inclined, as shown. Movement of the boring machine along such a curved rail during reaming, of course, would result in a correspondingly curved raise which, in most cases, would not satisfy normal raise specifications. It is evident that this problem

exists whether or not the wall anchor shoes 86, 112 are used, in conjunction with the rail anchor pins 102, 126, to anchor the machine to the reamed wall of the pilot hole. A unique and highly important feature of this invention resides in the fact that the reaction force exerted by the machine on the rail during each feed or reaming stroke of the machine places the rail under substantial axial tension. This axial tension counteracts the gravity induced bending moment in the rail and restores the latter to a substantially straight or linear condition during each feed stroke of the machine. The rail, therefore, is capable of providing accurate linear guidance for the boring machine during each feed stroke, thus resulting in an accurately linear finished raise.

We return now to the matter of anchoring the guide rail 18. It will be recalled that the rail under discussion is furnished by the pilot hole drill stem or string which is left in the pilot hole for this purpose at the conclusion of the pilot hole drilling operation. In actual practice, at the conclusion of this pilot hole drilling operation, the pilot hole drill string is advanced axially to a position wherein the leading small diameter drill stem section 18a projects a distance down the adjacent end of the pilot hole. At this point, the large diameter drill stem sections 18b are removed and the now exposed end of the leading drill stem section 18a is firmly attached to the surrounding earth formation. As shown in FIGURE 8, this may be accomplished by welding or otherwise rigidly securing an anchor plate 186 to the latter exposed end, at the proper angle to the axis of the drill string, and bolting or otherwise firmly anchoring the plate to the earth formation in such a way that the adjacent end of the drill string is centered in and extends axially of the pilot hole. The drill string may thus be anchored while the boring machine 10 is still coupled to the string and anchored within the socket or liner 164, whereby the string will be axially supported by the machine. It is assumed that the liner is firmly attached to the surrounding earth formation for this purpose.

After the leading end of the pilot hole drill string has been properly anchored, the opposite end of the string is uncoupled from the boring machine 10 and the drill string adaptor 168 is removed to expose the axial drill stem or drill string receiving opening in the machine. At this point, the reaming cutter 20 is installed on the machine. This cutter also has a central opening aligned with the central opening 22 to the machine. The boring machine 10 is then driven along the drill string which now functions as a guide rail for the machine, into initial reaming engagement with and then axially through the pilot hole to ream the latter, in the manner explained earlier.

At this point, it is evident that the reaming operation, under consideration, of the boring machine 10, like the reaming operation discussed earlier, involves two distinct phases, to wit, an initial phase during which the boring machine travels forwardly from the socket or liner 164 onto the adjacent end of the guide rail and then along this rail to a position at which the entire machine is contained within the initially reamed portion of the hole, and a final phase during which the machine travels forwardly along the remaining length of the rail and through the remaining length of the pilot hole. Considering first the final phase of the reaming operation, once the boring machine 10 has penetrated the earth formation to the depth just indicated, the adjacent end of the rail may be anchored to the surrounding earth formation in the same way as discussed earlier in connection with the distal or leading end of the rail. The reaming operation is then continued by driving the machine in stepwise fashion along the rail and through the pilot hole, in the manner explained earlier.

Let us now consider the initial phase of the reaming operation under discussion. It is evident that this phase of the operation requires transfer of the boring machine 10 from the socket bore liner 164 on to the guide rail 18 and lateral supporting of the adjacent end of the rail until the ma-

