

- [54] **REMOTE-CONTROLLED BORING MACHINE FOR BORING HORIZONTAL TUNNELS AND METHOD**
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- [22] Filed: **Jan. 3, 1972**
- [21] Appl. No.: **214,681**
- [52] U.S. Cl. **299/11, 61/85, 299/18, 299/30, 299/33**
- [51] Int. Cl. **E01g 3/04**
- [58] Field of Search **299/11, 18, 30, 31, 299/33; 61/85**

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 Attorney—Walter G. Maxwell et al.

[57] **ABSTRACT**
 A remote-controlled tunnel boring machine for drilling a substantially horizontal tunnel in a formation includes a rotary drilling head at the heading of the tunnel,

and a rotary drill pipe coupled to the drilling head and extending back to the portal of the tunnel for connection to drive means for rotating the drill pipe. The drilling head has fore and aft sections which are movable longitudinally relative to each other, the aft section being coupled with a series of interconnected tunnel liner sections jacked into place behind it from the portal as the drilling head advances through the tunnel. Hydraulic rams between the fore and aft sections periodically advance the drilling head to excavate material at the heading of the tunnel, the weight of the aft section and the tunnel liners acting as a thrust base or back-up for the extension of the rams. A second set of hydraulic rams at the portal periodically force new tunnel liner sections into place behind the string of tunnel liners. Cuttings are continuously removed from the tunnel heading by drilling fluid circulated in a closed system which includes an elongated conduit extending from the portal to the drilling head to continuously supply drilling fluid to the tunnel heading. The cuttings and drilling fluid are continuously returned from the tunnel heading to the portal area through the interior of the constantly rotating drill pipe. A ring-shaped inflatable balloon between the fore and aft sections of the drilling head forms a fluid-tight seal between the inner wall of the tunnel and the exterior of the drilling head to provide controlled hydrostatic fluid pressure at the tunnel heading.

