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(54) Depth determination

(57) In order to determine the depth of an inaccessible object 4, such as an underground boring tool, the depth of the object 4 is determined relative to a known horizontal reference plane p. Similarly the height of the ground surface, relative to the reference plane p is determined.

The horizontal distance travelled by the boring tool 4 from start point 22 and its depth d1 from the start point and hence reference plane P is determined using a known location system. Then knowing the distance travelled by tool 4 the estimated ground level d2 above the reference plane P can be calculated using trigonometry. The estimated depth of the boring tool is the sum d1 + d2.

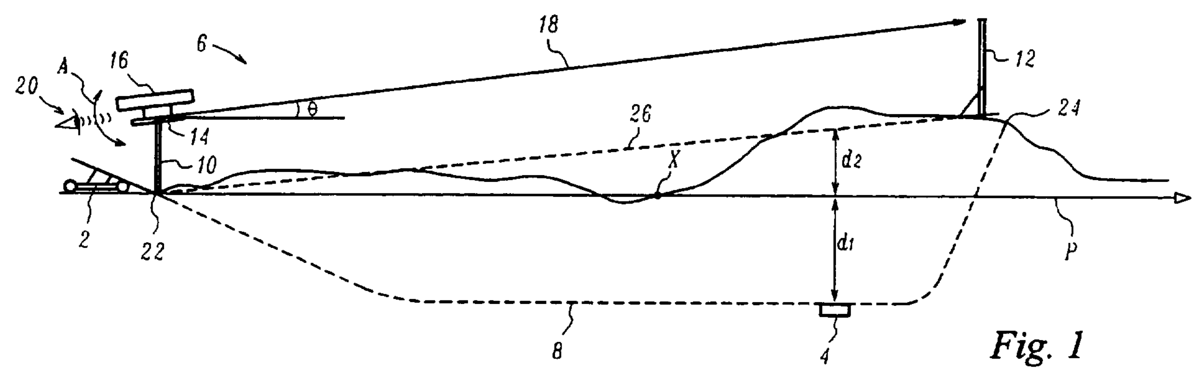

Fig. 1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The claims were filed later than the filing date within the period prescribed by Rule 25(1) of the Patents Rules 1995

