The invention provides an improved apparatus for directional boring and in particular an improved system for boring through hard and rocky substrates frequently encountered when boring under obstacles such as roadways. According to one aspect of the invention, a directional drilling apparatus includes a drilling head (30) having a front face (62) angled relative to the lengthwise axis of the tool and configured for steering the drilling apparatus, a housing (32) having an internal chamber for mounting an electronic locating device therein rearwardly of the drilling head (30) for transmitting a signal indicating the orientation of the angled face of the drilling head (30), and a joint (200) at which the drilling head is removably mounted to the housing of the locating device. The joint (200) includes a splined connection for passing torque from the sonde housing (32) to the bit (31) and an interlock mechanism which mechanically secures the bit (31) to the sonde housing (32) in a manner permitting the bit (31) to be manually removed from the housing (32) without undue difficulty.
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APPARATUS FOR DIRECTIONAL DRILLING

TECHNICAL FIELD

The invention relates to a method and apparatus for directional boring in rocky formations using an onboard sonde for controlling the direction of the bore.

BACKGROUND OF THE INVENTION

Directional boring apparatus or trenchless drills for making holes through soil are well known. The directional borer generally includes a series of drill rods joined end to end to form a drill string. The drill string is pushed or pulled though the soil by means of a powerful device such as a hydraulic cylinder. See McDonald et al. U.S. Patent No. 4,694,913, Malzahn, U.S. Patent Nos. 4,945,999 and 5,070,848, and Cherrington, U.S. Patent No. 4,697,775 (RE 33,793). The drill string may be pushed and rotated at the same time as described in Dunn, U.S. Patent No. 4,953,633 and Deken, et al., U.S. Patent No. 5,242,026. A spade, bit or head having one or more angled faces configured for boring is disposed at the end of the drill string and may include an ejection nozzle for water or drilling mud to assist in boring.

In one known directional boring system, the drill bit is pushed through the soil without rotation in order to steer the tool by means of the angled face, which is typically a forwardly facing sloped surface. For rocky conditions, a row of teeth may be added to the drill bit and the bit operated in the manner described in Runquist et al. U.S. Patent No. 5,778,991. Other toothed bits for directional boring through rock are shown in European Patent Applications Nos. EP 0 857 852 and EP 0 857 853, Cox U.S. Patent No. 5,899,283, Skaggs U.S. Patent No. 5,647,448 and Stephenson U.S. Patent No. 5,799,740. Steering systems for use with these devices require keeping track of the angle of rotation of the sloped face of the bit and/or the teeth.

According to another known system, a transmitter or sonde mounted in a tubular housing is mounted behind and adjacent to the bit and sends a signal that indicates the angle of rotation of the bit. The sonde is mounted in a predetermined alignment relative to the steering portion of the bit. Since the sonde housing is
generally made of steel, a series of longitudinal slots or windows are provided through the wall of the sonde housing to permit transmission of the signal. See generally Mercer U.S. Patent Nos. 5,155,442, 5,337,002, 5,444,382 and 5,633,589, Hesse et al. U.S. Patent No. 5,795,991, and Stangl et al. U.S. Patent No. 4,907,658. Mounting of the sonde in its housing has been accomplished by end loading as illustrated by the foregoing patent to Stangl et al. or through a side opening which is closed by a door or cover during use, as illustrated in Lee et al. U.S. Patent Nos. 5,148,880 and 5,253,721.

Prior attempts to use sondes in horizontal directional boring apparatus, particularly of the type for drilling consolidated rock formations, have proven less than ideal. Breakage of the sonde is to be avoided because sondes are difficult and expensive to replace. The sonde housing cover in side-loading sonde housings is prone to failure. The bolts used to secure the cover often loosen or break off as a result of the abrasion and stress applied to the sonde housing during boring, and the door or cover may work loose or collapse inwardly, crushing the sonde. A need remains for a more secure side-loading sonde housing which is nonetheless easy to open and close when necessary.

A need also persists for a directional boring system specifically adapted to horizontal boring through rocky formations, i.e., wherein the drilling head efficiently bores through consolidated rock formations which ordinary duckbill type bits are unable to penetrate. This can be particularly troublesome when mixed conditions are encountered during a bore, for example, the first portion of the bore is made through soft soil, but an unexpected rock formation is encountered. The connection between the bit and sonde housing should pass torque without undue strain, resist the unavoidable abrasion of surface metal that occurs during use, and yet readily permit disconnection, such as at the terminal end of a bore, at which point the drilling head (including both sonde housing and bit) is typically removed so that the drill string can be used to pull a pipeline back through the completed bore as it withdraws.

Threaded connections between the bit and the sonde housing are secure and shielded from abrasion, but difficult to disengage manually due to the high torque applied to the bit during operation. Bolts used to attach the bit to a sonde housing are exposed to abrasion and tend to loosen. It is also desirable to provide a bit which can
be rebuilt and used several times, doubling or tripling the service life of the unit. The present invention addresses these concerns.

SUMMARY OF THE INVENTION

The present invention provides an improved apparatus for directional boring and in particular an improved system for boring through hard and rocky substrates frequently encountered when boring under obstacles such as roadways. According to one aspect of the invention, a directional drilling apparatus includes a drilling head having a front face angled relative to the lengthwise axis of the tool and configured for steering the drilling apparatus, a housing having an internal chamber for mounting an electronic locating device therein rearwardly of the drilling head for transmitting a signal indicating the orientation of the angled face of the drilling head, and a joint at which the drilling head is removably mounted to the housing of the locating device.

The joint includes a splined connection for passing torque from the sonde housing to the bit and an interlock mechanism which mechanically secures the bit to the sonde housing in a manner permitting the bit to be manually removed from the housing without undue difficulty.

According to a preferred form of the invention, the interlock mechanism includes a projection, which may be the front end of the sonde housing or the rear end of the bit, and a socket into which the projection closely fits, which socket is formed on the other of the front end of the sonde housing or the rear end of the bit. The projection has a first opening having a lengthwise axis which lies in a plane substantially perpendicular to the axis of rotation of the drilling head, and a wall defining the socket has a second opening therein having a lengthwise axis which lies in a plane substantially perpendicular to the axis of rotation of the drilling head and which is brought into alignment (or near alignment, as described hereafter) with the first opening when the projection is fully inserted into the socket. A retainer is sized for insertion into the aligned openings. The retainer is preferably a pin or generally tubular insert that can be compressed from a relaxed state diameter to a retaining diameter at which an outer circumferential surface of the retainer tightly engages inner
surfaces of the openings and holds the bit in engagement with the sonde housing.

The splined connection between the bit and the sonde housing preferably includes a series of longitudinal, spaced splines in one of the rear end of the bit or the front end of the sonde housing, and a corresponding series of longitudinal, spaced grooves in the other of the rear end of the bit or the front end of the sonde housing. Since the bit and housing must be keyed to one another so that the position of the sonde is in a known alignment relative to the cutting face of the bit, a master spline and groove are preferably provided so that the bit and sonde housing fit together in one predetermined alignment. As described hereafter, the splines may be provided on the outside of the projection, and the grooves may be provided on the inside of the socket.

According to a preferred form of the invention, the improved joint comprises a projection extending from a front end portion of the locating device housing, which projection has a series of longitudinal, spaced splines thereon. The projection has a longitudinal axis which is offset from a longitudinal axis of rotation of the drilling head. A rearwardly opening socket formed in the drilling head has longitudinal, spaced grooves configured to receive the splines of the projection therein. A keying mechanism, such as the master spline and groove combination described above, is provided on the projection and the socket to permit insertion of the projection into the socket only in one (or a limited number of) predetermined orientations. Openings in the socket and projection are configured to receive a removable retainer, such as a rolled pin, for mechanically interlocking the projection in the socket with the splines of the projection inserted into corresponding grooves of the socket. Such a joint according to the invention is protected from abrasion because of its location away from the outer periphery of the head, provides a strong connection due to the substantial length and width of the splines, yet can be taken apart easily by manually removing the retaining pins.

In another aspect, the invention provides a cutting head with a plurality of cutting teeth raked into the cut of the drilling head. Such teeth are oriented at an angle of at least about 30 degrees relative to an imaginary line normal to an arcuate front surface of the cutting head from which the cutting teeth project. Such an arrangement
provides the desired shear cutting force against the rock face while simultaneously reducing the shock and vibration applied to sonde housing and the drill string. Preferred teeth for cutting rock according to the invention comprise a cylindrical base into which a carbide cutting tip is press-fitted or preferably brazed. These rock cutting teeth preferably have sufficient strength and width to survive and protect the tip from breaking away, plus sufficient length to project beyond the diameter of the brow, so that the teeth and not the body of the bit does the cutting. In a preferred embodiment, a small carbide rod can be inserted behind the tip to act as a back-up tooth when the carbide tip breaks away, as described further below. The cutting teeth are readily replaceable by tapping a used tooth out from behind using rearwardly opening tap-out holes provided for that purpose.

