SYSTEM AND APPARATUS FOR LOCATING AND AVOIDING AN UNDERGROUND OBSTACLE

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ABSTRACT

A method and apparatus for detecting and avoiding an underground object during a horizontal directional drilling operation. The apparatus comprises a boring tool with a ground penetrating radar detection system. The boring tool is operatively connected to a drill string and advanced through the earth to create a borehole. The radar detection system includes at least one transmitter, at least one detector, and a processor. The transmitter is located on a surface of the boring tool and is adapted to transmit electromagnetic waves. At least one detector is located on the surface of the boring tool, and detects the electromagnetic waves reflected by underground objects. The processor determines the location of the underground object from characteristics of the reflected waves. Using this information, the drill string may be pulled back up the borehole or redirected to avoid the object. The boring tool may be caused to breakout of the existing borehole using a pivoting boring tool. Alternatively, a shoe protruding from the boring tool may be engaged to push the boring tool into an opposite wall of the borehole.
SYSTEM AND APPARATUS FOR LOCATING AND AVOIDING AN UNDERGROUND OBSTACLE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of U.S. Provisional Patent Application No. 60/738,209, filed Nov. 16, 2005 and U.S. Provisional Patent Application No. 60/738,210, filed Nov. 16, 2005, the contents of which are incorporated fully herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to the detection and avoidance of underground obstacles during Horizontal Directional Drilling (HDD) applications.

SUMMARY OF THE INVENTION

[0003] One aspect of the present invention is directed to an apparatus for locating an underground object. The apparatus comprises a drill string, a boring tool, at least one transmitter, at least one receiver, and a processor. The drill string has a first end. The boring tool is operatively connected to the first end of the drill string. At least one transmitter is located proximate the boring tool. Said transmitter is adapted to transmit electromagnetic waves. At least one receiver is located proximate the boring tool. Said receiver is adapted to detect electromagnetic waves reflected from underground objects. The processor is adapted to determine the location of the underground object using the waves detected by the receiver.

[0004] Another aspect of the present invention is directed to a method for locating an underground object. The method comprises defining a planned bore path, transmitting electromagnetic waves, receiving reflected waves, and processing the received reflected waves. The electromagnetic waves are transmitted from a location on a boring tool. The received waves are reflected from the underground object. The received reflected waves are processed to determine a location of the underground object.

[0005] Another aspect of the present invention is directed to an apparatus for redirecting a drill string from an existing borehole. The apparatus comprises a boring tool and a shoe. The boring tool has a first end connectable to a drill string, a second end used for cutting, and a midsection. The second end comprises a cutting head. The shoe is operatively connected to the midsection of the boring tool. The shoe is adapted to be extended from the midsection of the boring tool.

[0006] Still another aspect of the present invention is directed to downhole tool for use in directional drilling. The downhole tool comprises a housing, a drill head, and a rotation assembly. The housing is connectable to a drill string. The drill head is pivotally connected to the housing. The rotation assembly is supported by the housing, and adapted to pivot the drill head relative to the housing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a side view of an HDD machine drilling in the presence of existing underground obstacles with the aid of a downhole radar system of the present invention.

[0008] FIG. 2 is a partially exploded view of a radar antenna set suitable for use with the present invention.

[0009] FIG. 3 is a partial perspective view of components of a downhole radar system.

[0010] FIG. 4 is a sectional side view drawing of a directional drill head for use with the present invention.

[0011] FIG. 5 is a sectional side view of a ceramic directional head adapted to house antennas of a downhole radar system.

[0012] FIG. 5A is a front view of the ceramic directional head shown in FIG. 5.

[0013] FIG. 6 is a sectional side view of a drill bit with a pneumatically controlled shoe for deflecting the drill bit from an existing bore hole.

[0014] FIG. 7 is a sectional side view of a drill bit with a pivoting drill head for causing the drill bit to exit an existing bore hole.

[0015] FIG. 8 is a side view of an alternate HDD machine backreaming in the presence of existing underground obstacles with the aid of the downhole radar system of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0016] Turning to FIG. 1, shown therein is a preferential embodiment of an Object Locating System 10. The system 10 is shown for use with a Horizontal Directional Drilling ("HDD") unit 12, the unit comprising a drilling machine 14, a drill string 16 and a downhole tool 18. The HDD unit 12 of the present invention is suitable for near-horizontal subsurface placement of utility services, for example under a roadway, building, river, or other obstacle. The drilling machine 14 is operatively connected to the drill string 16 at an uphole end 20 of the drill string 16. The downhole tool assembly 18 is operatively connected to a downhole end 22 of the drill string 16. The downhole tool 18 may be any of a variety of tools suitable for use during an HDD operation. For discussion purposes and as shown in FIG. 1, the downhole tool 18 comprises a directional drill head 24.