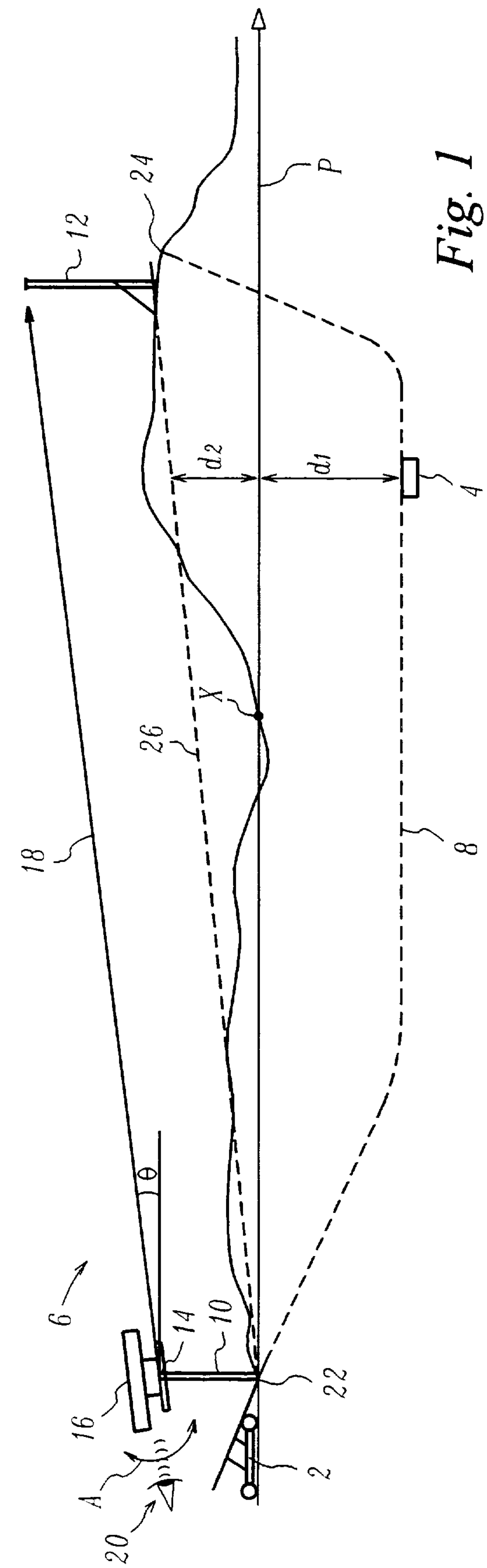

Fig. 1

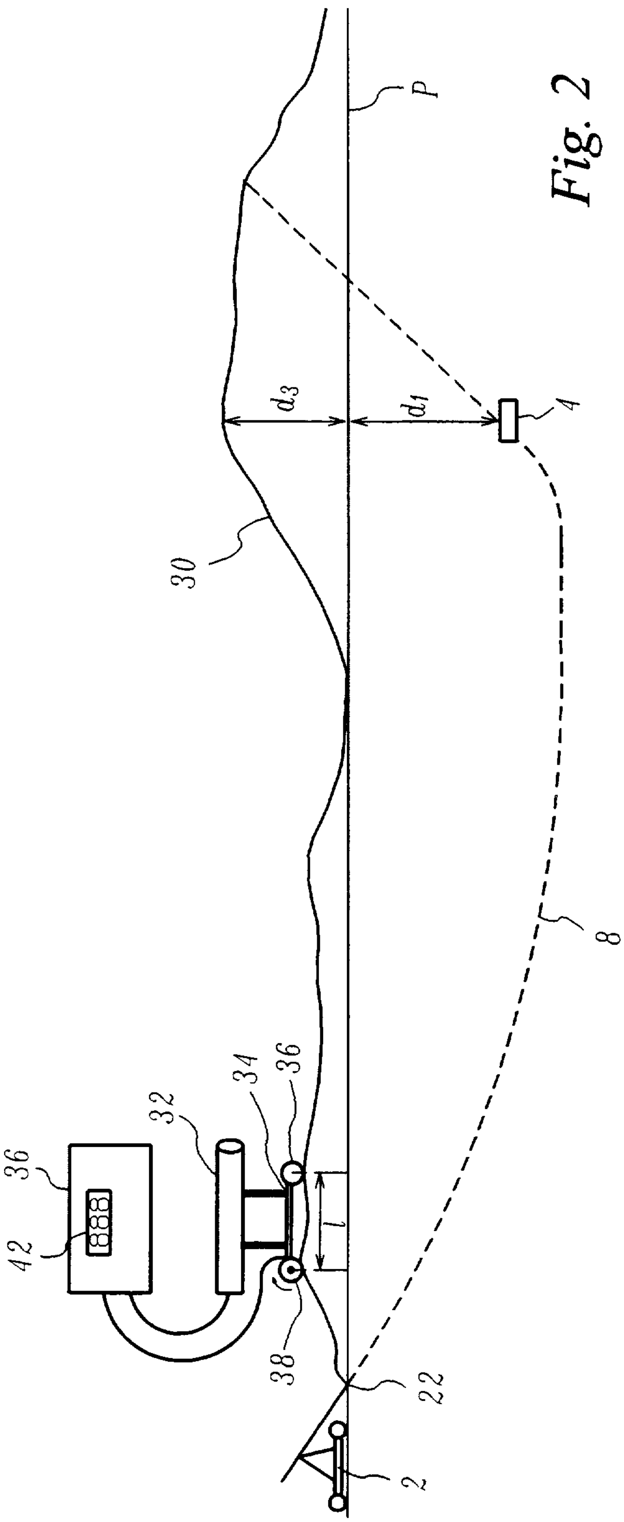

Fig. 2

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Depth Determination

The present invention relates to the determination of the depth of inaccessible objects. Particularly, but not exclusively, it relates to determining the depth of underground boring tools, especially during horizontal boring.