An improved drilling head according to the invention may further incorporate a rear, frustoconical crushing surface that defines a space or zone crescent-shaped in cross-section that narrows from front to rear. The crescent-shaped crushing zone extends nearly 360 degrees and is configured for crushing rock fragments torn loose by the cutting teeth mounted on the front of the head. The rear portion of the bit defining the crushing zone is free of large rounded projections that tend to cause loose stones and fragments in the crushing zone to bounce around, rather than be drawn into the narrowing end of the crescent for crushing.

The invention further includes an improved tooth for use on a rock drilling bit. Such a tooth includes a generally cylindrical tooth holder having a first frontwardly opening hole and a second frontwardly opening hole behind the first hole. A first cutting tip fits to a predetermined depth in the first hole. A second cutting tip fits to a predetermined depth in the second hole, such that the second cutting tip is positioned behind the first cutting tip. The second tip preferably is a separate piece from the first, and may have a smaller diameter than the first tooth such that it has a lower cost but is suitable for finishing a bore in progress when the first tooth breaks off.

In another aspect, the invention provides an apparatus for mounting an electronic device therein for use in an underground boring machine. Such an apparatus includes an elongated housing having means at opposite ends of the housing for connecting the housing to other components of the boring machine and an elongated
internal chamber configured to receive an electronic device such as a sonde therein and having an elongated access opening which extends along an exterior surface of the housing. A cover sized to close the access opening has edges that fit beneath one or more flanges of the housing. A retainer such as a roll pin is sized for insertion into openings in the cover and housing, which openings become aligned when the cover is positioned with the edges beneath the flange of the housing. The retainer can be compressed from a relaxed state diameter to a retaining diameter at which an outer circumferential surface of the retainer tightly engages inner surfaces of the openings and holds the first part in engagement with the second part.

According to a preferred embodiment, the access opening has a recessed rim including a pair of elongated sides and a pair of ends spanning the sides, each side including a step on which the cover rests when its covers the access opening, and a pair of laterally inwardly extending rim flanges on opposite sides of the access opening each having a pair of inclined undersurfaces, which undersurfaces taper in a direction laterally inwardly and upwardly away from the step. The cover has a pair of laterally outwardly extending cover flanges on opposite side edges of the cover, which cover flanges taper in a direction laterally outwardly and downwardly so that the cover flanges mate slidingly with the undersurfaces of the rim flanges, whereby upon placement of the cover into engagement with the step in a first position wherein the cover flanges and the rim flanges are offset, the cover may then slide in a lengthwise direction so that the cover assumes a second position wherein the cover flanges underlie the rim flanges and at which second position the means for releasably securing the cover may be engaged.

An improved sonde housing according to the invention makes use of strategically positioned hard, wear-resistant studs to protect the body of the sonde housing from abrasion. Such studs have been previously used on cutting bits, but the benefits of using studs on the sonde housing have not been appreciated. In particular, placement of studs on the top face of the housing and optionally in a pair of annular formations near the front and rear ends of the housing improve the service life of the housing. In one aspect, a sonde housing configured for mounting a sonde therein comprises a cylindrical steel body having a sonde-receiving recess therein. A portion
of the sonde housing body that receives a reaction force from a cutting bit has a series of hard, wear resistant studs mounted thereon effective to reduce wear on the portion of the sonde housing body that receives the reaction force. In another aspect, portions of the sonde housing body proximate opposite ends of the body have hard, wear resistant studs mounted thereon effective to reduce wear on end portions of the sonde housing body.

A further feature of the invention provides a coupling for a connecting two parts of a machine that rotates about an axis of rotation in use. Such a coupling comprises a first part of the machine that rotates in use, which first part has an first opening having a lengthwise axis which lies in a plane substantially perpendicular to the axis of rotation of the machine, a second part of the machine that rotates in use, which second part has a second opening therein having a lengthwise axis which lies in a plane substantially perpendicular to the axis of rotation of the machine and which is brought into alignment with the first opening when the first part is disposed next to the second part, and a retainer such as a roll pin which is sized for insertion into the aligned openings, wherein the retainer can be compressed from a greater relaxed state to a retaining diameter at which an outer circumferential surface of the retainer tightly engages inner surfaces of the openings and holds the first part in engagement with the second part. Such a coupling can maintain the two machine parts, such as a bit-sonde housing or sonde housing-starter rod, in mechanical engagement even without use of splines for passing torque. The recessed position of the resilient retainer during use shields it from surface abrasion, a common failure mode for bolts and other fasteners that must present an outwardly facing head.

The present invention further provides a joint for coupling a pair of elongated members such as a sonde housing and starter rod end to end. Such a joint includes a projection extending in a lengthwise direction from one end of one of the elongated members and a socket in an end of the other of the elongated members, which socket is sized to sliddingly receive the projection. A set of alignable transverse openings are provided in the projection and in a wall defining the socket, which openings are configured to receive a removable retainer for mechanically interlocking the projection in the socket. An interlock mechanism, such as a spline and groove
connection, prevents relative rotation between the elongated member (e.g., housing and starter rod) when the projection is fully inserted into the socket.

To maximize the strength of the joint, the interlock mechanism is preferably located outside of the projection and socket connection, most preferably as an annular formation of splines and grooves coaxial with the socket and projection and located either on the outside of the projection and the inside of the socket wall, or at a location outside of the socket and groove connection. The latter is most preferred since the strength of the interlock mechanism is maximized when it is located at the outer periphery of the joint and hence has the largest possible diameter. Similarly, while a partial circle or arcuate formation of splines and grooves could be used, the strength of the connection is maximized by locating the interlock mechanism around the entire outer periphery of the projection and socket connection. However, it is also possible to use a sufficient number of retainers such as roll pins at the joint so that torque may be passed without need for any interlock mechanism, such as the spline and groove arrangement described hereafter. This could be done at either or both of the ends of the sonde housing in the directional boring apparatus described hereafter.

The invention further provides a directional boring apparatus that includes a drill string and a directional boring machine for pushing or pulling as well as rotating the drill string. The head assembly of the boring machine includes a boring bit or head, a housing having an internal chamber for mounting an electronic locating device therein rearwardly of the drilling head for transmitting a signal indicating the orientation or location of the drilling head, and optionally other useful components such as a pressure fluid-powered impact hammer added to assist boring, which components may be connected head to tail in any desired order as long as the boring head or bit is at the front. An adapter or starter rod is mounted at the front end of the drill string. A joint according to the invention is provided at the location at which the starter rod is removably mounted to the head assembly. Normally the joint will be formed by a direct coupling between the front end of the starter rod and the rear end of the housing of the locating device, but other components of the head assembly may intervene.

The joint comprises a projection extending from one of the rear end of the
head assembly and the front end of the starter rod, which projection extends in the
lengthwise direction of the head assembly and the starter rod and can be inserted in
the lengthwise direction of the head assembly and the starter rod to slingly engage a
socket in the other of the head assembly and starter rod. One or more sets of alignable
transverse openings are provided in the projection and the wall defining the socket
configured to receive a removable retainer for mechanically interlocking the
projection in the socket. The retainer has suitable means for resisting disengagement
from the transverse openings due to rapid rotation of the joint about an axis which
coincides with a lengthwise direction of at least one of the starter rod and the head
assembly. An interlock mechanism such as the spline-and-groove arrangement
described above prevents relative rotation between the housing and the starter rod
when the projection is fully inserted into the socket. A similar joint may be provided
at any other joint in the head assembly, such as a joint between the boring head and
the sonde housing, or a joint between a mechanically or pressure fluid-powered
impact hammer added to assist boring and any adjacent component.

A back reamer may be provided that is configured to fit onto the starter rod
when the remainder of the head assembly is removed from the starter rod at the end of
the first run. The joint can be resecured using the back reamer instead of the head
assembly for the passage back through the borehole. For purposes of the joint, the
back reamer effectively is substituted for the head assembly after the head assembly is
removed, and for that purpose has a leading end that is configured in the same or
substantially the same manner as the rear end of the head assembly so that the back
reamer can be coupled with the front of the starter rod to resecure the joint. For this
purpose, if it was the head assembly that had the socket therein, then the back reamer
will likewise have the socket therein. The configuration of the lead end of the back
reamer is substantially the same as the rear end of the head assembly if the back
reamer can be coupled with the started rod to re-form the joint; details such as the
number of transverse openings and the number of retainers such as roll pins inserted
therein can be different as described hereafter. A back reamer according to the
invention has a rear conical portion and a front reduced diameter connecting portion
that has either the socket or the projection part of the joint formed at its leading end,
depending on how the starter rod is configured.