41 Claims, 7 Drawing Figures

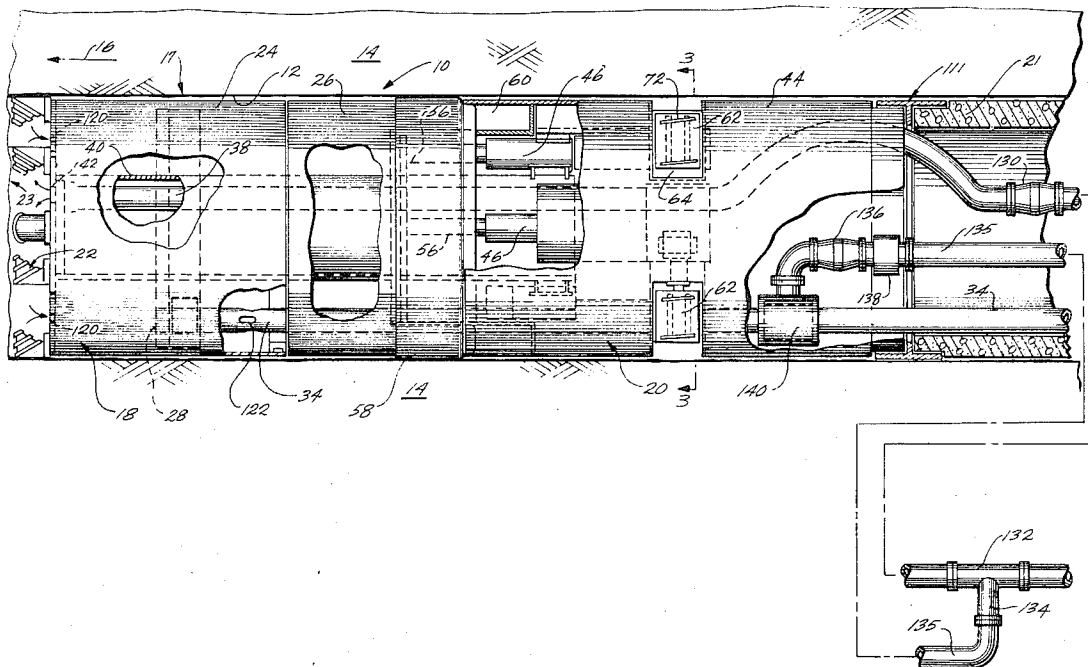


FIG. 1

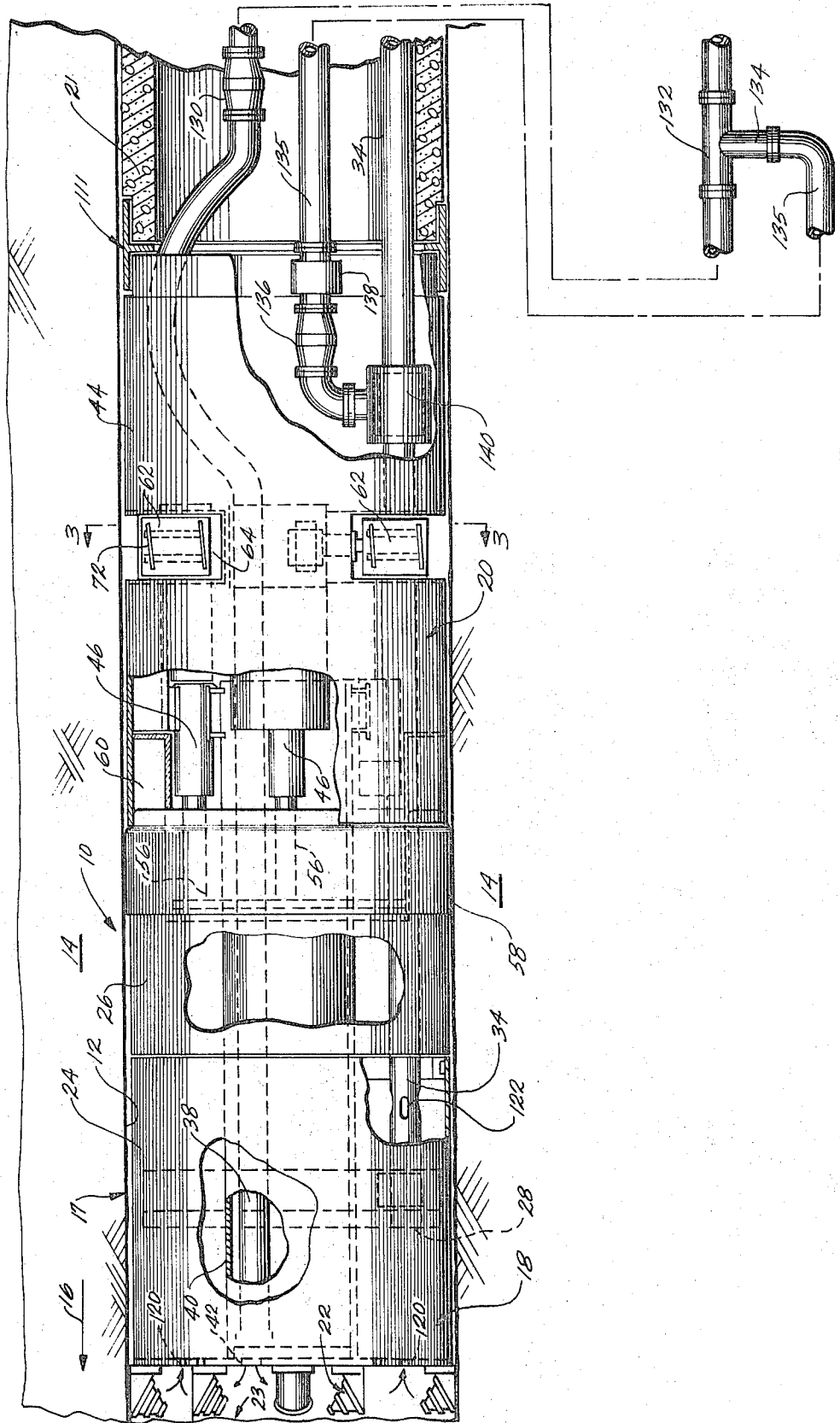


FIG. 2

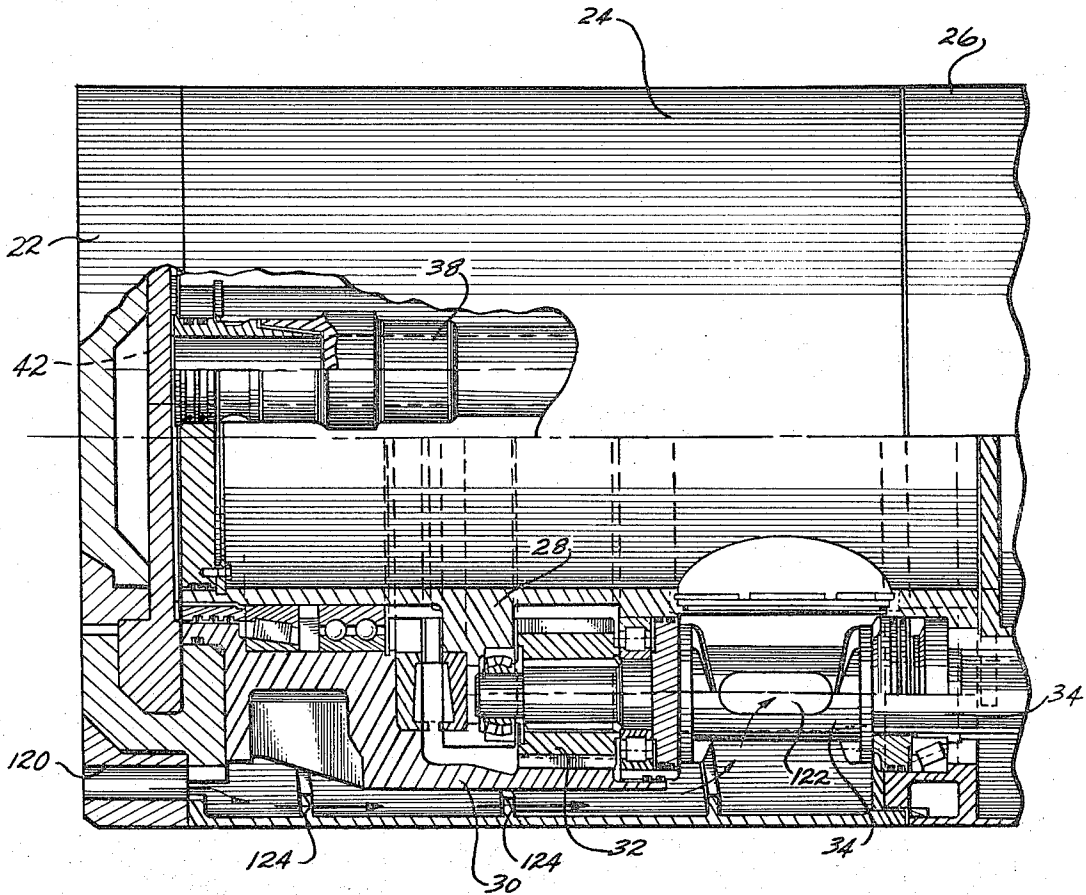


FIG. 3

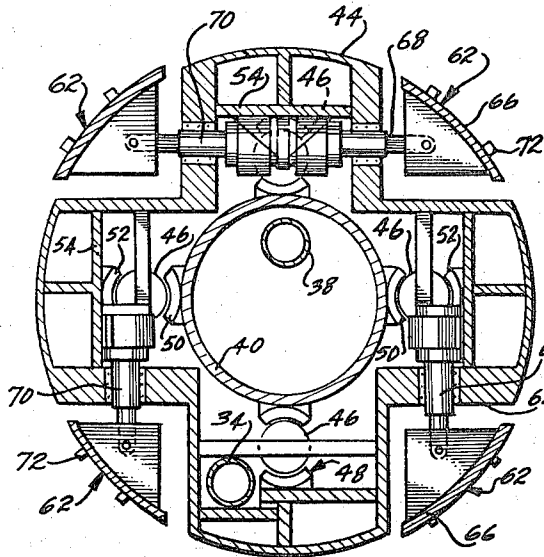


FIG. 6

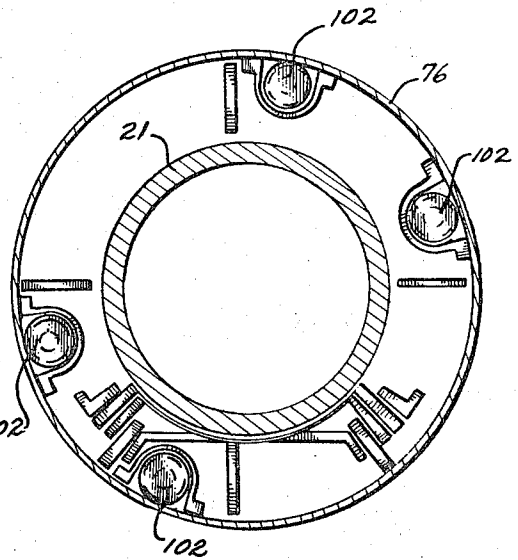


FIG. 5

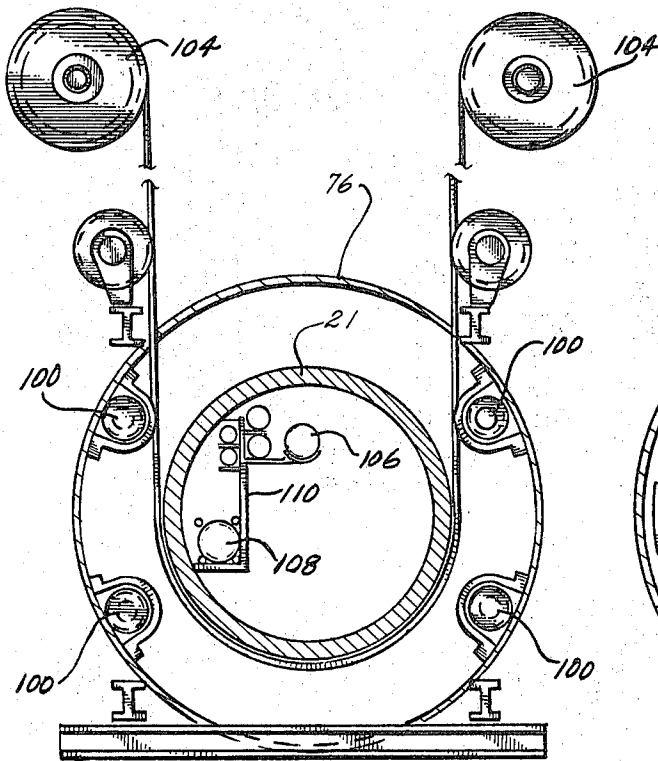


FIG. 7

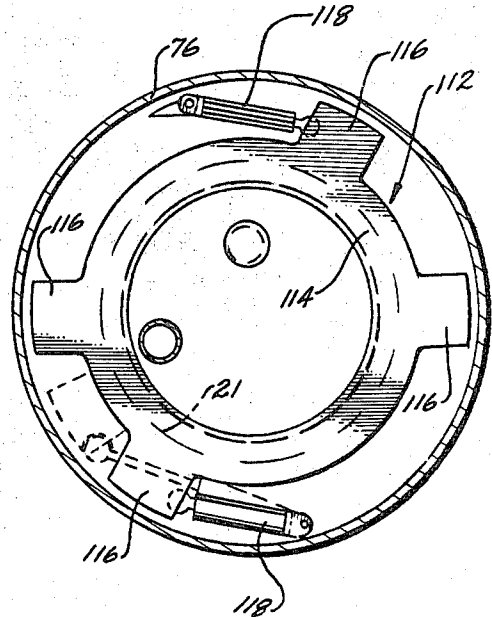
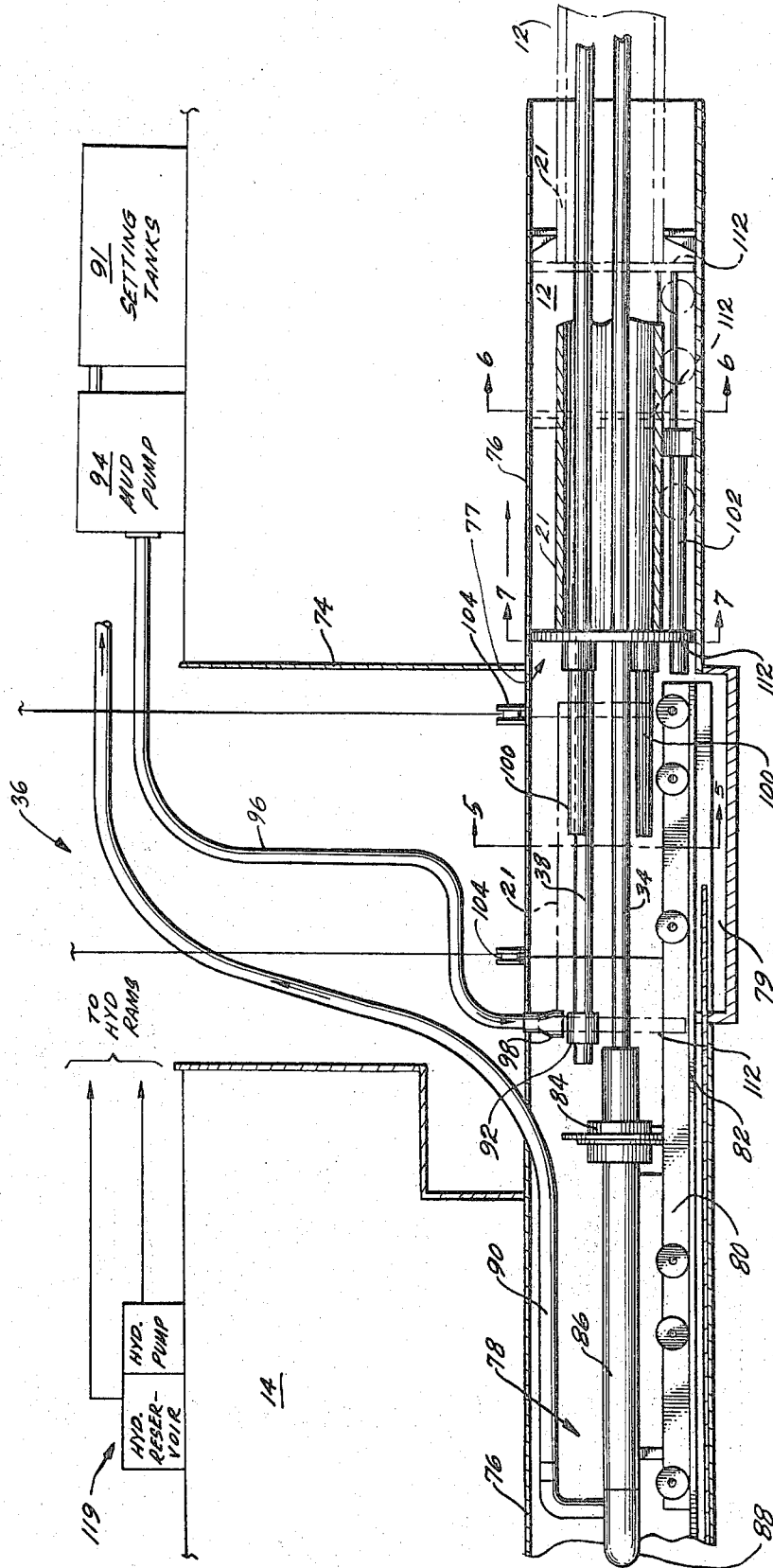


FIG. 4



REMOTE-CONTROLLED BORING MACHINE FOR BORING HORIZONTAL TUNNELS AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to tunnel boring machines, and more particularly to a remote-controlled boring machine for simultaneously drilling and lining a tunnel extending horizontally through a formation.

Underground tunnels for water lines, sewer lines, utility lines, and the like generally are constructed by forcing a string of interconnected pipe sections through the ground. A rotary boring head excavates the formation at the front of the pipeline, and new pipe sections are added to the end of the pipeline as boring progresses.

Generally speaking, prior art tunnel boring machines are operated by workmen stationed inside the machine near its front end. Since the prior art machines are of sufficient size to provide adequate room for the workmen and the equipment they operate, they are generally not capable of boring relatively long tunnels of small diameter, say three to six feet.