It can often be important to know the depth of an underground object below ground level. For instance, during horizontal boring it may be important to know the depth of the boring tool in order to safely avoid underground obstacles and also to bring the boring tool to the surface at the desired exit location.

It is known to detect the depth of an object from a location directly above the object. This can be done, for example, by measuring the attenuation of an electromagnetic field generated by a solenoid mounted on the boring tool. However, it is not always possible to gain access to a point on the ground directly above the underground object and, even if this is possible, it may not always be easy to establish exactly where that point is. Furthermore, this approach requires that the depth is detected simultaneously with the boring process, requiring additional manpower.

It has been proposed to address this draw-back by measuring the attenuation of the electromagnetic field using two vertically spaced antenna located at the start of the underground bore. However, this method suffers from the draw-back that it only measures depth of the boring tool relative to the measurement location (ie the start of the bore). Thus, it can not account for changes in surface level which, as mentioned above, can be particularly critical in certain situations.

The present invention is generally concerned with determining the depth below a surface of an underground object (e.g. a boring tool) by determining the depth of the object relative to a known horizontal reference plane, determining the level of the surface relative to the same horizontal reference plane, and summing the two results. Primarily the invention is concerned with the step of determining the level of the surface relative to the horizontal reference plane by utilising an inclination sensor in the determination of the average slope and/or the change in height of the surface between two measurement locations spaced apart along the intended path of the underground object.

In one aspect, it is proposed to determine the average slope and/or change in height of a surface between the two locations. This can be done using an inclination sensor mounted in a fixed relationship (preferably parallel) with an optical sight. The sight is positioned at a first measurement point which is a known distance above the surface at the first measurement location, and is aimed at a second measurement point which is a known distance above the surface at the second measurement location. The angle subtended between a line joining the first and second measurement points and horizontal is given by the output from the inclination sensor (corrected for any rotation of the axis of the inclination sensor relative to that of the sight), and this angle is then used in the determination of the average slope and/or the change in height of the surface between the two locations.

For instance, if the distance (either horizontal or line-of-sight) between the two measurement points is measured or otherwise known, the average slope and change in height can be calculated from this distance, the difference in the distances of the measurement points above their respective surface locations, and the angle output from the inclination sensor, using simple trigonometry.

It is preferable however to eliminate one or more of the variables from this calculation, to reduce its complexity. Two particularly preferred ways of achieving this are as follows.

(1) Positioning the first and second measurement

points the same distance above their respective surface locations. With this arrangement, the output from the inclination sensor alone directly gives the average slope of the surface. If the distance between the points (either horizontal or line of sight) is also known, the change in height of the surface between the two locations can be calculated using simple trigonometry.

(2) Adjusting the distance of the first and/or second measurement points above their respective surface locations such that the sight (positioned at the first point) is horizontal when it is aimed at the second point. Here the change in surface level between the two points can be calculated simply, it being the difference in distance above the respective surface locations of the first and second points. In this case, if the distance between the two points is known the average slope of the surface can be calculated using simple trigonometry.

It is possible to make these surface measurements simultaneously with the progress of the underground object along its path. However, it is much preferred to pre-determine the values of slope and/or change in height between the measurement locations, and record these for subsequent use during, for example, a horizontal boring process.

Whichever approach is used, assuming that the level of the surface relative to the horizontal reference plane is known at one of the two measurement locations, the surface level relative to the reference plane at any location along the line joining the two measurement locations can be estimated by interpolation. By summing this value with a calculated depth of the underground object relative to the reference plane, the actual depth of the object at any point along its path can be estimated.

Conveniently, the horizontal reference plane can be chosen to coincide with one of the measurement locations.

It is also preferred that the two measurement locations are selected to be the intended start and finish points of the path to be followed by the underground object, for example the entry and exit points of a bore to be made by an underground boring tool. In this way, particularly when the reference plane is also chosen to coincide with the start point of the underground path, the determination of initial values of object depth and surface level relative to the reference plane is made easy.