chine has penetrated the earth formation to the initial depth, referred to above, at which the latter end of the rail may be anchored to the earth formation. Transformation of the boring machine from the socket bore liner 164 to the guide rail 18 may be accomplished in various ways. For example, after the reaming cutter 20 has been mounted on the machine, and while the latter remains anchored within the liner one or more the drill stem sections 18a may be inserted axially upward through the central machine opening 22 and then coupled to the adjacent end of the main length of the guide rail which extends through the pilot hole, thus to permit the machine to advance forwardly from the liner and along the guide rail. In this case, the adjacent end of the extended guide rail may be anchored to the earth formation at the inner end of the socket bore liner 164 before the machine is driven forwardly from the liner to provide lateral support for the rail. To this end, suitable access means (not shown) to the rear or inner end of the liner may be provided to permit a workman to enter the liner and anchor the guide rail, as indicated. Alternatively, at the conclusion of the pilot hole drilling operation, the drill string may be simply coupled from the boring machine, and, after installation of the reaming cutter on the machine, the latter may be driven forwardly from the socket bore liner 164 onto the drill string or guide rail. In this case, lateral support for the adjacent end of the guide rail, during forward movement of the machine to the initial depth, referred to earlier, must be provided in some manner other than by anchoring the rail to the earth formation at the inner end of the socket bore liner in the manner just explained. Such lateral support may be provided by extending the socket bore liner to a position sufficiently close to the adjacent end of the pilot hole to enable the machine to advance directly from the liner into the earth formation. It will be recalled that this latter procedure was referred to earlier in connection with reaming operation of the machine without the assistance of the guide rail. This extended liner method of providing lateral support and guidance for the boring machine 10 during the initial phase of the reaming operation has been illustrated in FIGURE 1a, wherein it will be observed that the outer or lower end of the socket bore line 164 is extended to a position adjacent the floor of the mine drift 156 from which the pilot hole drilling and reaming operations are started.

It is significant to note at this point that the illustrated socket bore liner 164 is composed of two separate sections 164a and 164b which are bolted together. The rear or inner liner section 164a is contained within the socket bore 162 and has its outer end disposed adjacent the outer end of the bore. The front liner section or extension 164b is located externally of the socket bore and has its rear end bolted to the front end of the rear liner section. This permits only the rear liner section 164a to be used during the pilot hole drilling operation, thus to permit the drill stem sections 18a and 18b to be coupled into the pilot hole drill string during this operation. The front liner section 164b is installed only during the initial phase of the pilot hole reaming operation and is removed at the conclusion of this operating phase. In order to permit the front liner section 164b to be installed about the adjacent, extending end of the pilot hole drill string or guide rail 18 at the outset of the pilot hole reaming operation, the liner section is split axially into two halves which are bolted together in the manner illustrated in FIGURE 4. If desired or necessary, the front liner section may be provided with an access opening, as shown, to permit the workman to enter the section. This same liner construction may be used when reaming without the guide rail, as described earlier.

The foregoing description and the drawings relate to pilot hole drilling and reaming operations wherein the boring machine 10 travels in a downward direction through the earth formation. It is obvious, however, that the same basic operating procedures described may be fol-

lowed in those drilling and reaming operations in which the boring machine travels in an upward direction through the earth formation. Also, these same procedures may be followed when drilling and reaming from the surface. In this latter case, however, the liner 164 to which the machine 10 is anchored during the pilot hole drilling operation and the initial phase of the pilot hole reaming operation must be mounted on a suitable supporting structure which is firmly anchored to or recessed into the tunnel floor.

It is possible that in those cases where the angle between the vertical and the axis of the pilot hole is relatively large, the front socket bore liner section 164b which provides lateral support guidance for the boring machine 10 during the initial phase of the pilot hole reaming operation may have to be reinforced, in some way, against the lateral movement under the weight of the machine. This may be accomplished, for example, by simply anchoring the front end of the front section to the adjacent wall or floor of the mine drift as shown in FIGURE 1a.

It is important to recall at this point that during pilot hole drilling operation of the boring machine 10, the hydraulic hoses which connect the machine to the control panel 138 extend into the rear or inner end of the socket bore liner 164.

It is obvious that a problem of chip removal exists during both pilot hole drilling and reaming operations of the earth boring machine 10. Chip removal during pilot hole drilling operation of the machine is accomplished by directing a continuous stream of flushing fluid through the central passage 148a in the pilot hole drill string 18. In the illustrative embodiment of the invention, this flushing fluid comprises compressed air from the air compressor 176 which enters the drill string through the hose 174 and the swivel 172, the ear hose through the drill string to the leading end of the liner and then out into the pilot hole bore through openings (not shown) in the latter end of the string, adjacent the pilot hole cutter 36. The air then flows back through the pilot hole, between the wall of the latter and the drill string, carrying with it the chips produced by the drilling operation. At this point, it is significant to recall that the inner and outer pipes 148, 150 of the leading large diameter drill stem sections 18b are radially spaced, thus to define therebetween an annular flow space through which the returning air and chips may pass. The air and drilling chips emerging from the pilot hole enter the well 178 which, as noted earlier, is covered by the cover 180. The chips are exhausted from this well to a suitable receiver (not shown), such as a dump car, by the blower 184. Other means, such as a screw conveyor, may also be provided for this purpose. When drilling a pilot hole upwardly through the earth formation, the drilling chips obviously will tend to fall by gravity through the pilot hole. In this case, a suitable receiver may be installed at the lower end of the pilot hole, about the pilot hole drill strings, to receive the chips and from which the chips may be exhausted to a dump car, or the like.