In the prior art machines, boring usually proceeds at a relatively slow rate, particularly in soft formations. Boring speed is hampered because the prior art machines generally are not equipped to adequately support the formation against caving at the tunnel heading concurrent with the advancement of the tunnel heading. The bore usually is not adequately self-supporting to diameters necessary to receive a relatively long length of bore support liners trailing the boring head without developing an excessive amount of skin friction.

Prior art machines suffer from substantial build-up of skin friction when the bore support liners are placed and shoved forward from the portal of the tunnel. This tends to limit such prior art machines to boring tunnels of only a few hundred feet in length. Thus, when boring underground pipelines which are substantially longer than a few hundred feet, boring is periodically stopped and a new portal is constructed at the end of the bore. This procedure becomes a problem when buildings and the like are located above the desired site for the new portal.

Prior art machines usually are not adequately sealed against flooding. Therefore, if the machine drills through a water table, serious flooding can occur, which makes it hazardous to workmen operating the boring head.

SUMMARY OF THE INVENTION

Briefly, this invention provides a remote-controlled tunnel boring machine which includes a boring head having a fore and aft sections which are movable longitudinally relative to each other. A rotary drilling tool carried by the fore section excavates material at the heading of the tunnel. The aft section includes a string of interconnected tunnel liner sections coupled to the fore section. The fore section is periodically advanced away from the aft section, using the weight of the aft section tunnel liners as a back-up, to excavate material at the heading of the tunnel. The aft section is periodically advanced through the tunnel to close the gap between the fore and aft sections after each advancement of the fore section. A new tunnel liner is periodically advanced into the portal entrance of the tunnel and connected to the end of the string of tunnel liners each

time the end of the aft section is displaced from the portal by a certain distance.

Preferably, operation of the boring head is controlled from the portal of the tunnel by an elongated rotary drill pipe extending through the interior of the fore and aft sections for connection to the drilling tool. Drive means at the portal are coupled to the drill pipe to drive the drilling tool as the tunnel heading advances.

Thus, a workman need not be stationed in the interior of the boring machine to operate the boring head. Consequently, the boring machine of this invention has a smaller sized interior and eliminates man-support equipment of the prior art, and is therefore capable of forming tunnels of relatively small diameter, say 3 to 6 feet. Moreover, drilling is carried out with no hazard to workmen operating the machine.

Since the interior of the drilling machine is free of the necessity to provide space for workmen, additional control equipment may be disposed in the interior of the machine, when compared with prior art machines. For example, in one embodiment of the machine an elongated conduit extends from the portal of the tunnel, through the interior of the fore and aft sections, to the tunnel heading. During drilling operations, drilling fluid is continuously forced through the conduit to merge with the cuttings produced by the cutting tool as it advances through the formation. A closed circulation system continuously returns cuttings and fluid from the tunnel heading through a string of pipe which rotates and extends from the boring head to the portal area. This system eliminates the need for prior art systems in which cuttings are conveyed to the portal by other means which sometimes necessitate drilling a substantially larger diameter hole than is necessary.

In a preferred form of the invention, a deformable inflatable seal closes off the space between the exterior of the boring machine and the inner wall of the tunnel. The seal is inflated to an internal pressure greater than that existing in the surrounding formation, which substantially prevents passage of fluids from the tunnel heading to the rear of the tunnel, which makes it possible to provide controlled hydrostatic fluid pressure at the heading of the tunnel to support the formation against caving during drilling operations.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be more fully understood by referring to the following detailed description and the accompanying drawings in which:

FIG. 1 is an elevation view, partly in section and partly broken away, showing a boring machine drilling a horizontal tunnel in a formation;

FIG. 2 is an enlarged sectional elevation view showing the fore section of the boring machine shown in FIG. 1;

FIG. 3 is a sectional elevation view taken on line 3—3 of FIG. 1;

FIG. 4 is a fragmentary schematic elevation view, partly in section, showing means at the portal of the tunnel for remotely controlling the boring machine shown in FIG. 1;

FIG. 5 is a sectional elevation view taken on line 5—5 of FIG. 4;

FIG. 6 is a sectional elevation view taken on line 6—6 of FIG. 4; and

FIG. 7 is a sectional elevation view taken on line 7—7 of FIG. 4.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2, a tunnel boring machine 10 drills a horizontal tunnel 12 in a formation 14. The boring machine advances through the tunnel in the direction of arrow 16 shown in FIG. 1. Preferably, the boring machine includes an elongated tubular boring head having a fore section 18 adapted to move longitudinally relative to an aft section 20. The system for moving the fore and aft sections relative to each other is described in detail below. Aft section 20 is coupled with a series of interconnected tubular concrete tunnel liner sections 21 (one of which is shown in FIG. 1) which advance behind the advancing boring machine to simultaneously line the tunnel as boring of the tunnel proceeds.

Fore section 18 includes a rotary drilling tool 22 at the front of boring machine 10 for excavating the formation at a heading area 23 of the tunnel. Drilling tool 22 preferably includes steel tooth rolling cutters, disk cutters, or other conventional means for drilling through a formation.

Fore section 18 further includes a rotating drill head shell 24 coupled with the rear of the drilling tool, and a non-rotating metal tubular control shield 26 at the rear of shell 24. Drilling tool 22 is rotatably mounted on a frame 28 disposed centrally within shell 24. The drilling tool is driven by a ring gear 30 meshing with a pinion 32 (see FIG. 2).

Pinion 32 is keyed to the front end of an elongated rotary drill pipe 34 extending rearwardly through the interior of the boring machine to a portal area 36 (see FIG. 4) of the tunnel where the drill pipe is driven by means described in detail below. As shown best in FIG. 3, drill pipe 34 is located near the bottom central portion of the drill casing interior.

A stationary mud supply pipe 38 extends forward from the portal area, through the interior of the boring machine, for connection to the boring head. As shown best in FIG. 3, the mud supply pipe is disposed within the upper portion of an inner tubular drill head housing or shell 40 in the central interior portion of the drill casing. Drill head shell 40 is aligned coaxially with the longitudinal axis of the outer drill casing, and is held in a stationary position inside the outer drill casing by suitable means. Mud supply pipe 38 opens into the heading of the tunnel through a passage 42 extending through drilling tool 22. Drilling fluid, i.e., drilling mud, is pumped under pressure through the interior of mud supply pipe 38 so it passes through passage 42 to the heading area of the tunnel. The purpose of supplying the drilling fluid to the heading of the tunnel will be described in detail below.

Aft section 20 includes a non-rotating tubular control shield or shell 44. Rotatable drill head shell 24, control shield 26, and aft control shield 44 cooperate to form a continuous elongated tubular shell of the same diameter, the joints between these drill casing sections being sealed by suitable means to substantially prevent the intrusion of fluids, such as drilling fluid and ground water.