It is particularly advantageous that one of the measurement locations be the intended finish point of the object, e.g. the end of an underground bore, because any estimation errors due to surface level variations along the path of the object will be zero at the measurement location. This can be particularly important for example when bringing a boring tool to the surface at the target exit point.

To position the optical sight and inclination sensor at the desired distance above the first measurement location a sight pole or other such rigid support member or structure may be used. Similarly, the second measurement point may be provided as a mark or a target on a sight pole or other support. If required or desired, the optical sight and sensor can be pivotally mounted on their support so they can be inclined relative to the support to aim the sight at the second measurement point. Additionally or alternatively, the sight/sensor combination and/or the second measuring point can be vertically adjustable relative to their supports, for example slidable on the support, or the supports themselves can be vertically adjustable, to enable the distance of one or both of the measuring points above the respective surface locations to be adjusted.

As the optical sight, any suitable sight may be used, for example a rifle sight.

For the inclination sensor, an electromagnetic sensor is preferable. It is particularly preferred that the sensor is the same one to be used for sensing the attitude of inclination of the underground object (e.g. boring tool) as it progresses along its path. A suitable inclination sensor is described in US patent 5552703, but any other sensor preferably with an output unaffected by roll angle may be used.

Data from the sensor can be manipulated and stored locally, or alternatively it can be transmitted to a remote station. Examples of transmission methods include a hardwired connection, radio transmission, or the use of a modulated magnetic field produced for example by a solenoid associated with the sensor.

To improve the accuracy of this estimated depth reading, a series of measurement locations and respective measurement points spaced along the intended path of the underground object may be used, in order to reduce the distance over which the surface level must be interpolated. The average slope and/or height change of the surface between each pair of adjacent measurement locations can be determined, e.g. in turn, and stored.

In the extreme, a large number of measurement locations can be used to provide data giving a close approximation to the actual surface profile. This may be desirable for instance where the surface is particularly undulating and cannot therefore be easily resolved to only a few straight lines.

However, to use this method to give a complete surface profile is likely to prove a long and tedious task. In response to this problem it is possible to measure the inclination of the surface directly at a plurality of surface locations along the intended path of an underground object using an inclination sensor mounted on a support carriage, and to measure the distance between successive measuring locations. The data from these measurements may then be integrated into a full surface profile.

Thus, by making a series of height measurements, or by measuring inclinations at spaced-apart points along the surface, a profile may be developed corresponding to the surface. A second aspect of the present invention therefore proposes that such a profile is used in controlling the underground boring tool. The methods for deriving that profile which have been discussed above involve a series of discrete measurements at spaced-apart points, with the assumption that irregularities in surface level between those spaced-apart points will not be significant. This will normally be true if the points are relatively close together. However, it is also possible within the second aspect to derive a continuous height measurement, for example by passing a height sensor over the surface and continuously deriving signals therefrom, but for many practical situations this level of complexity is not necessary.

Assuming the level of one location along the path is known relative to a horizontal reference plane, the relative levels can be determined along the whole path, and the actual depth of an underground object can be tracked by summing this relative level and the depth of the object relative the reference plane.

The inclination sensor can be of the same type proposed for use with the first aspect above, and is preferably an electromagnetic sensor of the same type used for guiding the underground object.

The spacing intervals of the measurement locations can be chosen to give the required degree of resolution in relation to the length of the underground object, the measurement accuracy of the system, and the rate of change of surface inclination. For example, an undulating surface may need measurements every 0.3m, while every metre may be quite adequate for a reasonably level surface.

The measurements may be taken with the carriage stationary, or at measured intervals during motion.

To facilitate its movement across the surface, the support carriage preferably has ground engaging means such as skids, runners, rollers or wheels, or a combination of such parts. The ground engaging means are arranged, in fixed relation to one another, so that the slope of the surface under the carriage is reflected in the attitude of the carriage. The inclination sensor is rigidly fixed to the carriage so that changes in the slope of the surface, and hence the attitude of the carriage, are detected.