[0017] FIG. 1 illustrates the usefulness of HDD operations by demonstrating that a borehole 26 can be made without disturbing an above-ground structure, for example a roadway or walkway. Typically HDD operation begins by planning a bore path for placement of the utility. To cut or drill the borehole 26, the drill string 16 carrying the downhole tool 18 is rotationally driven by the drilling machine 14. When the HDD unit 12 is used for drilling a borehole 26, monitoring the position of the downhole tool 18 is critical to accurate placement of the borehole and subsequently installed utilities.

[0018] The Object Locating System 10 of the present invention is used for discovering underground objects 28, whether known or unknown. The underground object 28 can be a buried utility or similar line, but the system 10 may also be used for locating other buried objects. The object 28, if encountered, may complicate the operation of the HDD unit 12. For example, a drill head 24 striking a utility line may lead to loss of services in nearby buildings and dangerous conditions in the area of the strike. Some objects 28 are unknown at the time of drilling, while others are known but the precise location of the objects with respect to the advancing downhole tool 18 is unknown.

[0019] With continued reference to FIG. 1, the system 10 comprises a downhole radar system 30. The radar system 30 is preferably positioned proximate the downhole tool 18. The radar system 30 comprises a transmitter or emitter 32, a receiver 34, a communication transmitter 36, and a processor 38. The radar system 30 functions to detect the object 28 and may communicate information concerning the object to an
operator 40 at an above ground location. The operator 40 receives the information at a receiving unit 42 preferably including a display 44.

[0020] From the radar system 30, the emitter 32 produces emitted waves 46. The waves 46 are preferably electromagnetic and propagate through the earth. The emitter 32 preferably directs the waves 46 substantially along the intended path for the borehole 26. As the waves 46 travel through the earth, the emitted waves may encounter a discontinuity in the dielectric constant or the electrical conductivity of the soil, such as may be caused by the presence of the object 28. When the emitted waves 46 encounter such a discontinuity, a portion of energy from the waves is reflected back in the form of reflected waves 48.

[0021] The receiver 34 is adapted to detect the reflected waves 48. Preferably, the receiver 46 is positioned proximate the emitter 32. The receiver 34 is operatively connected to the processor 38 and communicates data signals representative of the reflected waves 48 to the processor 38. The processor 38 is adapted to receive and process the data signals. Preferably, the processor 38 may determine the distance of the object 28 from the downhole tool 18, the reflectivity, and the angular orientation of the object 28. As used herein, angular orientation is intended to mean the x, y, z coordinates of the object 28 with the system 30 as the origin.

[0022] The transmitter 36 is operatively connected to the processor 38 and is adapted to transmit the processed information to the receiving unit 42. At the receiving unit 42, the display 44 may be used to display the information about the object 28 so that it may be viewed by the operator 40. In an alternative embodiment, the transmitter 36 may communicate information up the drill string 16 to a receiving unit 42 located at the drilling machine 14.

[0023] Turning now to FIG. 2, shown therein is a preferred embodiment for a mounting 49 of the emitter 32 and the receiver 34. In any configuration, mounting of the emitter 32 and the receiver 34 requires that no metallic material obscures their faces nor their approximately 150° aperture. As shown in FIG. 2, the mounting 49 comprises a protective plate 50. The plate 50 provides protection from abrasion for the emitter 32 and receiver 34. Preferably, the plate 50 is made of electromagnetically transparent material, so as not to disrupt the transmission of the emitted waves 46 or the receipt of the reflected waves 48. Moreover, preferably, the plate 50 will be made of a ceramic material. Most preferably, the plate 50 will have a dielectric constant approximating that of the surrounding soil. Other similar material such as plastics may be suitable for transmission of the waves 46. The plate 50 must be capable of withstanding abrasive forces associated with horizontal drilling. To further prevent interference with the waves 46, other portions of the HDD system 12 adapted for use with the Object Locating System 10 may be constructed of such electromagnetically transparent material.