When reaming a pilot hole in the downward direction, the chips produced by the reaming operation will tend, simply, to fall by gravity through the lower end of the pilot hole in advance of the reaming cutter. Here again, a suitable receiver may be installed opposite the lower end of the pilot hole to receive the chips. In this case, the boring machine 10 does not tend to obstruct or impede movement of the chips from the pilot, and, accordingly, the machine need not be provided with chip clearance means. On the other hand, when reaming a pilot hole in the upward direction, the chips produced by the reaming operation fall back by gravity toward the machine which, then, blocks or impedes passage of the chips from the pilot hole. In this case, the machine must be provided with suitable chip clearance means to permit the chips to fall freely past the machine.

Such chip clearance may be accomplished in various ways. In the illustrated boring machine 10, for example,

the outer edges of the front thrust disc 53, front disc plate 40, feed carriage thrust plate 76, and rear thrust plate 42 are provided with a number of circumferentially spaced, longitudinally aligned chip clearance openings 188. The clearance openings in the front thrust disc, front thrust plate, and feed carriage thrust plate will be observed to be located in the regions between the adjacent, spaced ends of the front and rear anchor shoes 86, 112. The cylindrical wall 46 of the rotary cutter 14 is similarly provided with a number of circumferentially spaced, longitudinally extending chip clearance openings or grooves 190. It is obvious that during rotation of the support, the grooves 190 successively align themselves with the circumferentially openings 188, thus permitting the drilling chips to pass from the front end to the rear end of the machine. In some cases, the diameter of the rotary cutter support 14 may be made sufficiently small as to continuously expose the chip clearance openings 188 in the machine and thereby eliminate the necessity of externally grooving this support, as illustrated. In order to prevent the chips which pass rearwardly through the chip clearance openings 188 in the thrust disc 53 from entering the interior space of the machine and thereby interfering with relative axial movement of the carriages or damaging the machine, the latter is equipped with generally channel shaped chutes 192 which are secured to the front and rear thrust plates 40 and 42 on the main machine carriage 12, within the chip clearance openings 188 in these plates, and extend slidably through the chip clearance openings in the feed carriage thrust plate 76. These chutes confine the drilling chips which pass rearwardly along the machine, through the chip clearance openings, and thus prevent the chips from entering the interior of the machine.

It is now obvious that during a pilot hole reaming operation in which the boring machine 10 travels upwardly through the pilot hole, the chips produced by the reaming operation are permitted to fall by gravity rearwardly or downwardly through the chip chutes 192. As noted earlier, a suitable receiver may be installed at the lower end of the pilot hole for collecting these chips. While the chips may tend to accumulate in the cutter support grooves 190 during rotation of these grooves between their positions of alignment with the chip chutes 192 on the main carriage, periodic alignment of the grooves and chutes will dispose of the chips at a sufficiently rapid effective rate to prevent excessive chip accumulation which might interfere with the reaming operation.

The operation of the present earth boring machine 10 is believed now to be obvious. Thus, during a pilot hole drilling operation, the drilling machine is anchored in the socket bore liner 164 and the main carriage 12 of the machine is periodically driven forwardly in a feed stroke relative to the anchor feed carriage 24, while the machine motors 64 are operated to drive the pilot hole cutter 36 in rotation, thus to effect axial penetration of the cutter into the earth formation. At the conclusion of each feed stroke, the cutter motors are stopped, the drill string is uncoupled from the machine, and the main carriage is retracted to permit installation of one or more additional drill stem sections 18a or 18b, as the case may be. The cutter motors 64 are then again operated and the main carriage 12 is again driven forwardly in its feed stroke relative to the feed carriage to effect further axial penetration of the cutter 36 into the earth formation. During this pilot hole drilling operation, the enlarged drill stem sections 18b on the leading end of the drill string provide lateral support and guidance for the string, thereby permitting a pilot hole of maximum linearity to be drilled. During this pilot hole drilling operation, the drilling chips are flushed from the pilot hole by operation of the compressed air flushing system 176.