Preferably the inclination sensor is orientated relative to the carriage, and in particular its ground engaging means, such that it is parallel to the surface on which the carriage is stood, thus giving a direct measurement of the slope of the surface with respect to horizontal.

The wheelbase of the carriage is preferably less than the length of the underground object to give adequate sensitivity.

The support carriage may be driven or drawn across the surface in any suitable manner. For example, the carriage may be manually pushed or drawn, in which case a handle or tether is preferably provided to be grasped by an operator. Additionally or alternatively, powered travel of the carriage is possible, e.g. by winch or integral motor drive.

To measure the distance travelled by the carriage between adjacent measuring points it is possible to use a separate measuring device, e.g. a tape or surveyor's wheel. However, it is much preferred to incorporate a measurement device with the carriage. For example, the carriage may be equipped with a measuring wheel for contacting and rolling along the surface as the carriage moves over it. The rotation of the wheel can be detected, for example using Hall-effect or opto-electronic sensing, and the distance travelled by the carriage calculated from this. If a powered drive is used the distance travelled by the carriage (traverse measurements) may be derived from the power source, e.g. winch rope extension sensing, or integral motor turns counting.

Similarly to the first aspect, the angle and distance data gathered can be stored and manipulated locally, e.g. by a processor mounted on the carriage, and a display may be provide on the carriage to provide, for example, instantaneous readings to an operator - for instance if distance travelled is displayed the arrangement could be used as a surveyor's wheel. It is also possible for the data to be transmitted to a remote station, e.g. the base station of a boring system, which can then display, for example, a complete profile of the path followed along the surface.

For some applications, it may also be desirable for a "log point" facility to be provided, whereby specific points along the path followed by the carriage can be logged and stored. The logging can, for example, be carried out at the command of an operator who selects the points to be logged. Typically, the points chosen for logging would be selected for their relevance to the subsequent positioning of the underground object. Such a facility may be useful for example in a boring process to mark topographical features such as walls and ditches, or other obstructions, and also to mark the positions of other buried or above-ground services such as cables and pipes. The preferred location of boring tool guidance targets is another potential use.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 schematically shows an underground boring system making use of an embodiment of the first aspect of the invention; and

Fig. 2 schematically shows an underground boring system making use of an embodiment of the second aspect of the invention.

Referring to Fig. 1, an underground boring system includes a boring machine 2 with associated underground boring tool 4, and apparatus 6 for determining the variation in ground level above the intended path of the bore 8.

The ground level determining apparatus 6 includes start and finish sight poles 10, 12, and a rifle sight 14 and inclination sensor 16 both mounted on the start sight pole 10. The inclination sensor 16 is rigidly mounted with respect to the sight 14, with its measurement axis parallel to the sight-line 18 of the sight 14. Thus, the output of the inclination sensor 16 corresponds to the angle θ subtended between the sight-line 18 and horizontal.

The sight 14 and sensor 16 are pivotally mounted to the top of the start sight pole 10 so that, with the pole 10 held vertically, an operator 20 can pivot the sight 14 as indicated by arrow A to aim it at the top of the finish sight pole 12. The two sight poles 10, 12 are of equal height and the angle θ is therefore also the angle subtended between horizontal and a line joining the respective bottom ends of the two poles 10, 12, when the finish pole 12 is also held upright.

In use, the bottom end of the start pole 10 is placed on the ground at the intended entry point 22 of the bore 8, the pole 10 being supported in an upright position. The finish sight pole 12 is positioned at the intended exit point 24 of the bore 8, and is also supported in an upright position. The sight 14 is aimed at the top of the finish pole 12 and the angle θ measured by the inclination sensor 16 is assumed to be the average ground slope angle between the entry and exit points 22, 24 of the bore. This angle is used to define an estimated ground cover, indicated by line 26.