[0024] The radar system 30 illustrated herein is capable of “seeing” about twenty inches beyond the face of the emitter 32 in “typical” soils and about twenty-eight inches in ideal conditions. As used herein, the distance the radar system 30 can “see” means the practical range at which sufficiently strong reflected waves 48 will be returned from the object 28 to be detected by the receiver 34. Once detected, the object 28 can be avoided by redirecting the downhole tool 18 to construct an alternative borehole 26. Alternatively, automated shut-down of aggressive progress of the downhole tool 18 may be instigated. Preferably, shut-down is instigated upon receipt of a suspicious reflected wave 48. One skilled in the art can implement such control principles disclosed in U.S. Patent Application No. 2004/0028476 and in U.S. Pat. No. 5,550,547 by Payne, et al., which are incorporated herein by reference.

[0025] Turning now to FIGS. 3-4, the components of an embodiment of a downhole radar system 30 are shown in greater detail. The system 30 comprises the emitter 32 and receiver 34 antennas mounted at the forward end of the downhole tool 18. Preferably, the antennas 32, 34 have an aperture of about 150° and are located in a recess 52 in the downhole tool 18. Preferably, the antennas 32, 34 are protected by the electromagnetically transparent plate 50. Both antennas 32, 34 lie on the face of the drill head 24, which is preferably inclined approximately 30° off the axial centerline of the drill head. To project the emitted waves 46 in a more forward direction, the incline is preferably steeper than the 10°-15° incline common to slant-faced drill bits 24.

[0026] Preferably, the antennas 32, 34 are operatively connected to an electronics module 54 adjacent the drill bit 16. The electronics module 54 comprises a housing 56 for the processor 38 and the transmitter 36. The module 54 may also comprise a battery module 58 for power. The antennas 32, 34 are preferably connected to the transmitter 36 by a coaxial cable or other electrical connection.

[0027] Preferably, the downhole radar system 30 is powered by the battery terminal 58, eliminating the need for additional power cables or electronics within the drill string 16. The transmitter 36 provides the downhole tool 18 with a communications link to the receiving unit 42. In an alternative embodiment, the communication may be bi-directional, allowing aspects of the downhole radar system 30 to be remotely controlled from the receiving unit 42. An additional receiver (not shown) may be disposed in the electronics module 54 to facilitate bi-directional communication.

[0028] Preferably, a particularly useful feature of the system 30 is the ability to control ON/OFF operation of emitted waves 46 to conserve battery power during pauses in operation of the HDD system 12. Alternatively, ON/OFF signals may be instigated automatically in accordance with certain operational functions of the HDD system 12. Preferably, an operational function that triggers the operation of the downhole radar system 30 is the combination of pumping drilling fluid and advancing or rotating the drill string 16.

[0029] The system 30 may also be used to change the interval between emitted waves 46. This technique is useful to adjust for variations in soil that may occur along a given borehole 26. Such a technique is useful to overcome interference caused by emitted 46 and reflected 48 waves without having to build in pauses between the emitted waves.

[0030] The data signals transmitted to the receiving unit 42 may be reduced and have enhanced information by effecting additional downhole processing of the reflected waves 48. Preferably, a rotational sensor (not shown) is located near the downhole radar system 30. The rotational sensor is capable of dynamically indicating the roll angle of the downhole tool 18. Preferably, the reflected waves 48 can be accumulated in relationship to their respective roll angles. These accumulated relationships can be averaged over several revolutions of the drill head 24. This will mitigate spurious returns as well as reduce the data signals to be sent by the transmitter 36. More preferably, the reflected waves 48 may be compiled into angular rotational subsets, such as quadrants, of rotational position of the drill head 24, and transmitted as four or more signals.
per revolution. Another preferred method is to assemble data into the preferred method of display and send a compressed image to the receiving unit 42 instead of individual data signals. Those skilled in the art would recognize that numerous digital manipulations of the data are possible and, depending on the application, an alternative manipulation may produce superior results.

[0031] Power to and data signals to and from the radar system 30 may alternatively be through a wireline inside the drill string 16. Preferably, data signals may be sent up the drill string 16 as directly coupled or induced transmission of electromagnetic signals commonly termed drill string telemetry. Reverse communication from the drill unit 14 to the downhole tool 18 might preferably be transmitted via drill string telemetry.

[0032] Preferably, automated notification or shut-down of forward progress of the drill string 16 may be implemented whenever the reflected waves 48 are detected with parameters indicating danger of striking an object. Automated notification or shut-down can be accomplished by equipping the downhole tool 18 with additional processing, as previously mentioned. One skilled in the art can readily implement the additional control logic to provide the notification or shut-down feature. Automated notification can be accomplished by using a warning light or any number of other methods known to those skilled in the art.