At the conclusion of the pilot hole drilling operation, the drill string 18 is removed from or anchored in the pilot hole, in the manner explained earlier, depending upon whether or not the string is to be utilized as a

guide rail for the boring machine 10 during subsequent reaming of the hole to the desired diameter of the finished raise. In the event that the rail is removed, forward movement of the machine through the pilot hole, to ream the latter, as effected by extending and retracting the front and rear anchor shoes 86, 112 into and from anchoring engagement with the reamed wall of the pilot hole and driving the main carriage 12 in its forward feed stroke and the feed carriage 24 in its forward repositioning stroke in alternate sequence, all in the manner explained earlier, thus to effect stepwise forward movements of the machine through the pilot hole. In the event that the pilot hole drill string 18 is anchored in the pilot hole at the conclusion of the pilot hole drilling operation, to serve as a guide rail for the machine during the reaming operation, the machine is driven in its forward reaming movement along the rail and through the pilot hole by extending and retracting the front and rear anchor pins 102, 126 into and from anchoring engagement with the rail and driving the machine carriages in its feed and repositioning strokes in alternate sequence, all in the manner explained earlier. As noted before, the front and rear anchor shoes 86, 112 may be extended into and retracted from anchoring engagement with the reamed wall of the pilot hole simultaneously with extension and retraction of the respective adjacent anchor pins to provide the machine with maximum lateral support and guidance during the reaming operation.

During both the pilot hole drilling and reaming operations, it is generally necessary to periodically sharpen or replace the cutters. Replacement or resharpening of the pilot hole cutter 36 is accomplished by retracting the drill string 18 from the pilot hole. This, in turn, is accomplished by driving the main carriage 12 of the boring machine 10, which machine is then anchored in the socket bore liner 164, rearwardly relative to the feed carriage to elevate the drill string a distance out of the pilot hole. The lower portion of the string is then clamped, to prevent it from dropping back down the pilot hole, and one or more of the drill stem sections 18a are removed within the string. The main carriage 12 is then extended forwardly to its forward limiting position and recoupled to the drill string, whereupon the carriage is again driven rearwardly to elevate the remaining portion of the drill string a further distance out of the pilot hole. This procedure is repeated until the pilot hole cutter 36 is exposed for replacement or resharpening. The drill string is then reassembled and lowered into the pilot hole for the next portion of the pilot hole drilling operation by reversing this procedure.

When it becomes necessary to replace or resharpen the reaming cutter 20 during the pilot hole reaming operation, the entire earth boring machine 10 is removed from the hole. In the event that the reaming operation is carried out in a downward direction, the machine is hoisted from the pilot hole by means of the hoist cable 146 and winch 147. If, on the other hand, the pilot hole is reamed in an upward direction, the boring machine 10 is removed from the hole, for replacement or resharpening of the reaming cutter, by simply driving the machine backward through the pilot hole and toward its lower end. It is obvious, of course, that this backward driving of the boring machine is effected by simply reversing the sequence of operations, explained earlier, which effect forward movement of the machine.

As noted earlier, the several hydraulic actuators and cutter motors of the boring machine 10 are remotely controlled by the valves 140 on the control panel 138. These valves may be operated to effect the various sequential machine operations required for both the pilot hole drilling and the pilot hole reaming operations explained earlier. In addition, the control panel valves may be operated to selectively extend and retract the front and rear anchor shoes 86, 112 in such a way as to con-

trol the drilling direction of the machine, as explained earlier.

Reference is now made to FIGURES 13 and 14 which illustrate an alternative procedure for reaming the initial portion, i.e., the upper end of the pilot hole to a depth 5 sufficient to accommodate the earth boring machine or raise driver 10 and thereafter positioning or lowering the machine into the initial reamed portion of the hole. According to this alternative procedure, the machine remains anchored within the socket bore casing 164 during the initial reaming operation. An initial length of the drill string 18 containing one or more of the pilot hole drill string sections 18a, 18b, depending upon the available clearance space between the front end of the machine and the floor of the adjacent mine drift 156, is then attached to the rotary cutter support 14 of the machine in the manner explained earlier. The reaming cutter 20 is secured to the front end of this drill string. Thereafter, the main carriage 12 of the machine is driven forwardly in a feed stroke relative to the feed carriage 20 24, which is currently anchored to the casing 164, to ream the adjacent end of the previously drilled pilot hole. When the main carriage reaches the forward limit of its feed stroke, the drill string is uncoupled from the machine, the main carriage is retracted, an additional section 18a or 18b is inserted in the drill string, and the main machine carriage is again driven forwardly in a feed stroke relative to the feed carriage to ream an additional portion of the pilot hole. This procedure is continued until the pilot hole is reamed to a depth sufficient to accommodate the machine. 30