To estimate the depth of the boring tool 4 at any point along the bore 8 the above described measurement is used in the following way. The horizontal reference plane P is defined, conveniently, to contain the start point 22 of the bore 8. The horizontal distance travelled by the boring tool 4 from the start point 22 and its depth d1 below the start point 22, and hence the reference plane P, is determined, for example using a known location system, or that described in our co-pending patent application 9616151.8. Then, knowing the horizontal distance travelled by the boring tool 4, the estimated ground level d2 above the horizontal reference plane P can be calculated using simple trigonometry. The estimated depth of the boring tool 4 is the sum d1 + d2.

As seen for example at point "X" on the ground in Fig. 1, the above described method can give relatively poor results where the ground undulates significantly. The situation can be improved by including one or more intermediate measuring locations, for example a third sight pole at point "X", the estimated average ground cover then being represented by lines joining the base of sight pole 10 to point "X", and point "X" to the bottom of sight pole 12.

An alternative way in which the accuracy of estimating the ground profile may be achieved is illustrated in Fig. 2.

As with the arrangement shown in Fig. 1, the system schematically illustrated in Fig. 2 can be used to pre-determine a surface profile 30 along the intended line of a bore 8 to be formed using a boring machine 2 with associated boring tool 4. Using the surface profile data, which gives the level of the surface 30 relative to a horizontal reference plane P, the relative surface level d3 at any point can be calculated and can be summed with the depth d1 of the boring tool 4 relative to the plane P to give the overall depth below the surface 30 of the boring tool 4.

The system of Fig. 2 differs from that of Fig. 1 in the way that the surface profile data is captured.

An inclination sensor 32 is rigidly mounted to a carriage or trolley 34 which also carries a control unit 40. The trolley 34 has wheels 36, 38, two at the front and two at the back for engaging the surface 30. One of the rear wheels 38 is a measuring wheel, the rotation of which are counted by a suitable sensor, eg a Hall-effect or opto-electronic sensor.

The inclination sensor 32 is mounted to the trolley 34 such that when the wheels 36, 38 are in contact with a horizontal surface the sensor is also horizontal. In this way, with the sensor 32 rigidly fixed to the trolley 34, the output from the sensor 32 directly gives the average slope of the ground underneath the trolley 34.

In use, the output from the inclination sensor 32 is read as the trolley 34 is drawn or pushed across the surface 30. These readings are taken at pre-determined distance intervals, as detected by rotation of the measurement wheel 38. This distance and slope data can then be integrated to give an estimation of the surface profile. If the measurements are taken at relatively small distance intervals, for example about 0.3m intervals, an accurate estimate of the surface profile can be built up.

As will be appreciated, using this method the surface profile is established relative to the starting point of the measurements. This is chosen to coincide with the intended entry point 22 of the bore 8 through which the horizontal reference plane P passes.

During the data gathering operation, the control unit 40, which receives the outputs from the inclination sensor 32 and measurement wheel 38, can be used simply to store the measured data, to transmit it on (eg using a radiolink) to a remote station (eg the base station of the boring machine 2), or the data may even be operated on by the control unit 40, for instance to calculate the surface profile for subsequent use by the boring machine 2.

The control unit 40 has a display 42 which can be used to display the measured data, for example the distance travelled, slope, height relative to the reference plane P, or a combination of these.

Claims

1. A method for determining the depth below a surface of an underground object, comprising determining the depth of the object relative to a known horizontal reference plane, determining the level of the surface relative to the same horizontal reference plane, and summing the two results.

2. A method according to claim 1, wherein the step of determining the level of the surface relative to the horizontal reference plane comprises using an inclination sensor in the determination of the average slope and/or the change in height of the surface between two measurement locations spaced apart along the intended path of the underground object.

3. A method according to claim 2, wherein the determination of the average slope and/or change in height of a surface between the two measurement locations comprises using an inclination sensor mounted in a fixed relationship with an optical sight positioned at a first measurement point which is a known distance above the surface at the first measurement location, aiming the optical sight at a second measurement point which is a known distance above the surface at the second measurement location, determining the angle subtended between a line joining the first and second measurement

points and horizontal from the output from the inclination sensor, and using this angle to calculate the average slope and/or the change in height of the surface between the two locations.