A set of four longitudinally extending, radially spaced apart hydraulic thrust rams 46 are rigidly mounted in the interior of aft control shield 44. A separate cradle assembly 48 (see FIG. 3) rigidly secures each hydraulic ram in place between inner drill head housing 40 and

aft control shield 44. Each cradle assembly includes an inner cradle 50 rigidly secured to the outer surface of inner drill head housing 40 and cooperating outer cradle 52 secured to a respective rib 54 which in turn is rigidly secured to the inner wall of aft control shield 44. The respective inner and outer cradles comprise arcuate members which are tightly clamped around the exterior of the hydraulic thrust rams to hold them in a fixed position inside aft control shield 44.

Each thrust ram has a respective outwardly extendable and contractable piston arm 56, the end of which is rigidly coupled to the non-rotating control shield 26 of fore section 18. In use, hydraulic rams 46 are actuated to extend piston arms 56 forward toward the tunnel heading to move fore section 18 forward relative to aft section 20. Drilling tool 22 is thrust-loaded by the jacking pressure provided by the hydraulic rams so as to excavate material from the heading of the formation. The rib-like interior framework of aft control shield 44 (shown in FIG. 3), together with the string of tunnel liner sections behind aft section 20, provide a thrust base for the rams to work against when advancing fore section 18. Pressure in the rams is equalized by suitable means to maintain the boring machine and tunnel liner sections on a constant lining grade or heading during boring operations.

An inflatable joint expansion seal 58 is disposed between the fore and aft sections in an annular cavity 60 which spans the outer front portion of aft control shield 44. The expansion seal is a tire-like, thick-walled balloon, preferably approximately 40 durometer hardness rubber. The expansion seal is pre-inflated to an internal pressure greater than the ground pressure existing in the surrounding formation. In use, as the fore and aft sections separate during forward extension of thrust rams 46, expansion seal 58 progressively crawls out of cavity 60 and expands against inner wall 12 of the tunnel to develop a moving fluid-tight seal as drilling continues. The purpose of the joint expansion seal will be described in greater detail below.

Aft section 20 also carries four radially spaced apart torque anchor shoes 62 housed in respective indentations 64 in aft control shield 44. Each thrust anchor shoe comprises a relatively thin arcuately curved outer plate member 66 (see FIG. 3) which matches the adjacent outer contour of the aft control shield. Plate members 66 are coupled to extendable and contractable piston arms 68 of respective hydraulic rams 70 for pushing the anchor shoes radially outwardly from the drill casing against the inner wall of the tunnel.

In use, torque shoes 62 apply pressure to the wall of the tunnel via the hydraulic pressure applied by their respective rams. The pressure exerted by the thrust shoes stabilizes the drill casing torque to maintain constant attitude against roll of the boring machine as drilling proceeds. A servo system (not shown) operative in response to signals from load cells (not shown) measures the extension rate of thrust rams 46 and controls the movement of the torque shoes in response to drilling torque. That is, the extension rate of the rams is related to the hardness or softness of the formation drilled by the boring head cutters. The extension rate of each ram controls the amount of pressure applied by corresponding torque shoes, the pressure of the torque shoes being operative to maintain the boring machine in a constant heading.

The outer plate member of each torque shoe has a respective pair of substantially parallel, outwardly projecting ribs 72 which become embedded in the wall of the tunnel when pressure is applied by the torque shoes. During movement of the boring machine through the tunnel, the ribs permit the torque shoes to slide freely along the length of the tunnel as they are forced against it.

FIG. 4 shows portal area 36 of tunnel 12. The portal includes a vertical shaft 74 opening at the ground level and extending down into the upper interior portion of a horizontally extending tubular metal portal liner 76. Vertical shaft 74 preferably is rectangular and is about 15 ft. by 7 ft. in size so as to provide ample room for the placement of all equipment and supplies to the underground portal area. Moreover, the size of the vertical shaft is such that only a single curb-side line of a street is occupied to carry out the tunnel boring operations of this invention. As shown best in FIGS. 5 through 7, portal liner 76 is substantially larger in diameter than concrete tunnel liner sections 21. The right hand portion of portal liner 76 shown in FIG. 4 lines an entrance area 77 of the tunnel being drilled. The left hand portion of portal liner 76 shown in FIG. 4 provides an extended underground service area 78 to receive and store equipment described in detail below. A sump area 79 below vertical shaft 74 extends from about 2 to 3 feet below the bottom level of portal liner 76 to permit collection of water that may result from drainage in the tunnel bore.

An elongated wheeled tunnel liner dolly 80 runs back and forth on a track 82 in the lower portion of portal liner 76. The dolly is driven by a power supplied at the portal area.

Drill pipe 34 extends from boring head 22 through the boring machine and tunnel liner sections into the portal area where it is coupled with drive means 84 and a kelly 86 for rotation. The end of kelly 86 is coupled to a conventional rotary swivel 88 which, in turn, is coupled to a flexible hose 90 leading from the portal service area up through vertical shaft 74 to a mud sump or settling tank 91 at ground level.

Mud supply pipe 38 extends from boring head 22 into the portal area where it is coupled to a swivel and pressure diaphragm 92. A mud pump 94 at ground level delivers drilling mud through a flexible hose 96 to mud supply pipe 38. The flow of drilling mud to the mud supply pipe is controlled by a valve 98 coupled with swivel and pressure diaphragm 92.

A first set of four circumferentially spaced apart portal thrust rams 100 are anchored to the inner wall of the portal liner 76 below vertical shaft 74. A second set of four circumferentially spaced apart portal thrust rams 102 (only one is shown in FIG. 4 for clarity) are anchored to the inner wall of the portal liner at a point spaced approximately at the mid-point between the first set of portal thrust rams 100 and entrance 77 of tunnel 12. As shown best in FIGS. 5 and 6, the angular orientation of the second set of thrust rams 102 is offset from the first set, so that the second set does not interfere with the extension of the first set.

During drilling operations, portal liner rams 100 and 102 aid in pushing respective interconnected tunnel liner sections forward into tunnel 12 and behind the boring head as boring proceeds. Drilling tool 22 is advanced by thrust rams 46 to excavate the formation at the tunnel heading. The string of tunnel liner sections

behind the boring head act as a thrust base, or back-up, for the extension of thrust rams 46. After each forward stroke of thrust rams 46, a gap exists between the fore and aft sections of the boring head. Preferably, the tunnel liner sections are separated by separate downstream jacking stations (not shown) for moving the liner sections forward via a suitable jacking sequence. This movement of the liner sections closes the gap produced between the fore and aft sections of the boring head after each extension of the thrust rams. A preferred method of moving the entire string of tunnel liner sections is disclosed in a pending patent application entitled "Tunnel Liner Jacking System," Ser. No. 180,604, filed Sept. 15, 1971, and owned by the assignee of the present application.