The invention additionally provides a method for attaching and removing a head assembly to the foregoing directional boring apparatus. Initially the starter rod is positioned relative to the head assembly so that the interlock mechanism will become interlocked during insertion of the projection into the socket and the transverse openings provided in the projection and the wall defining the socket come into substantial alignment. The projection is inserted into the socket, thereby causing the interlock mechanism to become interlocked. The retainer is then inserted into the alignable transverse openings provided in the projection and the wall defining the socket to complete the joint. The directional boring machine is operated as needed, such as to bore a hole beneath a roadway. The retainer is then removed from the alignable transverse openings provided in the projection and the wall defining the socket, and the projection is removed from the socket to release head assembly from the drill string. At this point, if desired, the back reamer having a leading end configured in substantially the same manner as the rear end of the head assembly is substituted for the head assembly and mounted on the starter rod, re-forming the joint, and the same steps are substantially repeated, such as in a reverse direction to widen the existing borehole formed on the first pass.

These and other aspects of the invention are described in detail below.
BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, wherein like numerals denote like elements:

Figure 1 is a bottom view of a drill head according to the invention;
Figure 2 is a lengthwise sectional view of the drill head along the line 2-2 in Fig. 1;

Figure 3 is a top plan view of the cover for the sonde housing shown in Fig. 2;
Figure 4 is a side view of the cover of Fig. 3;
Figure 5 is a right side end view of the cover of Fig. 3;
Figure 6 is cross sectional view taken along the line 6-6 in Fig. 3;

Figure 7 is a perspective view of the drill head of Fig. 1, with the sonde cover removed to show the sonde compartment;

Figure 8 is a front view of the drill bit shown in Fig. 7;
Figure 9 is a top view of the drill bit shown in Fig. 7;
Figure 10 is a side view of the drill bit shown in Fig. 7;

Figure 11 is an enlarged rear view of the drill bit shown in Fig. 7, with crushing action shown schematically;

Figure 12 is a top view of the drill head shown in Fig. 1, with the sonde cover in place;

Figure 13 is a cross sectional view taken along the line 13-13 in Fig. 12;
Figure 14 is a cross sectional view taken along the line 14-14 in Fig. 12;
Figure 15 is a cross sectional view taken along the line 15-15 in Fig. 12;
Figure 16 is an enlarged cross sectional view taken along the line 16-16 in Fig. 12;

Figure 17 is a front corner perspective view of the drill bit shown in Figure 1;
Figure 18 is a sectional view taken along the line 18-18 in Fig. 17;
Figure 19 is a cross sectional view taken along the line 19-19 in Fig. 17;
Figure 20 is a front center perspective view of the drill bit shown in Figure 1;
Figure 21 is a sectional view taken along the line 21-21 in Fig. 20;
Figure 22 is a cross sectional view taken along the line 22-22 in Fig. 20;

Figure 23 is a front corner perspective view of the front end of the sonde housing shown in Figure 1, with the drill bit removed;
Figure 24 is a view of the front end of the sonde housing as shown in Figure 1, with the drill bit removed;

Figure 25 is a side view, partly in phantom, of the drill bit body of the invention with teeth and carbides removed, with the original blank from which the bit body was machined shown in phantom lines; and

Figure 26 is an enlarged, lengthwise sectional view of an improved cutting tooth according to the invention.

Figure 27 is a lengthwise sectional view of a directional drilling head and starter rod according to the invention;

Figure 28 is a rear end view of the sonde housing of Figure 27;

Figure 29 is a front perspective view of the starter rod shown in Figure 27;

Figure 30 is a front end view of the starter rod shown in Figure 29;

Figure 31 is an exploded view of a starter rod and back reamer assembly according to the invention;

Figure 32 is an assembled view of the starter rod and back reamer assembly of Figure 31; and

Figure 33 is a front view of the assembly of Figure 32.

While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts which can be embodied in a wide variety of contexts. The embodiments discussed herein are merely illustrative of specific ways to make and use the invention and do not limit the scope of the invention.
DETAILED DESCRIPTION OF THE INVENTION

Referring now to Figures 1 to 7, a drill head 30 according to the invention for use in a directional drilling apparatus includes a drill bit 31 removably mounted on the front end of a generally cylindrical sonde housing 32. A rear end socket 33 of housing 32 is configured for connection to a corresponding projection forming part of a starter rod 203 at the terminal end of a drill string as described in connection with Figures 27-33. Such a splined joint 201 may be used at the front end of sonde housing 32 as an alternative to the connection shown in Figs. 1-7. An internal flow passage 34 extends along the length of housing 32 from socket 33 to a front end face of housing 32 in order to conduct drilling mud or water to the bit, the use of which is well known in the art.

Sonde housing 32 has a lengthwise, laterally-opening sonde cavity 36 which is closed in use by a removable cover 37. Cavity 36 has a centered, rearwardly-facing L-shaped key 38 which engages a corresponding groove in the end of the conventional cylindrical sonde to securely position the sonde in the cavity 36 in a predetermined alignment relative to the cutting teeth 67 of bit 31 as described hereafter. Since drill head 30 is generally made of steel, it is necessary to provide a series of spaced, thin longitudinal slots 35 in housing 32 and cover 37 to that the signal from the sonde can be detected from the ground surface.

Cover 37 includes two (or more) pairs of longitudinally extending wings 39 extending laterally from the lengthwise axis of cover 37. Wings 39 matingly fit through lateral recesses 42 in a rim 43 of sonde housing 32, and then cover 37 slides rearwardly in the embodiment shown so that wings 39 slide beneath adjoining portions of rim 43 into grooves 44 (see Figs. 12-14.) It is preferred to provide at least two pairs of wings 39 at opposite ends of cover 37 in order to provide enhanced holding action. A third pair of wings and corresponding openings 42 may be located along the middle of cover 37 if desired. It is important that wings 39 have substantial length and thickness so that premature failure does not occur. Preferably, wings 39 extend at least about 10% of the total length of cover 37, preferably from about 15% to 40% thereof, and have an outwardly tapering, dovetailed shape in cross section (Figs. 6, 14) which matches an undercut profile of grooves 44.
Cover 37 is typically made of steel but is nonetheless subject to severe torque during use. To prevent cover 37 from collapsing inwardly, it is best to support cover 37 along the entirely of its sides, rather than rely solely on lateral wings for support. Cavity 36 has a pair of longitudinal shelves 46 which are coplanar with each other and with a pair of end shelves 47 which lie beyond opposite ends of a sonde-receiving recess 48. Shelves 46, 47 provide the support needed to prevent inward collapse of cover 37 in all but the most extreme conditions.

To further protect the sonde as it rests in recess 48, the ends of the sonde recess may be filled with a flowable compound such as a soft elastomer having a durometer in the range of about 10 to 20 on the Shore A scale. A urethane elastomer has proven most effective because it has a high chemical resistance to conventional drilling mud. After installation of the sonde onto key 38, the flowable compound is poured in and set or cured to form a pair of resilient shock absorbers that conform to the space around the sonde and protect it from shocks and vibrations. The compound may be filled into the ends only, for example, to the dotted lines shown in Fig. 7, filling in front rounded, rearwardly facing recesses 45A ahead of the sonde and rear rounded, frontwardly facing recesses 45B behind to a level just slightly beyond and covering the front face of key 38 (e.g., 0.05 inch) and to the same level on rear sonde holding projection 49. In the alternative, the compound can fill entirety of recess 48, and in any case does not hinder transmission of the sonde signal or removal of the sonde when necessary. The surface of cover 37 should be free of studs, since this would place undue stress on the cover.

The use of bolts to secure cover 37 is of course feasible, but bolts tend to loosen or break off during use. Use of a bolt head to hold the cover down is not preferred because the head of the bolt, which creates the clamping force, is necessarily located on the outside of the device and little can be done to protect it from abrasion. Accordingly, as the fasteners used to removably secure cover 37 to housing 32, it is preferred to use retainers 51 in the form of spiral-wound roll pins or a series of nested, split (C-) rings of the type which resiliently engage the walls of a mounting hole once inserted. Even a high-strength plastic rod, tubular or solid, could be used for retainer 51. A preferred roll pin comprises a steel sheet having a thickness in the range of
about 1/32-1/8 or 1/16-1/8 inch, a length of 2-4 inches, and a diameter in the range of
about 7/16 to 5/8 inch, more generally 7/16 to 1 inch, and which has been spiral
wound at least about one and one-half times, generally at least two times so as to
provide a doubled thickness. It has been found surprisingly that such retainers remain
in place in the rapidly spinning drill head even when no stop is provided in the
direction of rotation, yet can be removed manually with a hammer and pin. This type
of retainer is also used to connect the sonde housing 32 to the starter rod, as noted
above, and to connect the bit 31 to housing 32 as described hereafter.