After this initial reaming operation has been completed, the drill string 18 is removed from the boring machine 10 and the reaming cutter 20 is mounted directly on the rotary cutter support 14 of the machine. 35 The machine is then lowered into the reamed portion of the pilot hole. This may be accomplished in various ways. FIGURE 14, for example, illustrates the machine being lowered into the reamed hole by means of the cable 146 which is trained about pulleys 200 and 202 attached to the upper end wall of the socket bore 162. As noted earlier, this cable extends to a winch 147 (not shown in FIGURE 14). A suitable guide shoe 204 may be constructed from timbers or the like for supporting and guiding the boring machine 10 during its movement 45 across the mine drift 156 into the reamed portion of the pilot hole.

The discussion thus far has related primarily to use of the machine for drilling and reaming raises and subterranean mines. It is obvious, however, that earth boring machines according to the invention may be constructed and arranged to drill holes for any purpose in earth formations. For example, earth boring machines according to the invention may be designed to drill relatively large shafts and tunnels. In this case, a significant advantage of the invention resides in the fact that the pilot hole drill string 18 may be driven through the earth formation to a position at which a suitable anchorage is found for the leading end of the string. The reaming cutter 20 may then be mounted on the machine and the latter may be driven forwardly along the drill string, in the manner explained earlier, to ream or drive a tunnel through the formation. Thereafter, the pilot hole drill string may be again driven forwardly through the formation until another suitable anchorage is found for the drill string, after which the reaming operation is repeated to drive the tunnel further through the formation. This stepwise operation of the machine is repeated until the tunnel is completed. The advantage of this operation of the machine resides in the fact that the drill string guides the machine to maintain linearity of the tunnel and, in addition, provides a firm anchorage for the machine during passage of the latter through relatively soft earth formations. 70

It is now evident, therefore, that the invention herein 75

described and illustrated is fully capable of attaining the several objects and advantages primarily set forth.

While a presently preferred embodiment of the invention has been described and illustrated for illustrative purposes, it is obvious that numerous modifications in the design, arrangements of parts, instrumentalities, and method steps of the invention, are possible within the sphere and scope of the following claims.

What is claimed as new in support of Letters Patent is:

1. A self-propelled earth boring machine for boring a hole through an earth formation, comprising:

a main supporting carriage having front and rear ends, a rotary cutter mounted on the front end of said carriage for turning on a rotation axis substantially parallel to the longitudinal axis of the carriage, first power means operatively connected between said carriage and cutter for driving said cutter in rotation, a feed carriage rearwardly of and mounted on said main carriage for relative endwise movement of said carriages, means connecting said carriages to restrain the latter against relative rotation, second power means operatively connected between said carriages for driving said carriages in relative movement in either endwise direction thereof, thrust means mounted on said feed carriage for movement laterally of said feed carriage to and from positions of anchoring engagement with a fixed drive surface to restrain said feed carriage against longitudinal movement and rotation, and hydraulic means separate from and operable independently of said second power means for extending said thrust means to and retracting said thrust means from said anchoring positions.

2. An earth boring machine according to claim 1, wherein:

said main carriage comprises a front circular plate centered on said rotation axis, a rear circular plate coaxial with and located rearwardly of said front plate, and supporting rods fixed to and extending between said plates parallel to said axes, said plates having a common diameter approximating the cutting diameter of said cutter, said feed carriage comprises a third circular thrust plate centered on said rotation axis and is slidably supported on said rods and said second power means comprises hydraulic linear actuators operatively connected between said feed carriage and one of said plates.

3. An earth boring machine according to claim 1, including:

additional thrust means mounted on said main carriage for movement laterally of said main carriage to and from positions of anchoring engagement with a fixed drive surface to restrain said main carriage against longitudinal movement, and second hydraulic means separate from and operable independently of said first hydraulic means and said second power means for extending additional thrust means to and retracting said additional thrust means from said anchoring positions thereof.