[0033] An alternative embodiment of the downhole tool 18 is shown in FIGS. 5 and 5A. Shown therein is the drill bit 24 having an offset conical shape. In this embodiment, the recess 52 in the drill bit 24 is located on the non-slanted side of the bit. The recess 52 is covered by a protective plate 60. The protective plate 60 is preferably made of electromagnetic transparent material, so as not to disrupt the transmission of the emitted waves 46 nor the receipt of the reflected waves 48.

[0034] The offset conical shape of the drill bit 24 is intended for boring applications with little or no fluid assistance. While conventional bits are constructed of steel, drill bit 24 is preferably cast from an electromagnetically transparent material. More preferably, the bit 24 is cast from ceramic material. Suitable material is characterized by having low magnetic permeability, high resistivity, and an appropriate dielectric constant to closely match that of the surrounding soil. Preferably, a “family” of bits 24 may be constructed, providing a matching dielectric constant for multiple types of soil. Preferably, the electrical properties of the bit 24 and the antennas 32, 34 match that of the surrounding soil. Approximating this ideal reduces transmission losses for emitted 46 and reflected 48 waves.

[0035] Typical use of a HDD unit 12 is to construct a borehole 26 along a generally predetermined path. If, during the construction of the borehole 26, an object 28 is detected, three options exist. The operator may attempt to steer the downhole tool 18 around the object 28, abandon the borehole 26, or pull back a prescribed distance and attempt to redirect.

[0036] One skilled in the art will appreciate that a HDD unit 12 has difficulty breaking out of an existing borehole 26. Traditional slant-faced drill heads rely on an angled surface to steer through soil. Rotation of the drill bit 24 will enable the creation of a straight borehole 26. Pushing the bit 24 without rotation will cause the borehole 26 to curve away from the slanted face of the bit. When attempting to break out of an existing borehole 26, as to avoid the object 28, there is no soil to exert the force on the slanted face of the bit 24.

[0037] Turning again to FIG. 1, one can see how this problem might impact the effectiveness of the present invention. When the presence of the object 28 is detected by the downhole radar 30, steps may be taken to alter the borehole 26. However, if the bit 24 is too close to the object 28 when the object is detected, it may not be practical to use traditional slant-faced steering methods to avoid striking the object. It may be equally difficult to pull the drill string 16 back up the borehole 26 to break out of the borehole, due to the above issues.

[0038] An aspect of this invention to overcome this difficulty is shown in FIG. 6. Shown therein is a preferred embodiment of a downhole tool 62 for redirecting the borehole 26. The downhole tool 62 comprises the drill bit 24, an extension assembly 63 and a protruding shoe 72. The extension assembly 63 preferably comprises a pressurized gas tank 64, a pressure regulator 66, valve assemblies 68, and a piston 70. Air is released from the gas tank 64 into the valve assemblies 68 by the regulator 66. The increased pressure in the valve assemblies 68 causes the piston 70 to extend. When the piston 70 extends, it forces the shoe 72 to protrude from a wall of the downhole tool 62.

[0039] When the shoe 72 is protruding from the downhole tool 62 into a wall of the borehole 26, the drill string 16 will be deflected into the opposite wall of the borehole. Preferably, the shoe 72 will be positioned on the opposite side of the borehole 26 as the straight end of the slant-faced bit 24. In this way, the bit 24 will be pushed into the opposite wall of the existing borehole 26 to steer the drill string 16 away from the object 30.

[0040] Another aspect of this invention that overcomes the difficulty in borehole breakout is given by FIG. 7. Shown therein is an alternate preferred embodiment of a downhole tool 74 for redirecting the borehole 26. The downhole tool 74 comprises a housing 75, the drill bit 24 pivotally connected to the housing, and a rotation assembly 77 adapted to rotate the drill bit relative to the housing. The housing 75 is connectable to the drill string 16. The rotation assembly 77 preferably comprises a motor 76, a gearhead 78, a cam mechanism 80, a pivot pin 82, and the drill bit 24. When break out of a borehole 26 is desired, the motor 76 is initiated. Preferably, the motor 76 is powered by the battery terminal 58. The motor 76 causes the rotation of the gearhead 78, which is rotatably coupled with the cam mechanism 80. The cam mechanism 80, when engaged, causes the drill bit 24 to pivot about the pivot pin 82. Preferably, the bit 24 is continuously variable from zero to ten degrees of rotation about the pivot pin 82.