As illustrated in Figures 12 and 14, a pair of spaced, parallel, transverse holes
52 are provided in sonde housing 32 which open on the rear surface of housing 32 and
on end shelves 47 thereof. Holes 52 preferably have axes slightly offset from a
lengthwise axis A1 of housing 32 and emerge at an acute angle relative to flat shelves
47. Similarly, angled holes 54 in cover 37 align with holes 52 when cover 37 slides to
its closed position, whereupon roll pins 51 are inserted to prevent cover 37 from
sliding back to its original position until pins 51 are removed, such as by tapping them
out from behind in the opposite direction from the direction of insertion. In the
embodiment illustrated, roll pins 51 are confined for sliding movement between a pair
of stops (annular steps) 56, 57 provided in the walls of holes 52, 54, respectively.
Pins 51 have a length slightly less than the length of the longer hole 52, so that
tapping with a chisel or rod from hole 54 drives pin 51 against step 57 to a position at
which cover 37 can slide away, and tapping from the opposite side drives it against
step 56 to a position as which cover 37 is locked from sliding. This arrangement is
preferred in that pins 51 need never be completely removed and slide only a short
distance between positions, making opening cover 37 much easier than with bolts.

Pins 51 and holes 52, 54 are angled as shown in order to avoid passage 34 (see
Fig. 14). Otherwise, since pins 51 do not provide a hold-down or clamping force on
the cover as the standard bolts used in the prior art do, holes 52, 54 could extend
radially so that pins 51 would extend in a direction normal to the outer surface of
cover 37 when installed. Mechanical engagement of wings 39 with corresponding
inclined undersurfaces 50 of grooves 44 holds the cover down, and pins 51 act only to
prevent cover 37 from sliding back in a lengthwise direction.
Referring to Figure 7, carbide studs 68 are preferably deployed on sonde housing 32 in strategic locations to reduce wear on the base metal. In particular, a lengthwise row of studs 68A is placed on the top surface of housing 32 opposite the primary cutting teeth 67 because reaction force from the teeth 67 tends to produce high wear in this area. Placement of studs along the periphery of rim 43 also reduces wear to cover 37. It is also desirable to provide an annular formation of studs 68B to protect the associated joint (splines) on the front end of housing 32, and a further annular group of equiangular studs 68C to provide similar protection for the rear joint 201 connecting housing 32 to the starter rod 203.

Referring now to Figures 8-12 and 16-22, drill bit 31 of the invention is illustrated in detail. Bit 31 preferably comprises a cut-away cylindrical body with a generally semi-cylindrical bottom section 61, a flat, angled top face 62 which slopes forwardly and across the tool axis A1 at an angle in the range from about 8 to 35 degrees relative to the tool axis A1 (25° as shown), and a nose section 63. Numerous rounded tungsten carbide studs 68 are distributed over the surface of bit 31 as shown. Carbides 68 serve a two-fold purpose of grinding cuttings passed back from the front of the bit 31 and protecting the surface bit 31 from excessive abrasion during use. Carbides are typically interference fitted into apertures 58 in head 30, or may be brazed therein.

Face 62 can be used to steer head 30 through dirt by forward thrust without rotation in a manner known in the art, and when drilling in rocky conditions (forward thrust with rotation), can serve to guide the bit along a shelf as generally described in Runquist et al. U.S. Patent No. 5,778,991, issued July 14, 1998, and discussed further below. Face 62 has a pair of first and second central, forwardly flaring grooves 64, 66 each of circular cross section (frustoconical) for channeling cuttings rearwardly from the head. First groove 64 is preferably deeper and flares more widely than second groove 66, which is positioned such that cuttings are funneled to it by groove 64.

Nose section 63 includes a radially extending, arc-shaped rim or flange 65 on which three large cutting teeth 67A, 67B, 67C are mounted so that the cutting ends thereof extend outwardly beyond the outer diameter of the bit body. Nose section 63 has three large holes 71A, 71B, 71C for receiving cutting teeth 67. Holes 71 (i.e.,
71A-C, Figs. 17-19) are evenly spaced in a generally semi-circular arc across along a front face 72 of rim 65. Carbides 68 are distributed over front face 72 and especially on an outer face 80 to protect the metal and provide increased grinding action. Holes 71 are canted at an angle of from about 30° to 60° relative to an imaginary line normal to curved front face 72 in the direction of rotation of cutting head 30. In one embodiment, the cutting teeth 67 are angled in the cutting direction at approximately 30°. The exact angle will depend in part on the slope of the conical end portions 21 of the cutting teeth, with a more tapered, sharper point requiring greater canting for the associated tooth 67 to provide the desired degree of shearing force to the formation being bored. A canting angle of less than about 30 degrees, especially 25 degrees or less, provides no significant improvement in cutting.

The cutting teeth of at least one prior art cutting head project straight from the cutting head, with the side teeth diverging slightly in opposite directions relative to the center tooth. In this configuration, the teeth of the prior art head produce a violent cutting action with the teeth bouncing onto and off of the rock being cut. It has been discovered that the resulting shock and vibration cause a higher rate of failure of the sonde and directional drilling machine. The smoother cutting action of the canted teeth 67 of the present invention reduces these problems.

Referring to Figs. 19 and 26, teeth 67 of the invention are specially configured for extended life and replacability. Each tooth 67 has a generally cylindrical holder 70 with a front portion 73 which has a diameter great enough to securely mount a carbide tip 74 and a rear reduced diameter portion 76 which fits into hole 71 to a predetermined depth. Holder 70 is made of a conventional steel such as a 4140 alloy. Tips 74 are preferably cylindrical pellets made of a hard, wear resistant material which is not excessively brittle, e.g. high carbon tool steel, diamond, or a ceramic such as tungsten carbide. A tungsten carbide having a Rockwell hardness on the A scale of at least about 87 is preferred. An exposed front end face 79 of tip 74 is conical and more pointed than the generally hemispherical protruding portions of grinding buttons 68. Relative to lengthwise tooth axis T, for example, conical front face 79 defines an included angle G in the range of 60° to 120°.

Rear portion 76 of tooth 67 has an outer circumferential groove 77 into which
a C-spring retaining clip 78 is mounted. It is fairly common in use that tip 74 and the adjoining annular end of front portion 73 will break off, leaving only a stump of the tooth with little cutting capability. According to the invention, a secondary cylindrical recess 81 behind cylindrical recess 82 containing the base of tip 74 contains a further carbide cylindrical rod-shaped insert 83, which is preferably separate from and of smaller diameter (e.g., 25%-75%) than tip 74. When tip 74 finally breaks or wears off, insert 83 is provided to give the tooth enough cutting action to complete the bore then in progress.

When cutting teeth 67 are inserted into apertures 14, the C-spring retaining clips expand into a shallow corresponding annular groove 75 (only about 0.015 inch) to secure cutting teeth 67 in position. As shown in Figs. 18 and 19, tap-out holes 69 are provided as linear, reduced diameter extensions of holes 71. When a tooth 67 must be replaced, it can be removed by insertion of a rod into hole 69 into contact with the back of tooth 67, followed by tapping the rod with a hammer until tooth 67 loosens. Figures 17-19 illustrate the foregoing structures for middle tooth 67B. Teeth 67A and 67C are configured in a like manner but at different positions as dictated by the geometry of bit 31.

Referring to Figures 20-22, flange 72 of bit 31 also has a row of three fluid ejection ports 86 provided at spaced positions to provide optimum flushing action for teeth 67. Typically the fluid is a drilling mud, for example, a mixture of water, polymer and clay. The drilling mud serves to lubricate and cool the cutting head 10 and to sweep rock chips and other bored material away from the cutting head during operation. Ports 86 receive fluid from associated angled passages 87 which meet at the inner end of rear recess 92, described hereafter, and receive fluid from passage 34 (see Fig. 2). Figures 20-22 illustrate the foregoing structures for middle passage 86. Side ports 86 are configured in a like manner but at different positions as dictated by the geometry of bit 31. Ports 86 have a smaller diameter than conventional fluid injection outlets in order to achieve a higher velocity flow, and are positioned to the cutting side of each tooth 67A,B,C to wash cuttings from each of teeth 67.

A secure connection between bit 31 and sonde housing 32 must be provided. Typical bits or "duckbills" known in the art are bolted directly onto an angled face of
the sonde housing. Since abrasion to the device occurs from the outside in, it would be more desirable to provide a connection that is partly or completely shielded from such wear, in contrast to bolts. Bolts also have relatively poor resistance to the high strain induced by drilling and often break during use.