4. A self-propelled earth boring machine for boring a hole through an earth formation, comprising:

a main supporting carriage having front and rear ends, a rotary cutter mounted on the front end of said carriage for turning on a rotation axis substantially parallel to the longitudinal axis of the carriage, first drive means on said carriage for driving said cutter in rotation, a feed carriage rearwardly of and supported on said main carriage for endwise movement relative to said main carriage, second drive means operatively connected between said carriages for driving said carriages in relative movement in either endwise direction thereof, a number of first thrust shoes mounted on said main carriage behind said cutter for movement laterally of said main carriage between extended positions wherein said thrust shoes

are disposed for anchoring engagement with the wall of said hole to restrain said main carriage against movement in both longitudinal directions in said hole, and retracted positions wherein said shoes are disposed to release said main carriage for axial movement in said hole, a number of second thrust shoes mounted on said feed carriage for movement laterally of said feed carriage between extended positions wherein said second shoes are disposed for anchoring engagement with the wall of said hole to restrain said feed carriage against axial movement in both longitudinal directions in said hole, and retracted positions wherein said second shoes are disposed to release said feed carriage for axial movement in said hole, said thrust shoes having outwardly presented thrust surfaces for engaging the wall of said hole, said thrust shoes being circumferentially spaced about said carriages, respectively, in such manner that said thrust shoes, when extended, are adapted to restrain the respective carriages against lateral movement in said hole in all lateral directions of said hole, said thrust surfaces being substantially equally radially spaced from said rotation axis a distance approximating said cutting radius when said thrust shoes are retracted, thereby to form lateral support means on said carriages, respectively, for restraining said carriages against lateral movement in said hole in all lateral directions of said hole, first hydraulic means separate from and operable independently of said second drive means for selectively extending and retracting said first thrust shoes, and second hydraulic means separate from and operable independently of said first hydraulic means and second drive means for selectively extending and retracting said second thrust shoes.

5. A self-propelled earth boring machine for boring a hole through an earth formation, comprising:

- a main supporting carriage having front and rear ends, a front circular plate mounted on the front end of said carriage, a rear circular plate mounted on the rear end of said carriage, said plates having a common axis, supporting rods fixed to and extending between said thrust plates generally parallel to said axis, a cutter rotatably mounted on the front end of said carriage forwardly of said front plate for turning on said axis, said plates having a diameter approximating the cutting diameter of said cutter, drive means on said carriage for driving said cutter in rotation, a feed carriage slidably mounted on said supporting rods for movement endwise of said main carriage, linear hydraulic actuators operatively connected between said feed carriage and one of said plates for driving said carriages in relative movement in either endwise direction thereof, a number of front thrust shoes circumferentially spaced about said main carriage and mounted on the latter carriage for movement laterally thereof between extended positions wherein said thrust shoes are disposed for anchoring engagement with the wall of said hole to restrain said main carriage against endwise movement in both longitudinal directions in said hole, and retracted positions wherein said thrust shoes are disposed to release said main carriage for endwise movement in said hole, a number of rear thrust shoes circumferentially spaced about said feed carriage and mounted on the latter carriage for movement laterally thereof between extended positions wherein said second thrust shoes are disposed for anchoring engagement with the wall of said hole to restrain said feed carriage against endwise movement in both longitudinal directions in said hole, and retracted positions wherein said second shoes are disposed to release said feed carriage for endwise movement in said hole, first hydraulic means separate from and operable independently of said hydraulic

actuators for selectively extending and retracting said first shoes, and second hydraulic means separate from and operable independently of said hydraulic actuators and said first hydraulic means for selectively extending and retracting said second thrust shoes.

6. A self-propelled earth boring machine for reaming a predrilled pilot hole extending through an earth formation and containing a central longitudinally fixed rail, comprising:

- a main supporting carriage having a central longitudinal axis and front and rear ends, a rotary cutter mounted on the front end of said carriage for turning on said axis, a feed carriage rearwardly of said main carriage, means supporting said feed carriage on said main carriage for relative endwise movement of said carriages and restraining said carriages against relative rotation on said axis, first drive means operatively connected between said carriages for driving said carriages in relative movement in either endwise direction thereof, second drive means operatively connected between said main carriage and cutter for driving said cutter in rotation, whereby during reaming operation of said machine a longitudinal reaction force and a reaction torque are transmitted through said main carriage to said feed carriage, said carriages and cutter having a central opening therethrough to slidably receive said rail, thrust means mounted on said feed carriage for movement to and from an anchoring position wherein said thrust means are disposed to engage said rail for restraining said feed carriage against both rotation and longitudinal movement relative to said rail under the action of said reaction torque and reaction force, respectively, and operating means for moving said thrust means to and from said anchoring position.