[0041] Pivoting the bit 24 causes the bit to push into the wall of the existing borehole 26. When the drill string 16 is advanced without rotation, the pivoted bit 24 will cause the drill string to break out of the existing borehole 26. Each time rotation of the drill bit 24 is initiated, the bit must have a zero degree offset to function properly. Preferably, the drill bit 24 will automatically reset before rotation is initiated.

[0042] Additional antenna sets can be utilized in any embodiment of the Object Locating system 10 to provide desired detection of objects in the soil. One example of an alternate antenna location is shown in FIG. 8. In this alternative embodiment, a set of antennas is placed radially approximate the downhole tool 18. Antennas may be placed at various locations and angles along the drill string 16 to accommodate the particular application of the system 10.

[0043] Various modifications can be made in the design and operation of the present invention without departing from the
An apparatus for redirecting a drill string from an existing borehole, the apparatus comprising:
a boring tool, having a first end connectable to a drill string, a second end comprising a cutting head, and a midsection; and
a shoe, operatively connected to the midsection of the boring tool, the shoe adapted to be extended from the midsection of the boring tool.

19. The apparatus of claim 18 wherein the cutting head comprises a slant-faced drill head.

20. A downhole tool for use in directional drilling, the downhole tool comprising:
a housing connectable to a drill string; pole a drill head pivotally connected to the housing; and
a rotation assembly, supported by the housing, the rotation assembly adapted to pivot the drill head relative to the housing, such that the drill head is forced into a wall of an existing borehole.

21. An apparatus for redirecting a drill string from an existing borehole, the apparatus comprising:
a housing supported on the drill string;
a drill bit operatively connected to the housing; and
a redirection assembly adapted to force the drill bit into a wall of an existing borehole.

22. The apparatus of claim 21 further comprising an underground object locating system.

23. The apparatus of claim 22 wherein the underground object locating system comprises:
at least one transmitter located proximate the drill bit, wherein said transmitter is adapted to transmit electromagnetic waves;
at least one receiver located proximate the drill bit, wherein said receiver is adapted to detect electromagnetic waves reflected from underground objects; and
a processor adapted to determine a location of the underground object using the waves detected by the receiver.

24. The apparatus of claim 23 wherein the at least one transmitter transmits ground penetrating radar.

25. The apparatus of claim 21 wherein the redirection assembly comprises:
a shoe operatively connected to the housing; and
an extension assembly operatively connected to the shoe; wherein the extension assembly operates to extend the shoe from the housing.

26. The apparatus of claim 25 wherein the extension assembly comprises a piston.

27. The apparatus of claim 25 wherein the drill bit comprises a slant-faced bit.

28. The apparatus of claim 27 wherein the shoe is extended from the housing proximate the slant-faced side of the drill bit.

29. The apparatus of claim 25 further comprising an underground object locating system.

30. The apparatus of claim 29, wherein the underground object locating system comprises:
at least one transmitter located proximate the drill bit, wherein said transmitter is adapted to transmit electromagnetic waves;
at least one receiver located proximate the drill bit, wherein said receiver is adapted to detect electromagnetic waves reflected from underground objects; and
a processor adapted to determine a location of the underground object using the waves detected by the receiver.

31. The apparatus of claim 31 wherein the redirection assembly comprises a rotation assembly supported by the housing, wherein the rotation assembly is adapted to pivot the drill bit relative to the housing.

32. The apparatus of claim 31 wherein the drill bit comprises a slant-faced bit.

33. The apparatus of claim 31 further comprising an underground object locating system.

34. The apparatus of claim 33 wherein the underground object locating system comprises:
at least one transmitter located proximate the drill bit, wherein said transmitter is adapted to transmit electromagnetic waves;
at least one receiver located proximate the drill bit, wherein said receiver is adapted to detect electromagnetic waves reflected from underground objects; and
a processor adapted to determine a location of the underground object using the waves detected by the receiver.

35. The apparatus of claim 31 wherein the rotation assembly comprises:
a gearhead supported in the housing;
a cam mechanism operatively coupled to the gearhead and the drill bit; and
a pivot pin adapted to rotatably connect the housing to the drill bit; and
wherein rotation of the gearhead causes the cam mechanism to pivot the drill bit about the pivot pin.

36. A method for redirecting a drill string from an existing borehole, the method comprising:
pulling back the drill string a predetermined distance in the borehole;
pivoting the drill bit at an end of the drill string such that the drill bit is forced into a wall of the borehole; and
advancing the drill string without rotation so the drill bit exits the borehole through the wall of the borehole.

37. The method of claim 36 further comprising advancing and rotating the drill string so a new borehole is created.