5 Bit 31 is coupled to sonde housing 32 by means of a splined projection 91 provided on the front end of sonde housing 32 that fits into a corresponding rearwardly opening recess 92 in bit 31. Recess 92 is eccentrically positioned relative to the central axis of the cutting head 10. Such eccentric positioning of the coupling between the sonde housing and cutting head provides advantages in directional drilling as described hereafter.

10 Splines 93 are arranged in a radial circular formation on projection 91 in the manner of gear teeth. Splines 93 are preferably elongated in the lengthwise direction of sonde housing 32 to enhance the ability of the drill string and sonde housing 32 to pass torque to the bit 31. Splines 93 are received in spline receiving grooves 94 in recess 92 as shown in Fig. 16. A widened master spline 93A is received in a corresponding master groove 94A, which are in turn in a predetermined alignment relative to key 38 so that bit 31 fits onto sonde housing 32 only in one predetermined orientation. This assures that the orientation of the sonde relative to teeth 67 is always correct. This contrasts with prior sonde housings mounted on bits by means of threaded connections, wherein slight over- or under-rotation of the bit relative to the sonde housing would cause the sonde signal to become out of alignment with the bit, leading to misdirected boring. Although, as illustrated, splined projection 91 is generally cylindrical, other geometries for splined projection 91 and recess 92 could be used. Likewise, it is within the scope of the invention to reverse parts described; in this case, the splined projection 91 would be part of bit 31 and fit into a corresponding recess in the sonde housing 32. The splines may be relocated closer to the surface of the bit as described in the sonde housing-starter rod joint 201 described in connection with Figures 27-33 below.

15 Bit 31 includes a pair of parallel retainer (pin) receiving holes 96 which extend in a direction perpendicular to and laterally offset from the lengthwise axis A1 of drill head 30, as shown in Figs. 11 and 16. Preferably a pair of such holes are positioned
on opposite sides of axis A1, but even a single hole 96 could be used, depending on
the anticipated drilling conditions. Holes 96 intersect corresponding outwardly
opening semi-circular grooves 97 on opposite sides of projection 91 (see Figs. 16, 23,
24.)

Once fully inserted, splined projection 91 is mechanically secured in recess 92
by pins 98 inserted into holes 96. Steps 100 for preventing over-insertion may be
provided near one end of each hole 96. Pins 98 are inserted at the other end of each
hole 96 and reach a fully inserted position when in contact with steps 100. In one
embodiment, the pins 98 are spiral-wound steel plates as described above for the
sonde cover 37 that act in the manner of coil springs when inserted into holes 96
engaging the walls of holes 96 and grooves 97 and thereby remaining in place despite
the violent movements of the head 31 during use. In operation, pins 98 are also
disposed well within bit 31 and thus protected from surface abrasion.

Referring now to Figure 16, grooves 97 each define an axis which is slightly
skewed in a transverse (cross sectional) direction relative to the lengthwise axis of
each hole 96. As indicated by the lines L drawn along the bottom of each groove 97,
which are parallel to the axis of each groove 97, there will be a slight interference fit
as pins 98 are inserted, tending to push the splines in a counterclockwise direction as
shown. In the embodiment shown, the angle is about 1° relative to the adjoining
sidewall 99 of each hole 96, and an angle of from half a degree up to about 2 degrees
should be considered "slightly angled" for purposes of the invention. Insertion of pins
98 therefore preloads splines 93 in the driving direction against lead end walls 101 of
the corresponding slots 94. This prevents working of the resulting front joint 200
during boring operation that would otherwise shorten the life of the connection.

When projection 91 is fully inserted and secured with pins 98 as shown in Fig.
2, clearance is provided so that an inner, reduced diameter end portion of recess 92
forms a chamber 102 which distributes fluid from passage 34 to each of passages 87.
For this purpose, a front end of projection 91 ahead of the front ends of splines 93 has
an outwardly opening circumferential groove 103 (Fig. 2) wherein an O-ring can be
mounted to seal chamber 102.

Cuttings from teeth 67 mix with the drilling mud injected from ports 86 and
pass rearwardly along the outside of bit 31 under the pressure of the mud flow. Grooves 64, 66 aid in passing a large portion of the cuttings back to a crushing surface 106 on the upper rear corner of the tool opposite nose portion 62. Crushing surface 106 defines the outermost diameter of bit 31 on its top side as shown in Fig. 10, and is preferably studded with carbides 68, optionally including a pair of central, enlarged carbides 60 (see Fig. 9). In general, flow from grooves 64, 66 is directed toward crushing surface 106. Surface 106 has a semi-circular shape (its width tapers rearwardly) and slopes forwardly as shown, so that pieces of rock that pass through are gradually pulverized as the space between the wall of the borehole and surface 106 decreases.

Referring now to Figure 25, to provide the desired configuration for the crushing surface 106, bit 31 is machined from a radially symmetrical blank 108 having a rear frustoconical portion 109 that increases in diameter in a rearward direction as illustrated, a central cylindrical portion 111, and a front frustoconical portion 112. The lengthwise axis A1 of drill head 30 coincides with the longitudinal axis of blank 108 and recess 92. A second axis A2 is established at a location parallel to and radially offset from axis A1. A crescent-shaped portion of metal is removed based on a circle centered on A2, resulting in an exterior profile rearward of nose 63 that is a composite of arcuate surfaces based on the diameters of the circles based upon axes A1 and A2. At its rear end, bit 31 has a circular cross section centered on axis A2 and thus offset from tool axis A1. The axis of rotation of A3 of head 30 is located at a point intermediate axes A1 and A2, specifically along a line equidistant from lines tangent to the points defining the maximum outer diameter of bit 31, namely a rear corner 114 at the end of crushing surface 106, and a diametrically disposed outer face or rim 80 of nose 63.

Bit 31 having the foregoing configuration provides an improved cutting action. Due to its eccentric positioning relative to the sonde housing and the smooth transition of its circular profile from back to front, bit 31 provides a crushing profile that is substantially arcuate (circular) along the entire cross-section of the borehole. As shown in Fig. 11, the resulting space between the inner surface 116 of the borehole and crushing surface 106 forms a crescent-shaped crushing zone 117. A stone or
fragment 120 caught in crushing zone 117 as bit 31 rotates is forced into a gradually narrowing end 119 of the crescent which coincides with surface 106, and is thus more likely to be crushed than to bounce around inside crushing zone 117. In this manner, drill bit 31 of the invention provides a more efficient crushing action.

In order to steer the drill head 30 through rock in the desired direction, such as up or down, the cutting head is operated to cut in an arc or semicircular profile in the desired direction of travel. After the arc is bored, cutting head 10 is retracted and rotated back a like distance, or the rotation is completed with the head withdrawn so that no cutting occurs. Head 30 is then returned to engagement at the same location and the steps are repeated. This process may be accomplished as described in Runquist et al. U.S. Patent No. 5,778,991, issued July 14, 1998. As noted above, material from the arc-shaped bore hole collects in the tapered grooves 64, 66, forming a ramp upon which bit 31 can ride. This process gradually results in a change in boring direction, after which the mode of operation is returned to normal to form a circular borehole.

In the above-described process, the apparatus of the invention can drill a borehole through a rocky substrate, which tunnel is curved or has several angled segments representing initial entry into the ground, horizontal boring under an obstacle such as a roadway, and upward travel towards the surface at the end of the borehole. Drill head 30 may also be used in the same manner as a convention duckbill-style bit to bore through soil or soft strata without drilling, but with reduced efficiency as compared to a boring head designed for normal push-and-turn directional boring through soil.

Other advantages of drill head 30 will be evident to those skilled in the art. Bit 31 is readily removable from sonde housing 32 by tapping out roll pins 98 from apertures 96. This allows bit 31 to be readily replaced or rebuilt when worn. For purposes of rebuilding, the generally cylindrical shape of bit 31 gives it more mass and makes it far more re-usable than toothed duckbills ("bear claws") known in the art and other bits which are essentially flat plates mounting teeth. Sonde housing 32 provides ready access to the sonde by means of cover 37, which can be readily removed and replaced, yet has sufficient strength and support from beneath to resist
crushing. Roll pins 98 preferably replace conventional bolts which are highly 
vulnerable to loosening and breakage.

The rear end of sonde housing 32 is likewise secured by retainers such as roll 
pins 120 inserted though holes 121 forwardly of torque-passing splines 122 into 
corresponding holes in a projection of the starter rod 203 at the front end of the drill 
string. This permits removal of head 30 at the receiving end of the bore and 
replacement with a back reamer to be pulled back through the hole with the 
directional boring machine.