7. An earth boring machine according to claim 6, wherein:

- said thrust means comprises a thrust member mounted on said feed carriage for lateral movement relative to said feed carriage between an extended position wherein said thrust member is disposed for engagement with said rail, thereby to restrain said feed carriage against longitudinal movement and rotation relative said rail, and a retracted position wherein said thrust member is disposed to release said feed carriage for movement along said rail, and said operating means comprise hydraulic means for extending and retracting said thrust member.

8. An earth boring machine according to claim 6, including:

- additional thrust means mounted on said main carriage for movement to and from an anchoring position wherein said additional thrust means are disposed to engage said rail for restraining said main carriage against longitudinal movement relative to said rail, and operating means for moving said additional thrust means to and from said anchoring position thereof.

9. A self-propelled earth boring machine for reaming a predrilled pilot hole extending through an earth formation and containing a central longitudinally fixed rail, comprising:

- a main supporting carriage having front and rear ends, a rotary cutter mounted on the front end of said carriage for turning on an axis substantially parallel to the longitudinal axis of said carriage, first drive means on said carriage for driving said cutter in rotation, a feed carriage supported on said main carriage for endwise movement relative to said main carriage, second drive means operatively connected between said carriages for driving said carriages in relative movement in either endwise direction thereof, said carriages and cutter having a central opening therethrough to slidably receive said rail, and thrust means on said feed carriage engageable with said rail for restraining said feed carriage

against retrograde movement relative to said rail, said thrust means comprising a first thrust member mounted on said feed carriage for lateral movement relative to said feed carriage between an extended position wherein said thrust member is disposed for driving engagement with said rail, thereby to restrain said feed carriage against movement along said rail, and a retracted position wherein said thrust member is disposed to release said feed carriage for movement along said rail, a second thrust member mounted on said main carriage for lateral movement relative to said main carriage between an extended position wherein said second thrust member is disposed for driving engagement with said rail, thereby to restrain said main carriage against movement along said rail, and a retracted position wherein said second thrust member is disposed to release said main carriage for movement along said rail, and means for extending said first thrust member, retracting said second thrust member, and operating said second drive means in unison in such manner as to drive said main carriage forwardly in a feed stroke relative to said feed carriage and retracting said first thrust member, extending said second thrust member, and operating said second drive means in unison in such manner as to drive said feed carriage forwardly in a repositioning stroke relative to said main carriage.

10 A self-propelled earth boring machine for reaming a predrilled pilot hole extending through an earth formation and containing a central longitudinally fixed rail, comprising:

a carriage having front and rear ends, a cutter rotatably mounted on the front end of said carriage for turning on an axis substantially parallel to the longitudinal axis of said carriage, first drive means on said carriage for driving said cutter in rotation, said cutter and carriage having a central opening therethrough to slidably receive said rail, second drive means on said carriage engageable with said rail for driving said carriage forwardly along said rail, thrust means mounted on said carriage for movement laterally of said carriage to and from extended positions wherein said thrust means are disposed for engagement with the wall of the reamed hole, and hydraulic means separate from and operable independently of said second drive means for extending and retracting said thrust means.

11. An earth boring machine according to claim 10, wherein:

said second drive means comprises a feed carriage supported on said first mentioned carriage for endwise movement relative to said first carriage, drive means for driving said carriages in relative movement in either endwise direction thereof, first thrust means on said first carriage engageable with said rail for restraining said first carriage against retrograde movement along said rail, second thrust means on said feed carriage with said rail for restraining said feed carriage against retrograde movement along said rail, and means for selectively extending and retracting said latter first and second thrust means into and from engagement with said rails, additional thrust means mounted on said feed carriage for movement laterally of said feed carriage to and from extended positions wherein said additional thrust means are disposed for engagement with the wall of the reamed pilot hole, and hydraulic means separate from and operable independently of said second drive means and said first hydraulic means for extending and retracting said additional thrust means.