Each new tunnel liner section 21 (shown in phantom line in FIG. 4) is lowered through vertical shaft 74 by a twin spool hoist system 104 mounted either at the shaft entrance or on a truck trailer bed. During lowering of the pipe liner section, kelly 86 and swivel 92, together with flexible lines 90 and 96 are backed up into service area 77 of the portal to provide clearance for the incoming pipe section. Upon reaching the bottom of vertical shaft 74, the incoming pipe section is placed on liner dolly 80, which is moved forward to the position at the bottom of the portal shaft shown in phantom line in FIG. 4.

As shown best in FIGS. 5 and 6, the interior portion of each incoming tunnel liner section 21 contains all the service pipe extensions necessary to continue jacking the new tunnel liner into tunnel 12. The service pipe extensions include a mud supply pipe connection 106, a rotary drill pipe connection 108, and other equipment such as hydraulic, air, and electric power utility lines carried by a fixture 110 mounted inside the pipe liner section. After the incoming pipe section reaches the bottom of the portal entry shaft, each service line extension is connected to its respective line in the tunnel bore.

Prior to making these connections, pressures are sealed in drill string 34 and mud supply line 38. Preferably, swivels 88 and 92 have respective inflatable diaphragm seals (not shown) recessed inside them. These diaphragm seals are inflated to lock pressures in pipe-lines 34 and 38. Thereafter, the pipe extensions are added between the expanded diaphragm and the swivel head, diaphragm pressures are released, and the new tunnel liner section is ready to be jacked into the tunnel.

After these connections are made and all circulation systems through their connecting swivels are operative, the incoming tunnel liner section is sealed to the previous tunnel liner section. Preferably, the seal is provided by a T-ring 111 (shown best in FIG. 1) which provides a fluid-tight seal between the interconnected pipe liner sections.

A thrust indexing shoe 112 is coupled to the rear portion of each incoming pipe liner section. As shown best in FIG. 7, each indexing shoe includes a rotatable flat ring-shaped body 114 abutting against the rear portion of the pipe liner, and four circumferentially spaced apart flanged portions or ears 116 projecting laterally outward from the outer surface of the tunnel liner. Ears 116 are rotatable so they may be aligned with either set of portal thrust rams 100 or 102. The rotational orientation of the ears is controlled by a pair of tangentially extending rams 118 adapted to apply a substantially

tangential force to the thrust shoe to rotate it to the desired angular orientation.

The incoming tunnel liner sections **21** are jacked forward by the following procedure. Tunnel liner dolly **80** moves the tunnel liner section to an entrance **77** of the tunnel bore, where it supports the tunnel liner until the thrust indexing shoe **112** at the end of the liner is engaged with the first set of portal thrust rams **100**. The thrust rams **100** are pressurized to push the tunnel liner section into the tunnel. At the end of the forward stroke of rams **100**, thrust indexing shoe **112** is automatically aligned with the second set of portal thrust rams **102**. At this point rams **118** of the indexing shoe are moved to rotate the shoe so that ears **116** are in engagement with the second set of portal thrust rams. Thereafter, the jacking pressure in the second set of thrust of rams is initiated to push the tunnel liner section further into the tunnel.

Thus, the portal arrangement of this invention permits all equipment and service lines to the underground portal to be accessible through portal shaft **74**, which is of a size confined to the curb lane of a boulevard or street. Moreover, all service systems, such as the main power plant, the hydraulic power plant **119** (see FIG. 4), the mud pumps, and portable reservoirs and the like may be arranged on a curb lane and permit their access through shaft **74** to the portal underground. All service equipment necessary to drill the tunnel bore, such as liners, drill pipe, hydraulic lines, air and electrical lines, are simply lowered to the portal area within each incoming concrete pipe liner.

During boring operations, the drilling mud supplied under pressure to boring head **17** through mud supply line **38** provides means for removing cuttings from the tunnel heading to the portal area. The drilling mud produces a column of fluid in the area between the tunnel heading and the boring head. The rotating boring head produces a turbulence in the fluid which picks up cuttings and keeps them circulating in the fluid. The fluid-borne cuttings and drilling mud pass backwardly through ports **120** in the boring head to the interior of the drill head shell **24**, and then through an intake opening **122** in drill pipe **34**, which continuously returns the mud and cuttings to the portal area for collection and removal. Thus, this invention provides a closed circulation path for the drilling fluid which is continuously fed to the boring head through mud supply pipe **38** and returned through rotary drill pipe **34**. The rotational action of the drill pipe sustains the cuttings circulating in the drilling fluid and thereby prevents debris in it from settling and plugging the interior of the pipe. Thus, the rotating drill pipe acts as a conveyor for the removal of cuttings and drilling fluid. Helical fins or flightings **124** on the inner wall of rotatable drill head shell **24** assist in circulating the drilling fluid and cuttings rearwardly to the intake **122** of the drill pipe. Ports **120** are sized smaller than the diameter of the drill pipe to act as a screen for preventing the passage of particles which would otherwise be large enough to plug the pipe.

Joint expansion seal **58** bears against the inner wall of the tunnel to substantially prevent drilling fluid, except in small amounts, from escaping past the drilling machine as it advances in the hole. Thus, drilling fluid under pressure pumped through the mud supply line **38** is constantly maintained at the annular open area exterior of the boring machine at the heading of the forma-

tion. Thus, the inflatable seal provides means for maintaining controlled hydrostatic mud pressure externally of the boring machine to reduce jacking force through mud lubricity and to stabilize the heading of the formation against caving. In the latter instance, external mud pressure is maintained at a higher level than that existing in the formation and thereby substantially prevents caving and ground water intrusion.

FIG. 1 shows a by-pass to the mud circulation system described above. The by-pass system is necessary when the boring machine encounters ground pressures in excess of the mud pressures applied through mud supply line **38**. In this instance, debris from the heading would enter line **38** and plug it. (Since line **38** does not rotate, it would be difficult to prevent plugging.) The by-pass system becomes operative when a sudden drop in pressure through line **38** is sensed, at which time a ball valve **130** in line **38** is closed, either automatically or manually, to shut off circulation to line **38** to prevent plugging by incoming material from the tunnel heading.

The by-pass system includes a T **132** in line **38** which has a by-pass extension **134** coupled to a line **135** having a second ball valve **136** and check valve **138**. Line **135** opens into a rotary swivel **140** connected to rotary drill pipe **34**.