Referring to Figures 27-33, at joint 201, starter rod 203 provides a more secure 
connection to sonde housing 32, but one which can be readily manually removed. A 
rear end portion 204 of starter rod 203 has a threaded recess 205 for securing rod 203 
on the front end of the drill string. A cylindrical projection 210 coaxial with a 
lengthwise axis of starter rod 203 extends from a enlarged diameter front end portion 
206 of starter rod 203. Projection 210 has four transverse holes 212 extending 
therethrough at spaced positions, preferably offset from the lengthwise axis of starter 
rod 203 as shown. An axial mud flow passage 214 extends the length of starter rod 
203 for feeding drilling mud to the cutting head 10 through passage 34 in sonde 
housing 32. A flared end 216 of passage 214 and a radial, semi-cylindrical groove 
217 aligned with a master spline 226 permit communication between passages 214 
and 34. A pair of annular grooves 218, 220 are provided on the outer periphery of 
projection 210 near its front and rear ends. Groove 220 receives an elastomeric O-
ring 221 or other suitable seal to prevent leakage from the front end of projection 210. 
Rear groove 218 is a stress relief undercut.

An interlock mechanism according to this embodiment includes an annular, 
frontwardly-facing portion 222 of a front end of starter rod 203. Annular portion 222 
is located radially outwardly of projection 210 to provide maximum strength to the 
connection. Portion 222 has a series of arcuate, spaced, frontwardly-extending splines 
224 including master spline 226 having a greater width which performs a keying 
function in the same manner as master spline 93A as described above.

Splines 224, 226 are configured to closely engage corresponding grooves 228, 
230 in a rearwardly extending annular wall 232 of sonde housing 32, which grooves
228, 230 form the other half of the interlock mechanism. Splines 224, 226 have radially inwardly tapering sides and curved outer surfaces that coincide with the outer periphery of the front end of starter rod 203. Splines 224, 226 have a length greater than the depth of the associated grooves 228, 230, leaving at least some space between adjacent splines into which a tool for prying apart the elongated members can be inserted.

Projection 210 is slidingly insertable into rearwardly opening socket 33 in sonde housing 32. Wall 232 has a series of parallel pairs of opposed, elongated, cylindrical through-holes 121A, 121B (four in the embodiment shown in Fig. 2, but two or even one may be used) which are brought into near alignment with holes 212 when master spline 226 engages master groove 230. Each pair of holes 121A, 121B has a common lengthwise axis perpendicular to the lengthwise axis of cylindrical projection 210 and socket 33.

Alignment of holes 121A, 121B with holes 212 is imperfect because holes 212 are slightly canted in the same manner as described above in connection with grooves 97. When a roll pin 120 is inserted into each set of holes 212, 121A and 121B, splines 224, 226 are preloaded in the driving direction against a side wall of the associated groove 228, 230. If desired, an inwardly-facing step may be provided in holes 121A or 121B to prevent over-insertion of the roll pins. However, it has been found that at joint 201 the force of rotation is great enough to cause gradual back out of pins 120 unless steps 237 are provided in offset, opposed positions as shown in Figure 15. Pins 120 will tend to be thrown against steps 237 in the embodiment shown.

Referring to Figures 31 to 33, as mentioned above, upon completion of a first boring run, the boring head emerges into an exit pit or trench at a location far removed from the directional boring machine. At this point, a worker may manually remove roll pins 120 with a hammer and chisel, and then remove the boring head 30. A back reamer 240 having a front end configuration substantially matching the rear end of sonde housing 32 may then be mounted on starter rod 203 in place of housing 32, and in this manner the joint 201 according to the invention is re-formed. (The "front" of the device is reversed in this description because the direction of travel is now reversed.) There may be minor differences in the configuration of the front end of
reamer 240 in comparison to the rear end 33 of housing 32, for example, fewer holes 121A, 121B may be provided because joint 201' formed with back reamer 240 does not need to be as strong, and the preloading of splines 224, 226 may not be required. If desired, mud or other drilling fluid may flow during back reaming.

Back reamer 240 has an enlarged diameter rear portion 242 which can be pulled or spun and pulled through soft earth to widen the initial borehole during the second run. The forwardly tapering midportion 244 of reamer 240 may have a radially spaced series of longitudinal grooves 246 therein which have edges 248 useful in grinding away rock if the borehole extends through a rock formation.

Grooves 246 then conduct material back from the cutting area when reamer 240 functions as a drill bit in this manner. When the back reamer 240 emerges into the original entrance pit, it can be removed from starter rod 203 in the same manner as before, and boring head 30 can be reattached if another borehole needs to be made in a nearby location, such as parallel to the first one. During back reaming, providing enlarged diameter front end portion 206 with one or more annular formations of carbide studs 68D has been found to greatly reduce wear on the starter rod 203, which becomes most severe during back reaming.

While certain embodiments of the invention have been illustrated for the purposes of this disclosure, numerous changes in the method and apparatus of the invention presented herein may be made by those skilled in the art, such changes being embodied within the scope and spirit of the present invention as defined in the appended claims.
Claims:

1. In a directional drilling apparatus including a drilling head having an angled face configured for steering the drilling apparatus, a housing having an internal chamber for mounting an electronic locating device therein rearwardly of the drilling head for transmitting a signal indicating the orientation of the angled face of the drilling head, and a joint at which the drilling head is removably mounted to the housing of the locating device, the improvement wherein the joint comprises:

   a projection extending from a front end portion of the locating device housing, which projection has a series of longitudinal, spaced splines thereon, the projection having a longitudinal axis which is offset from a longitudinal axis of rotation of the drilling head;

   a rearwardly opening socket formed in the drilling head having longitudinal, spaced grooves configured to receive the splines of the projection therein;

   a keying mechanism provided on the projection and the socket which permits insertion of the projection into the socket only in one or more predetermined orientations; and

   openings in the socket and projection configured to receive a removable mechanism for mechanically interlocking the projection in the socket with the splines of the projection inserted into corresponding grooves of the socket.

2. The apparatus of claim 1, wherein the keying mechanism comprises a master spline on the projection having a different shape than the other splines and a master groove in the socket configured to receive the master spline therein.

3. The apparatus of claim 1, wherein the openings are a pair of spaced through-holes extending in a direction perpendicular to the lengthwise axis of the drilling head and laterally offset therefrom so that pins inserted therein engage splines on the projection in a manner effective to prevent withdrawal of the projection from the socket.
4. The apparatus of claim 3, wherein the openings are configured so that insertion of pins therein preloads the splines against one wall of each of the corresponding grooves of the socket, which preloading force is exerted in a driving direction when the drill head is actuated.

5. The apparatus of claim 1, further comprising a tubular retainer which is sized for insertion into the openings in the socket, wherein the tubular retainer can be compressed from a relaxed state diameter to a retaining diameter at which an outer circumferential surface of the retainer tightly engages inner surfaces of the openings.

6. The apparatus of claim 1, wherein the retainer comprises a rolled pin.

7. A coupling for a connecting two parts of a machine that rotates about an axis of rotation in use, comprising:
   a first part of the machine that rotates in use, which first part has an first opening having a lengthwise axis which lies in a plane substantially perpendicular to the axis of rotation of the machine;
   a second part of the machine that rotates in use, which second part has a second opening therein having a lengthwise axis which lies in a plane substantially perpendicular to the axis of rotation of the machine and which is brought into alignment with the first opening when the first part is disposed next to the second part; and
   a tubular retainer which is sized for insertion into the aligned openings, wherein the tubular retainer can be compressed from a relaxed state diameter to a retaining diameter at which an outer circumferential surface of the retainer tightly engages inner surfaces of the openings and holds the first part in engagement with the second part.

8. The coupling of claim 7, wherein the tubular retainer comprises a spiral-wound plate.
9. The coupling of claim 7, wherein the tubular retainer comprises a plurality of nested split C-tubes.

10. The coupling of claim 7, wherein the tubular retainer has at least a doubled thickness.

11. The coupling of claim 7, wherein one of the openings has a step therein which is engaged by one end of the tubular retainer.

12. The coupling of claim 10, wherein the step is positioned to prevent movement of the tubular retainer past the step in a lengthwise direction of the openings, wherein centrifugal force created by rotation of the machine in one direction would tend to cause such movement.

13. The coupling of claim 7, wherein the tubular retainer is fully inserted in the openings.

14. The coupling of claim 7, wherein each of the openings is open at its ends.

15. The coupling of claim 8, wherein the plate is made of steel and has a thickness in the range of about 1/16-1/8 inch, a length of 2-4 inches, an outer diameter in the range of about 7/16 to 5/8 inch, and which has been spiral wound at least about one and one-half times.