12. A self-propelled earth boring machine for reaming a predrilled pilot hole in an earth formation, comprising: a carriage having a central longitudinal axis and front

and rear ends, a rotary cutter mounted on the front end of said carriage for turning on said axis, first drive means operatively connected between said carriage and for driving said cutter in rotation, whereby during operation of said machine a longitudinal reaction force and a reaction torque are exerted on said carriage, said cutter and carriage having an opening extending axially therethrough, a rail extending slidably through said opening, said rail being adapted to be centrally disposed within said pilot hole and having a length at least equal to the length of said pilot hole, means on the ends of said rail for anchoring said rail ends to said earth formation at the end of said pilot hole, thereby to restrain said rail against endwise movement in said pilot hole, and second co-acting drive means on said carriage and rail for driving said carriage longitudinally along said rail against the action of said reaction force and restraining said carriage against rotation relative to said rail under the action of said reaction torque.

13. A self-propelled earth boring machine for reaming a predrilled pilot hole in an earth formation, comprising: a carriage having front and rear ends, a rotary cutter mounted on the front end of said carriage for turning on an axis substantially parallel to the longitudinal axis of said carriage, first drive means on said carriage for driving said cutter in rotation, said cutter and carriage having an opening extending axially therethrough, a rail extending slidably through said opening, second drive means on said carriage engageable with said rail for driving said carriage forwardly along said rail, said rail being adapted to be centrally disposed within said pilot hole and having a length at least equal to the length of said pilot hole, and means on the ends of said rail for anchoring said rail ends to said earth formation at the end of said pilot hole, thereby to restrain said rail against endwise movement in said pilot hole, said second drive means comprising a feed carriage supported on said first mentioned carriage for movement endwise of said first carriage, power means operatively connected between said carriages for driving said carriages in relative movement in either endwise direction thereof, first thrust means mounted on said first carriage for movement between an extended position of driving engagement with said rail and a retracted position out of driving engagement with said rail, second thrust means mounted on said feed carriage for movement between an extended position of driving engagement with said rail and a retracted position out of driving engagement with said rail, and means for retracting said first thrust means, extending said second thrust means, and operating said power means in unison in such manner as to drive said first carriage forwardly in a feed stroke relative to said feed carriage and extending said first thrust means, retracting said second thrust means, and operating said power means in unison in such manner as to drive said feed carriage forwardly in a repositioning stroke relative to said first carriage.

14. An earth boring machine according to claim 12, wherein:

said rail comprises a pipe having thrust holes spaced therealong, and said second drive means comprises thrust means engageable in said thrust holes to provide driving engagement between said carriage and rail.

15. A self-propelled earth boring machine for reaming a predrilled pilot hole in an earth formation, comprising:

a carriage having front and rear ends, a rotary cutter mounted on the front end of said carriage for turning on an axis substantially parallel to the longitudinal axis of said carriage, first drive means on said car-

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riage for driving said cutter in rotation, said cutter and carriage having an opening extending axially therethrough, a rail extending slidably through said opening, second drive means on said carriage engageable with said rail for driving said carriage forwardly along said rail, said rail being adapted to be centrally disposed within said pilot hole and having a length at least equal to the length of said pilot hole, and means on the ends of said rail for anchoring said rail ends to said earth formation at the end of said pilot hole, thereby to restrain said rail against endwise movement in said pilot hole, said second drive means comprises a feed carriage supported on said first mentioned carriage for endwise movement relative to said first carriage, power means operatively connected between said carriage for driving said carriages in relative movement in either endwise direction thereof, first front thrust means mounted on said first carriage for lateral movement relative to said first carriage between an extended position of driving engagement with said rail and a retracted position out of driving engagement with said rail, second front thrust means mounted on said first carriage for lateral movement relative to said first carriage between an extended position wherein said second thrust means are disposed for driving engagement with the wall of the reamed pilot hole and a retracted position wherein said second thrust means are disposed to disengage said wall, first rear thrust means mounted on said feed carriage for lateral movement relative to said feed carriage between an ex-

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tended position of driving engagement with said rail and a retracted position out of driving engagement with said rail, second rear thrust means mounted on said feed carriage for lateral movement relative to said feed carriage between an extended position wherein said latter thrust means are disposed for driving engagement with the wall of said reamed pilot hole and the retracted position wherein said latter thrust means are disposed to disengage said wall, and means for simultaneously retracting said front thrust means, simultaneously extending said rear thrust means, and operating said power means in unison in such manner as to drive said first carriage forwardly in a feed stroke relative to said feed carriage and simultaneously extending said front thrust means, simultaneously retracting said rear thrust means, and operating said power means in unison in such manner as to drive said feed carriage forwardly in a repositioning stroke relative to said first carriage.

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