Ball valve **136** is normally closed during drilling operations to prevent return circulation from flowing to the stationary mud supply pipe **136**. Pressure in line **38** is to be maintained at a higher level than ground pressure to assure an open line to the circulating slurry. When ground pressure build-up is sensed, such as by a lowering of pressure in line **38**, ball valve **136** opens and check valve **138** opens. Swivel **140** includes a pressure sensitive check valve (not shown) which is controllable from the portal. When ground pressure build-up is sensed, the check valve in swivel **140** is closed to shut off back flow through line **34** to the portal. The operator then increases the circulation pressure of drilling mud in line **38** to an amount greater than the ground pressure at the heading. The check valve **140** allows the drilling mud to circulate through open valves **136** and **138**. Circulation and pressure build-up through lines **106**, **135**, valve **130** and line **38** across the tunnel heading proceeds until the pressure in the system builds up to balance and stabilize ground pressures. At this point, the check valve in swivel **140** is opened to allow continued circulation through drill pipe **34**. A pressure transducer (not shown) at swivel **140** senses pressure at the swivel, and when the pressure is greater than the formation pressure, the check valve opens to re-establish circulation.

Thus, the boring machine is capable of boring relatively long tunnels, with all functions being remote-controlled from the portal area. The remote-control aspect of the machine eliminates the need for workmen being present in the machine itself, which reduces the size of the boring machine and thereby allows boring of tunnels having relatively small diameters, say 3 to 6 feet.

The continuous removal of cuttings by the closed mud circulation system enables longer tunnels to be bored than with prior art tunnel boring procedures. Thus, new portals do not have to be constructed every few hundred feet, which substantially reduces the cost of boring the tunnel. Moreover, the controlled mud pressure at the tunnel heading substantially prevents caving at the tunnel heading which enables tunnels to

be constructed even in relatively unstable formations.

I claim:

1. A machine for boring a substantially horizontal tunnel in a formation, the machine including an elongated tubular casing disposed in the tunnel, a rotary boring head connected with the casing and operative for excavating material at the heading of the tunnel, and a circulation system for removing cuttings excavated by the boring head, the system including an elongated fluid supply conduit extending through the casing to the vicinity of the boring head, means for delivering drilling fluid under pressure through the supply conduit to the heading of the tunnel, an elongated tubular drill pipe extending through the casing and connected to the boring head, drive means for rotating the drill pipe to operate the boring head, means for providing a fluid seal between the casing and the tunnel rearward of the boring head for exerting pressure against the interior wall of the tunnel to substantially prevent passage of fluids and cuttings exterior of the casing from the tunnel heading rearward of the seal to maintain fluid pressure at the tunnel heading, and fluid return means opening into the heading of the tunnel and extending to the interior of the rotary drill pipe to channel drilling fluid and cuttings excavated by the boring head from the tunnel heading into the drill pipe interior for continuous removal during boring operations.

2. Apparatus according to claim 1 in which the casing includes a rotatable fore section adapted to rotate with the boring head and forming an exterior wall portion of the fluid return means; and including conveyor means in the fluid return means driven by the rotatable fore section of the casing.

3. Apparatus according to claim 1 in which the tunnel extends through the formation from a portal entry, and including pump means at the portal entry connected with the circulation system for maintaining sufficient fluid pressure in the system to remove the cuttings passing into the drill pipe to the portal.

4. Apparatus according to claim 3 in which the drill pipe and the supply conduit extend to the portal area for connection with the pump means in a closed circulation system.

5. Apparatus according to claim 1 in which the seal forming means comprises a deformable inflatable seal extending continuously around the entire exterior circumference of the casing rearward of the boring head for exerting pressure against the interior wall of the tunnel.

6. Apparatus according to claim 5 in which the seal is pre-inflated to a pressure greater than that existing in the surrounding formation.

7. Apparatus according to claim 5 in which the deformable seal is a ring shaped balloon.

8. Apparatus according to claim 5 in which the casing has fore and aft sections, means for moving the fore section and the boring head forward relative to the aft section, and in which the deformable seal is pre-inflated to a pressure greater than the ground pressure in the surrounding formation, and including means for housing the deformable seal in the casing so it expands radially outward against the inner wall of the tunnel as the fore section moves away from the aft section.

9. A method of boring a substantially horizontal tunnel in a formation with a boring machine having a boring head coupled to the front of a casing disposed in the tunnel, the method comprising rotating an elongated

drill pipe to operate the boring head to excavate material at the heading of the tunnel, forcing drilling fluid under pressure to the heading of the tunnel through a supply conduit in the casing, maintaining fluid pressure at the tunnel heading via a fluid seal between the exterior of the casing and the tunnel wall to substantially prevent passage of fluid and cuttings exterior of the casing from the tunnel heading rearward of the seal, and continuously returning the cuttings and drilling fluid from the tunnel heading through the interior of the rotating drill pipe, as boring proceeds, to provide a closed system with sufficient fluid pressure therein for continuously circulating the drilling fluid to and from the tunnel heading.

10. The method according to claim 9 in which the tunnel extends through the formation from a portal entry, and including providing pump means at the portal connected with the circulating system provided by the supply conduit and the drill pipe for maintaining sufficient pressure in the system to remove cuttings to the portal area.

11. The method according to claim 10 in which the drill pipe and the supply conduit extend to the portal area, and including the step of connecting the drill pipe and the supply conduit with the pump means in a closed pressure system in which cuttings are discharged at the portal area.

12. A tunnel boring machine comprising an elongated tubular casing disposed in a substantially horizontal tunnel in a formation, a rotary boring head connected with the casing for excavating material at the heading of the tunnel, and a deformable inflatable seal extending continuously around the entire exterior circumference of the casing rearward of the boring head for exerting pressure against the interior wall of the tunnel to substantially prevent passage of fluids and cuttings exterior of the casing from the tunnel heading rearward of the seal.

13. Apparatus according to claim 12 in which the seal is pre-inflated to a pressure greater than that existing in the surrounding formation.

14. Apparatus according to claim 12 in which the deformable seal is a ring-shaped balloon.

15. Apparatus according to claim 12 in which the casing has fore and aft sections, means for moving the fore section and the boring head forward relative to the aft section, and in which the deformable seal is pre-inflated to a pressure greater than the ground pressure in the surrounding formation, and including means for housing the deformable seal in the casing so it expands radially outwardly against the inner wall of the tunnel as the fore section moves away from the aft section.

16. Apparatus according to claim 12 including means for forcing drilling fluid under pressure through the interior of the casing to the heading of the tunnel such that controlled hydrostatic fluid pressure exists exterior of the casing at the tunnel heading and forward of the deformable seal.

17. A method of drilling a substantially horizontal tunnel in a formation with a tunnel boring machine having an elongated tubular casing disposed in the tunnel and a rotary boring head connected with the casing for excavating material at the heading of the tunnel, the method comprising forming a deformable inflatable seal between the inner wall of the tunnel and an exterior portion of the casing to provide a substantially fluid-tight seal rearward of the boring head, and forcing

drilling fluid under pressure through the interior of the casing to the tunnel heading, the pressure of the fluid being higher than that existing in the surrounding formation to thereby prevent passage of the drilling fluid exterior of the casing from the tunnel heading rearward of the seal and provide controlled hydrostatic fluid pressure at the tunnel heading to support the formation from caving.