4. A method according to claim 3, wherein the first and second measurement points are positioned at the same distance above their respective surface locations.

5. A method according to claim 3, wherein the distance of the first and/or second measurement points above their respective surface locations is adjusted such that the sight is horizontal when it is aimed at the second point.

6. A method according to any one of claims 3 to 5, wherein the horizontal reference plane coincides with one of the measurement locations.

7. A method according to any one of claims 3 to 6, wherein one of the measurement locations is selected to be the intended start or finish point of a path to be followed by the underground object.

8. A method according to any one of claims 3 to 7, wherein a series of measurement locations and respective measurement points spaced along the intended path of the underground object are used,the average slope and/or height change of the surface between each pair of

adjacent measurement locations being determined to provide data representing a surface profile.

9. A method according to claim 1, comprising measuring the inclination of the surface directly at a plurality of surface locations along an intended path of the underground object using an inclination sensor mounted on a support carriage, measuring the distance between successive measuring locations, and integrating the data from these measurements into data representing a full surface profile.

10. A method according to any one of the claims 2 to 9, wherein the inclination sensor is an electromagnetic sensor.

11. A method according to any one of claims 2 to 10, wherein data from the sensor is transmitted to a remote station.

12. A method for controlling an underground boring tool, comprising determining and storing data representing a surface profile corresponding to the surface above the intended path of the boring tool, using the surface profile data to calculate the level of the surface at a point above the boring tool relative to a horizontal reference plane, and summing the calculated surface level with a depth of the boring tool relative to the reference

plane to give the depth of the boring tool below the surface.

13. Apparatus for use in determining a surface profile, for use in a method according to claim 9 or 12 comprising a support carriage, an inclination sensor mounted on the support carriage in fixed relation to it, and means for recording the output from the inclination sensor, the support carriage having ground engaging means arranged in fixed relation to one another, whereby the slope of the surface under the carriage is reflected in the attitude of the carriage.

14. Apparatus according to claim 13, wherein the inclination sensor is orientated relative to the ground engaging means of the carriage, such that it is parallel to the surface on which the carriage is stood, thereby to give a direct measurement of the slope of the surface with respect to horizontal.

15. Apparatus according to claim 13 or 14, comprising means for determining the distance travelled by the carriage over a surface, and means for recording this distance information.

16. Apparatus according to claim 15, wherein the carriage is equipped with a measuring wheel for contacting and rolling along a surface as the carriage

moves over it, and sensing means to sense the rotation of the wheel, to determine the distance travelled by the carriage.

17. Apparatus according to any one of claims 13 to 16, comprising a processor mounted on the carriage to store and manipulated the angle and distance data gathered, and a display on the carriage to provide instantaneous readings to an operator.

18. Apparatus according to any one of claims 13 to 17, comprising means for transmitting measured data to a remote station.

The Patent Office

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Application No: GB 9622190.8
Claims searched: ALL

Examiner: Michael Walker
Date of search: 12 August 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Int Cl (Ed.6): E21B 47/02,47/024, 47/04; G01B 5/18, 7/26, 11/22, 21/18; G01C 5/00, 9/00, 9/02, 15/00

Other: On-line : WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	GB 2115261 A	(DAISY D) whole document	1,9
X,Y	GB 2101077 A	(RUNE NILSSON) see abstract	X : 1,2,11,12 Y:9,13-17
Y	GB 1000747	(LANCERINI) whole document	9
Y	GB 0802290	(TRINKL) whole document	9
Y	WO 89/06783 A1	(PERRY) see abstract	1,2,9,12
Y	EP 0318471 A1	(FLOWMOLE) see, for example, col.6,ll.20-36; col.8,ll.39-63	1,2,9,12 at least
Y	US 5051934	(WIKLUND) whole document	1,2,9,12 at least
Y	US 4726682	(HARMS) see abstract	1,9,12-17

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