16. The coupling of claim 7, wherein the first part is a cover and the second part is a housing having a compartment over which the cover is secured during use of the machine.

17. The coupling of claim 7, wherein the first and second parts each have a lengthwise axis which is coincident with the axis of rotation of the machine.
18. The coupling of claim 17, wherein the first and second parts are mechanically engaged with each other in a manner that passes torque from one to the other during operation of the machine.

19. The coupling of claim 18, wherein the second part has a third opening therein spaced from the second opening, and the first opening is disposed in between and in alignment with the second and third openings when the first and second parts are mechanically engaged, such that the tubular retainer spans the first, second and third openings.

20. The coupling of claim 19, wherein one of the first and second parts is a rotary drill bit.

21. The coupling of claim 17, wherein the first and second openings when aligned define a common axis which is radially offset from and perpendicular to the axis of rotation.

22. The coupling of claim 7, wherein one of the first and second parts is a drill head and the other is a sonde housing, and the first and second parts are mechanically engaged with each other in a manner that passes torque from one to the other during operation of the machine.

23. The coupling of claim 7, wherein the machine is a directional boring machine.

24. In a rock drilling bit for a directional drilling apparatus, the improvement wherein a row of frontwardly extending rock cutting teeth are angled at least about 30 degrees away in a cutting direction from a direction perpendicular to an arcuate, frontwardly facing surface of the bit from which the cutting teeth project.
25. In a rock drilling bit for a directional drilling apparatus, the improvement wherein a frontwardly tapering rear outer circumferential surface of the drill head in combination with an inner surface of a hole being drilled defines a crushing zone that is crescent-shaped in cross section.

26. A tooth for use in a rock drilling bit, comprising:
   a generally cylindrical tooth holder having a first frontwardly opening hole and a second frontwardly opening hole behind the first hole;
   a first cutting tip which fits to a predetermined depth in the first hole;
   a second cutting tip which fits to a predetermined depth in the second hole, such that the second cutting tip is positioned behind the first cutting tip.

27. The tooth of claim 26, wherein the first and second cutting tips comprise carbide inserts.

28. The tooth of claim 27, wherein the first cutting tip is a generally cylindrical and has a tapered end that protrudes from the first hole.

29. The tooth of claim 28, wherein the second cutting tip is generally cylindrical and has a smaller diameter than the first tip.

30. The tooth of claim 28, wherein the tooth holder has front, enlarged diameter portion which surrounds the first cutting tip and a rear reduced diameter portion behind the front portion.

31. The tooth of claim 30, wherein the rear portion has an outwardly opening circumferential groove therein configured to receive a retaining clip.

32. An apparatus for mounting an electronic device therein for use in an underground boring machine, comprising:
   an elongated housing having means at opposite ends of the housing for
connecting the housing to other components of the boring machine, and an elongated internal chamber configured to receive an electronic device therein and having an elongated access opening which extends along an exterior surface of the housing, a cover sized to close the access opening, which cover has edges that fit beneath a flange of the housing; and

5 a retainer sized for insertion into openings in the cover and housing, which openings become aligned when the cover is positioned with the edges beneath the flange of the housing, wherein the retainer can be compressed from a relaxed state diameter to a retaining diameter at which an outer circumferential surface of the retainer tightly engages inner surfaces of the openings and holds the first part in engagement with the second part.

33. The apparatus of claim 32, wherein the retainer comprises a roll pin.

34. In an apparatus for mounting an electronic device therein for use in an underground boring machine, comprising:

an elongated housing having means at opposite ends of the housing for connecting the housing to other components of the boring machine, an elongated internal chamber configured to receive an electronic device therein and having an elongated access opening which extends along an exterior surface of the housing, a cover sized to cover the access opening, and means for releasably securing the cover over the access opening,

5 wherein the access opening has a recessed rim including a pair of elongated sides and a pair of ends spanning the sides, each side including a step on which the cover rests when its covers the access opening, and a pair of laterally inwardly extending rim flanges on opposite sides of the access opening each having a pair of inclined undersurfaces, which undersurfaces taper in a direction laterally inwardly and upwardly away from the step; and

10 wherein the cover has a pair of laterally outwardly extending cover flanges on opposite side edges of the cover, which cover flanges taper in a direction laterally outwardly and downwardly so that the cover flanges mate slidingly with the
undersurfaces of the rim flanges, whereby upon placement of the cover into engagement with the step in a first position wherein the cover flanges and the rim flanges are offset, the cover may then slide in a lengthwise direction so that the cover assumes a second position wherein the cover flanges underlie the rim flanges and at which second position the means for releasably securing the cover may be engaged.

35. A sonde housing configured for mounting a sonde therein which comprises a cylindrical steel body having a sonde-receiving recess therein, improved in that a portion of the sonde housing body that receives a reaction force from a cutting bit has a series of hard, wear resistant studs mounted thereon effective to reduce wear on the portion of the sonde housing body that receives the reaction force.

36. The housing of claim 35, wherein the sonde housing further has a side opening for loading and unloading a sonde and a cover for the side opening, which cover is free of the studs.

37. A sonde housing configured for mounting a sonde therein which comprises a cylindrical steel body having a sonde-receiving recess therein, improved in that portions of the sonde housing body proximate opposite ends of the body have hard, wear resistant studs mounted thereon effective to reduce wear on end portions of the sonde housing body.

38. The housing of claim 37, wherein the wear resistant studs are disposed in two annular formations at opposite ends of the sonde housing.

39. The housing of claim 37, wherein the sonde housing further has a side opening for loading and unloading a sonde and a cover for the side opening, which cover is free of the studs.
40. A joint for coupling a pair of elongated members end to end, comprising:
a projection extending in a lengthwise direction from one end of one of the
elongated members,
a socket in an end of the other of the elongated members, which socket is sized
to slidingly receive the projection;
a set of alignable transverse openings in the projection and in a wall defining
the socket, which openings are configured to receive a removable retainer for
mechanically interlocking the projection in the socket; and
an interlock mechanism for preventing relative rotation between the housing
and the starter rod when the projection is fully inserted into the socket.

41. The joint of claim 40, wherein the projection is cylindrical and the
transverse opening therein comprises an elongated, cylindrical through-hole having a
lengthwise axis perpendicular to a lengthwise axis of the cylindrical projection.

42. The joint of claim 41, wherein the joint has at least two sets of alignable
transverse openings in the projection and the wall defining the socket, which sets of
openings are at spaced positions on opposite sides of the lengthwise axis of the
cylindrical projection.

43. The joint of claim 40, wherein the transverse opening in the projection
comprises an elongated, cylindrical through-hole having a lengthwise axis
perpendicular to a lengthwise axis of the projection.

44. The joint of claim 43, wherein the transverse opening in the wall defining
the socket comprises a pair of opposed, coaxial cylindrical through-holes alignable
with the transverse opening in the projection.
45. The joint of claim 40, further comprising a removable retainer which is insertable into the set of alignable transverse openings in the projection and the wall defining the socket for mechanically interlocking the projection in the socket, which retainer has means for resisting disengagement from the transverse openings due to rapid rotation of the joint about an axis which coincides with a lengthwise direction of at least one of the elongated members.

46. The joint of claim 45, wherein the removable retainer comprises an elongated roll pin, and the means for resisting disengagement comprises configuring the roll pin to resiliently engage inner surfaces of the alignable transverse openings.

47. The joint of claim 46, wherein the transverse opening in the wall defining the socket has a stop therein which engages one end of the roll pin when the roll pin is fully inserted in the aligned transverse openings, which stop is effective for preventing overinsertion of the roll pin.

48. The joint of claim 47, wherein the stop comprises an annular step formed on an inner surface of the transverse opening in the wall defining the socket.

49. The joint of claim 45, wherein the roll pin comprises a steel sheet having a thickness in the range of about 1/16-1/8", a length of 2-4", and a diameter in the range of about 7/16 to 5/8", and which has been spiral wound at least about one and one-half times.

50. The joint of claim 41, wherein the cylindrical projection has a lengthwise fluid passage extending therethrough, which passage opens on a front end face of the projection, and has an annular gasket which engages the wall defining the socket and is effective for preventing fluid leakage from the joint.

51. The joint of claim 41, wherein the interlock mechanism comprises a series of spaced splines which extend in a lengthwise direction of the elongated members
and engage a series of grooves in the other of the elongated members in a manner effective to prevent relative rotation between the elongated members when the cylindrical projection is fully inserted into the socket.

52. The joint of claim 51, wherein the splines and grooves are disposed in an annular formation on the outer periphery of the projection and on the wall defining the socket.

53. The joint of claim 51, wherein the splines and grooves are disposed in an annular formation at a position radially outwardly from the socket and projection.

54. The joint of claim 53, wherein the splines taper radially inwardly and a radially outermost curved surface of each spline is disposed on an outer periphery of the associated elongated member.

55. The joint of claim 53, wherein the splines have a length greater than the depth of the associated grooves, leaving at least one space between adjacent splines into which a tool for prying apart the elongated members can be inserted.

56. In a directional boring apparatus including a drill string, a directional boring machine for pushing as well as rotating the drill string, a head assembly including a boring head and a housing having an internal chamber for mounting an electronic locating device therein rearwardly of the drilling head for transmitting a signal indicating the orientation or location of the drilling head, a starter rod mounted at the front end of the drill string, and a joint at which the starter rod is removably mounted to a rear end if the head assembly, the improvement wherein the joint comprises:

a projection extending from one of the head assembly and a starter rod, which projection extends in the lengthwise direction of the head assembly and the starter rod, and can be inserted in the lengthwise direction of the head assembly and the starter rod to slidingly engage a socket in the other of the head assembly and starter rod,
wherein one or more sets of alignable transverse openings are provided in the
projection and the wall defining the socket configured to receive a removable retainer
for mechanically interlocking the projection in the socket; and
an interlock mechanism for preventing relative rotation between the housing
and the starter rod when the projection is fully inserted into the socket.

57. The apparatus of claim 56, wherein the interlock mechanism comprises a
series of spaced splines arranged in an arcuate formation on one of the head assembly
and the starter rod, which splines extend in a lengthwise direction of the head
assembly and the starter rod and engage a series of grooves in the other of the head
assembly and starter rod in a manner effective to prevent relative rotation between the
housing and the starter rod.

58. The apparatus of claim 56, wherein the projection is cylindrical and the
joint has at least two sets of alignable transverse openings in the projection and the
wall defining the socket, which sets of openings are at spaced positions on opposite
sides of the lengthwise axis of the cylindrical projection, and the transverse openings
in the cylindrical projection comprise a pair of elongated, parallel, cylindrical through-
ohles having a lengthwise axis perpendicular to a lengthwise axis of the cylindrical
projection, and each transverse opening in the wall defining the socket comprises a
pair of opposed, coaxial cylindrical through-holes alignable with the associated
transverse opening in the projection.

59. The apparatus of claim 56, further comprising a removable retainer which
is insertable into the set of alignable transverse openings in the projection and the wall
defining the socket for mechanically interlocking the projection in the socket, which
retainer has means for resisting disengagement from the transverse openings due to
rapid rotation of the joint about an axis which coincides with a lengthwise direction of
at least one of the starter rod and the head assembly.
60. The apparatus of claim 59, wherein the removable retainer comprises an elongated roll pin, and the means for resisting disengagement comprises configuring the roll pin to resiliently engage inner surfaces of the alignable transverse openings.

61. The apparatus of claim 60, wherein the transverse opening in the wall defining the socket has a stop therein which engages one end of the roll pin when the roll pin is fully inserted in the aligned transverse openings, which stop is effective for preventing overinsertion of the roll pin.

62. The apparatus of claim 56, wherein the projection has a lengthwise fluid passage extending therethrough, which passage opens on a front end face of the projection, and has an annular gasket which engages the wall defining the socket and is effective for preventing fluid leakage from the joint.

63. The apparatus of claim 57, wherein the splines and grooves are disposed in an annular formation at a position radially outwardly from the socket and projection.

64. The apparatus of claim 63, wherein the splines have radial side walls such that the splines taper radially inwardly, and a radially outermost curved surface of each spline is disposed on an outer periphery of the associated starter rod or head assembly.

65. The apparatus of claim 63, wherein the starter rod has a front cylindrical portion and a rear cylindrical portion, the radially outermost curved surface of each spline adjoins a cylindrical outer periphery of the front end portion of the starter rod, and the rear cylindrical portion of the starter rod has a threaded opening therein configured for connection to the drill string.
66. The apparatus of claim 57, wherein the splines have a length greater than the depth of the associated grooves, leaving at least one space between adjacent splines into which a tool for prying apart the starter rod and the head assembly can be inserted.

67. The apparatus of claim 56, wherein the outer surface of the projection is configured for direct linear insertion into the socket without rotating the projection relative to the socket.

68. A method for attaching and removing a head assembly to a directional boring apparatus including a drill string and a directional boring machine for pushing or pulling as well as rotating the drill string, wherein the head assembly includes a boring head, a housing having an internal chamber for mounting an electronic locating device therein rearwardly of the drilling head for transmitting a signal indicating the orientation or location of the drilling head, a starter rod mountable at the front end of the drill string, and a joint at which a front end of the starter rod is removably mounted to a rear end of the head assembly, wherein the joint comprises a projection extending from one of the rear end of the head assembly and the front end of the starter rod, which projection extends in the lengthwise direction of the head assembly and the starter rod and can be inserted in the lengthwise direction of the head assembly and the starter rod to slidingly engage a socket in the other of the head assembly and starter rod, wherein one or more sets of alignable transverse openings are provided in the projection and a wall defining the socket configured to receive a removable retainer for mechanically interlocking the projection in the socket, the retainer having means for resisting disengagement from the transverse openings due to rapid rotation of the joint about an axis which coincides with a lengthwise direction of at least one of the starter rod and the head assembly, and an interlock mechanism for preventing relative rotation between the head assembly and the starter rod when the projection is fully inserted into the socket, the method comprising the steps of:

   positioning the starter rod relative to the head assembly so that the interlock mechanism will become interlocked during insertion of the projection into the socket
and the transverse openings provided in the projection and the wall defining the socket come into substantial alignment;

inserting the projection into the socket, thereby causing the interlock mechanism to become interlocked;

inserting the retainer into the alignable transverse openings provided in the projection and the wall defining the socket;

operating the directional boring machine;

removing the retainer from the alignable transverse openings provided in the projection and the wall defining the socket; and

removing the projection from the socket so that the head assembly is removed from the started rod.

69. The method of claim 68, further comprising the steps of:

substituting for the head assembly a back reamer having a leading end configured in substantially the same manner as the rear end of the head assembly;

positioning the starter rod relative to the back reamer so that the interlock mechanism will become interlocked during insertion of the projection into the socket and the transverse openings provided in the projection and the wall defining the socket come into substantial alignment;

inserting the projection into the socket, thereby causing the interlock mechanism to become interlocked;

inserting the retainer into the alignable transverse openings provided in the projection and the wall defining the socket;

operating the directional boring machine a second time in a manner effective to widen an existing hole use the back reamer;

removing the retainer from the alignable transverse openings provided in the projection and the wall defining the socket; and

removing the projection from the socket so that the back reamer is removed from the started rod.
70. The method of claim 68, wherein the removable retainer comprises an elongated roll pin and the means for resisting disengagement comprises configuring the roll pin to resiliently engage inner surfaces of the alignable transverse openings, wherein the retainer inserting step further comprises hammering an end of the roll pin into the transverse openings, and the retainer removing step further comprises hammering an end of the roll pin inside the transverse openings in a manner effective to move the roll pin out of the transverse openings.
# INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

- **IPC(6)**: E21B 10/00
- **US CL**: 166/65.1; 175/398; 285/305; 403/359.5
- According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

- **Minimum documentation searched**: (classification system followed by classification symbols)
  - U.S.: 166/65.1, 242.6; 175/398, 325.5, 325.6, 325.7, 19, 45; 285/305, 330, 404; 403/359.5, 359.6

- **Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched**
  - none

- **Electronic database consulted during the international search (name of database and, where practicable, search terms used)**
  - none

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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</thead>
<tbody>
<tr>
<td>X</td>
<td>US 4,484,783 A (EMMERICH) 27 November 1984 (27/11/84), see entire document.</td>
<td>26-31</td>
</tr>
<tr>
<td>X</td>
<td>US 5,899,283 A (COX) 04 May 1999 (04/05/99), see entire document.</td>
<td>24,25,32,33</td>
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<td>1,3-23, 40-46, 49-53, 55-61, 63, 65, 68</td>
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<tr>
<td>Y</td>
<td>US 5,667,332 A (LINDHOLM) 16 September 1997 (16/09/97), see entire document.</td>
<td>1,3-23, 40-46, 49-53, 55-61, 63, 65, 68</td>
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*Further documents are listed in the continuation of Box C.*

- **Special categories of cited documents**
  - *A* document defining the general state of the art which is not considered to be of particular relevance
  - *E* earlier document published on or after the international filing date
  - *L* document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  - *O* document referring to an oral disclosure, use, exhibition or other means
  - *P* document published prior to the international filing date but later than the priority date claimed

### Date of the actual completion of the international search

- **05 DECEMBER 1999**

### Date of mailing of the international search report

- **03 FEB 2000**

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