18. The method according to claim 17 including the step of inflating the seal to a pressure greater than the ground pressure in the surrounding formation.

19. A method of simultaneously drilling and lining a substantially horizontal tunnel extending through a formation from a portal entry, the tunnel being drilled by a boring machine disposed in the tunnel and having fore and aft sections which are movable longitudinally relative to each other, the fore section having a boring head for excavating material at the heading of the tunnel, with the aft section including a series of interconnected tunnel liner sections, the method comprising periodically advancing the fore section away from the aft section, using the weight of the aft section tunnel liners as a thrust base back-up, to excavate material at the heading of the tunnel; periodically forcing the aft section forward through the tunnel to close the gap between the fore and aft sections after each advancement of the fore section; and advancing a new tunnel liner section through the portal entrance and connecting it to the end of the aft section each time the end of the aft section is displaced from the portal entrance by a certain distance.

20. The method according to claim 19 including connecting a thrust indexing shoe to each new tunnel section to be advanced, pushing the new tunnel liner into the tunnel via a first set of force-applying means acting on the thrust indexing shoe, thereafter rotating the indexing shoe, and pushing the new tunnel liner further into the tunnel via a second set of force-applying means angularly displaced from the first set and acting on indexing shoe after it is rotated.

21. The method according to claim 19 including disposing an elongated drill pipe in the interior of the fore and aft sections so the drill pipe extends from the portal entry to the boring head, and applying rotary power to the drill pipe at the portal entry to drive the boring head.

22. The method according to claim 21 including disposing an elongated conduit in the interior of the fore and aft sections so the conduit extends forward from the portal entry and opens into the tunnel heading, and forcing drilling fluid from the portal entry, through the conduit, to the tunnel heading during rotation of the boring head to pick up cuttings removed by the boring head and circulate them to the interior of the boring machine.

23. The method according to claim 22 including forcing drilling fluid through the conduit at a pressure greater than the pressure existing in the formation at the heading of the tunnel.

24. The method according to claim 22 including continuously returning the drilling fluid and cuttings from the formation, through the interior of the rotary drill pipe, to the portal entry during rotation of the boring head.

25. The method according to claim 24 including forming a substantially fluid-tight seal between the exterior of the drilling machine and the inner wall of the

tunnel and, pressuring the seal to a pressure greater than that of the surrounding formation to substantially prevent passage of the drilling fluid exterior of the drilling machine from the tunnel heading rearward of the seal to provide controlled hydrostatic fluid pressure at the tunnel heading.

26. The method according to claim 25 including periodically expanding the seal against the inner wall of the bore each time the fore section advances away from the aft section.

27. The method according to claim 26 including periodically retracting the seal into the interior of the drilling machine each time the aft section is advanced toward the fore section.

28. The method according to claim 21 including periodically adding sections to the drill pipe to the end of the aft section as the fore and aft sections advance through the tunnel.

29. The method according to claim 28 including disposing an elongated conduit in the interior of the fore and aft sections so it extends forward from the portal entry and opens into the tunnel heading.

30. The method according to claim 29 including periodically adding sections to the conduit as the fore and aft sections advance through the tunnel, and mounting each added section of drill pipe and each added section of conduit to a separate new section of tunnel liner which is advanced through the portal entrance for connection to the end of the aft section.

31. The method according to claim 30 including forcing drilling fluid from the portal entry through the conduit to the tunnel heading during operation of the boring head to pick up cuttings removed by the boring head, continuously returning the drilling fluid and cuttings from the formation through the rotary drill pipe to the portal entry during operation of the boring head, and periodically closing off the flow of drilling fluid in the conduit and closing off the flow of fluid and cuttings returning through the drill pipe each time a new section of conduit and drill pipe is added.

32. The method according to claim 29 including forcing drilling fluid from the portal entry through the conduit to the tunnel heading during operation of the boring head to pick up cuttings removed by the boring head, and continuously returning the drilling fluid and cuttings from the formation through the rotary drill pipe to the portal entry during operation of the boring head.

33. The method according to claim 32 including sensing when pressure in the conduit drops below the ground pressure in the surrounding formation, stopping the return flow of cuttings and drilling fluid through the drill pipe to the portal entry when said pressure drop is sensed, continuously circulating drilling fluid through the conduit and across the tunnel heading until pressure in the conduit is equilized with the ground pressure, and thereafter starting return flow through the drill pipe.

34. Apparatus for simultaneously drilling and lining a substantially horizontal tunnel extending through a formation from a portal area, the apparatus comprising a substantially tubular boring machine disposed in the tunnel and having fore and aft sections which are coupled to each other and movable longitudinally relative to each other, the fore section having a rotary boring head for excavating material at the heading of the tunnel, the aft section comprising a series of intercon-

nected tunnel liner sections; means coupled with the aft section for periodically forcing the fore section away from the aft section and forward in the tunnel; drive means at the portal entry and coupled with the boring head for rotating the boring head, during its advancement away from the aft section, to excavate material at the heading of the tunnel; and force-applying means rigidly secured at the portal area for periodically forcing the aft section forward through the tunnel to close the gap between the fore and aft sections after each advancement of the fore section.

35. Apparatus according to claim 34 including a rigid portal liner at the portal area, and in which the thrust-applying means are rigidly secured to the portal liner.

36. Apparatus according to claim 35 in which the thrust-applying means are hydraulic cylinders.

37. Apparatus according to claim 34 including an elongated drill pipe extending from the portal area, through the interior of the fore and aft sections, to the boring head, and in which the drive means at the portal area is coupled with the drill pipe.

38. Apparatus according to claim 37 including an

elongated conduit extending from the portal area, through the interior of the fore and aft sections, and opening into the tunnel heading, and means at the portal area for forcing drilling fluid through the conduit.

39. Apparatus according to claim 38 including conveyor means in the passage to assist removal of the cuttings and drilling fluid.

40. Apparatus according to claim 38 including a passage in the fore section opening into the tunnel heading and extending to the interior of the drill pipe, whereby rotation of the drill pipe continuously returns drilling fluid and cuttings from the formation, through the drill pipe, to the portal area.

41. Apparatus according to claim 40 including a substantially fluid-tight deformable seal formed between the exterior of the drilling machine and the inner wall of the tunnel to substantially prevent passage of drilling fluid exterior of the drilling machine from the tunnel heading rearward of the seal to provide controlled hydrostatic fluid pressure at the tunnel heading.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,778,107 Dated December 11, 1973

Inventor(s) John C. Haspert

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 45, "axi" should read -- axis --

Col. 4, line 3, after "and" insert -- a --

Col. 5, line 17, "line" should read -- lane --
line 33, delete "a"

Col. 7, line 40, "cuttins" should read -- cuttings --

Col. 10, line 56, "exists" should read -- is maintained --
(Claim 16)

Col. 13, line 6, "axcavate" should read -- excavate --
(Claim 34)

Signed and sealed this 16th day of April 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents